Changing practices of energy consumption: The influence of smart grid solutions in households

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Abstract

New challenges follow with the decarbonisation of the energy system. In particular, the challenge of balancing energy production and consumption has become salient due to the intermittent nature of renewable energy sources. Some suggest solutions at a system level (e.g. using excess electricity to produce hydrogen for transport use), whereas others emphasise the role of individual consumers. The latter approach is dominant within the smart grid vision.

In this paper, we explore implications of smart grid technologies in households for the everyday practices related to electricity consumption. The analysis is based on qualitative interviews with Danish households with photovoltaics (PVs) installed in combination with electric vehicles, heat pumps or household batteries (for local storage of electricity). The main research questions are: How does the installation of local electricity production (microgeneration) influence the everyday practices? What kind of influence does the combination of PVs with other "smart" energy technologies have on everyday practices and electricity consumption patterns? A specific focus is on the time patterns of households' energy consumption.

The analysis is based on a practice theoretical approach. It shows a surprisingly high commitment to time shifting electricity consumption, especially dishwashing and laundering. Different explanations are identified, including the characteristics related to PVs and to producing one's "own" electricity, but also the type of account settlement scheme (hourly versus annual net metering) and the trial context play a role. Also, the study finds a broader interest in increasing the level of self-sufficiency through combining PVs with home batteries. Finally, the paper discusses a distinct (male) gendering in relation to who is most actively engaged in energy monitoring and management, and it identifies possible system implications of the findings.

Introduction

As energy systems decarbonize by integrating intermittent renewable electricity production, the challenge of balancing supply and demand in the electricity grid is increasing. From a system perspective, the consumption should ideally follow the variations in the electricity generation. Achieving this is one of the key challenges targeted by smart grid initiatives. However, as energy consumption is closely tied to the performance of social practices that are themselves structured within the temporal patterns of other practices, there are clearly limits to how much practices such as cooking, laundering and car driving can be shifted in time (Friis & Christensen 2016; Nicholls & Strengers 2015).

Along with the increased focus on demand-side management within the smart grid field, we have witnessed an increase in the installation of small renewable power plants such as photovoltaics (PVs) and small wind turbines within private households. This is part of the decarbonisation of the energy generation and often supported by national subsidies. In addition, energy technologies like heat pumps and electric vehicles (EVs) are slowly getting a wider uptake in households, and new solutions like home batteries seem to be within the future horizon and get increasingly more attention from technology developers as well as the public.

In other words, things are changing both in the energy system at large and for individual households. It is still an open question if the integration of new technologies in households will contribute to balancing the current grid, or if it will end up challenging the very model that current electricity grids and markets are based on (e.g. Parag and Sovacool 2016). This paper explores how some of the new technologies associated with the smart grid are integrated in households, and how they become part of or challenge existing everyday practices or feed in to new practices. Special attention will be paid to possible implications for the timing of electricity consumption as this is of importance for the discussion about time shifting electricity consumption through demand-side management.

We base our analysis on qualitative interviews with Danish households who have installed microgeneration in form of PVs within the last 4-5 years. These households both consume and produce electricity and therefore belong to an increasing number of what has been termed *prosumers* (Olkkonen et al. 2016; Toffler 1980). Further, the selected households also combine microgeneration with EVs, heat pumps or home batteries (for local storage of electricity). This allows us to explore possible implications on everyday practices and electricity consumption of combining microgeneration with other energy technologies.

Our analysis is rooted in the practice theoretical approach, which understands energy consumption as the result of, or an ingredient of, performing practices such as laundering or dishwashing (Shove & Walker 2014). Consequently, practice theories shift focus from studying the energy consumption as such (e.g. through studies of people's energy behaviours or attitudes towards energy and environment) to studying practices and how these are reproduced and changed over time. By placing social practices at the centre of analysis, practice theories de-centre the individual (human) and instead view practices as collective entities constituted by interlinked and heterogeneous elements such as materials, embodied habits (competences) and engagements (images or teleoaffective goals) (Gram-Hanssen 2011; Schatzki 1996; Shove & Pantzar 2005).

In the following, we will first present a brief review of existing literature on microgeneration and everyday practices. Then follows an introduction to the Danish context of home PV installations and a presentation of the paper's research methods, before we delve into the empirical analysis. We first zoom in on households' specific interactions with their PVs and, secondly, explore their experiences with combining PVs with other technologies. The paper closes with an analytical conclusion, in which we summarize the main findings from the empirical analysis and discuss theoretical and policy-related implications.

Studies on microgeneration and household practices

The term *prosumer* (and prosumption) was originally coined by Alvin Toffler (1980) as a way of describing individuals who produced products for themselves, rather than acquiring such products at the market place. Now, the term has become widely used within the energy field (as well as other fields, e.g. digital media). A fruitful way to think about prosumption is as a set of what Strengers (2013, p. 135) called "energy making practices", in other words a specific combination of things, competence and "doings" that produces energy. The current wave of prosumption is likely enabled by a combination of home practice changes and technological innovations resulting in lower costs on microgeneration technologies (such as PVs) and the development of smart grid technologies (Olkkonen et al. 2016). In this brief literature review, we focus on studies exploring how home-based production of electricity might influence the patterns of energy use and production as well as the daily practices of households.

As Olkkonen et al. (ibid.:3-4) note, with reference to Devine-Wright (2007), one specific characteristic of microgeneration is that the household residents *"live in very close proximity of their production units and take interest in how their devices operate, which changes the psychological distance and awareness of energy production from 'plug and forget' to 'in sight and mind'"*. To this, one might also add that a longer process of information seeking and considerations often precedes the final decision of installing the microgeneration unit. This implies that the process of becoming a prosumer is a project that requires long-term dedication (see also Throndsen et al. 2017).

Based on an empirical study of Finish energy prosumers, Olkkonen et al. (2016) found that the prosumers' decisions to acquire PVs were not only based on an understanding of it as a profitable investment, but also influenced by their general interest in technology, do-it-yourself activities and producing their own electricity. Throndsen et al. (2017) note that those who become prosumers typically have a technical background and an interest in new technologies. In addition, Olkkonen et al. (2016) found that the prosumers changed their consumption behaviour in order to be able to consume as much as possible of their own electricity generation during the daylight hours. This was done through measures such as using timers on household devices and was a reaction to unfavourable account settlements of selling excess electricity to the grid. This also exemplifies the more general finding that the attitude and actions of energy companies toward prosumers can affect the way prosumers consume energy.

Like Olkkonen et al., an older interview study from the UK also found that households with microgeneration (PV, wind turbines or heat pumps) attempt to shift their consumption to the hours with microgeneration (Dobbyn & Thomas 2005). The authors relate this to a higher awareness or alertness towards issues of energy consumption in these households; it appears as the households' interaction with microgeneration acts as a vehicle for getting involved in various strategies of energy saving and energy management. On basis of a focus group with members from homes with PVs installed in the Nottingham area, Goulden et al. (2014) found similar examples of time shifting and observe that microgeneration appears to trigger a reorientation towards energy as an active component of practices*; "this was prompting the development of new knowledge and skills"*, including *"checking the weather forecast and setting the washing machine to run when the sun was out"* (ibid.: 26).

Dobbyn & Thomas (2005) found differences between individual households with microgeneration, especially between households who had been actively involved in the decision and acquisition of the microgeneration technologies versus households who had not. Particularly the former was engaged in changing behaviour. To some extent this seemed to be the result of a predominance of environmental committed households within this group, although the authors also note that *"even in these households there appeared to be something about the process of DIY generation which caused them to shift even further in their attitudes and behaviour"* (Ibid.: 8).

Other studies indicating that households with PVs time shift their electricity consumption to hours with peak production include a Dutch statistical analysis by Kobus et al. (2015). However, as Bergman & Eyre (2011) observe on basis of their literature review, there are also studies indicating that microgeneration does not affect consumption patterns.

Installing household PVs entails a re-configuration of the socio-technical relations of a home, and a potential re-ordering of relations in the energy system more broadly. This brief literature review indicates that a quite common result of this re-configuration is both the establishment of new energy making practices and changing practices of energy consumption. In what follows, we will explore the implications of this in the Danish context.

The Danish context

Only few Danish households had PVs installed untill 2011. However, with falling prices on PV installations, and relatively high electricity prices (approximately 30 cent euro per KWh, including taxes), the installation of PVs began to increase rapidly during 2012. From 2011 to 2016, the number of PV installations in Denmark increased from less than 1,000 to almost 100,000 with a total power capacity of about 800 MW. The Danish tax regulation has played an important role in relation to both the rapid increase in 2012 and the sudden slow down that followed a few years later. (Wittrup, 2016)

According to Danish tax regulation, households with privately owned PVs installed are excempted from paying taxes on the electricity they privately produce and consume. In practice, this is done through the so-called "net energy metering", or "net settlement of accounts", which means that the amount of privately consumed electricity is deducted from the amount of electicity produced. If consumption exceeds production, the household pay the taxes related to the net consumption. If production exceeds consumption, the household will get an income of typically 8 cent euro per kWh surpluss electricity sold to grid. Thus, compared to the customer electricity price, it is profitable to consume the PV-generated electricity rather than selling it to the grid. (Wittrup, 2016)

However, depending on when the PVs were installed, household accounts are settled according to two different net metering schemes: the original net metering scheme from 2005 was based on annual net metering, which meant that, e.g., surplus PV production in the summer months would be deducted from surplus consumption during winter months. With falling prices on PV installations, the net metering scheme became increasinly profitable for private household, which spurred a take-off in installations of privately-owned PVs in 2011. This threatened to undermine the tax revenue from electricity consumption. In response, the Danish parliament passed a new bill in december 2012 that changed the net metering to be hourly based, which stalled the installations of new PVs in private households. (Wittrup 2016)

Method

Our study is based on semi-structured qualitative interviews (Kvale 1996) with 13 households. In total, 20 interviewees participated. Twelve of the households included two adults (all couples), and except in four cases, both adults took part in the interview. All households live in single-family detached homes in villages and the countryside. Of the 13 households, only three comply with annual net metering, while the remaining ten households follow the hourly net metering scheme. Thus, the latter group of households have a larger economic incentive for synchronising consumption and production than is the case with the former group. See Table 1 for further details about the interviewed households.

The households are situated in two parts of Denmark. Nine households are from a small island in the northern Jutland (the first nine households in Table 1). These households had recently taken part in a EU-funded trial, which tested a variety of smart grid technologies in households with the aim of creating increased regulation and reserve power within the low-voltage grid. The trial included PVs, heat pumps, home batteries and a home energy monitoring and management system. Households with PVs in combination with either heat pumps or batteries were selected for the present study (although, due to miscommunication, it turned out that one of the households neither had batteries or heat pumps in combination with their PVs). Further, in the selection of households, we aimed at maximising the diversity of the sample regarding household size, age and occupation.

The remaining four households are from the southern Jutland. They were recruited on basis of a list of households that have carried out various energy measures. The interviewed households were recruited on basis of the criterion that they should have PVs installed in combination with having an EV. Here, we also aimed for a high diversity with regard to age, household size and occupation.

As the study focuses on how smart energy installations are integrated in the everyday life of households and the interaction between household members and the technologies, the interviews covered the following themes: everyday life and patterns of energy consumption, the household's experiences with the process of technology installation and, finally, experiences with the technologies since installation (including possible changes in daily practices). The interviews also included a tour in the house, where the interviewees showed the installations.

The interviews typically lasted about 1 hour (except for one lasting almost 2 hours and one lasting only about 40 minutes). All interviews were recorded, transcribed and coded in NVivo with reference to identified key analytical themes.

Table 1. Key information about the interview households. All names are pseudonyms.

Pseudonyms	Household composition	Age of interviewees	Occupation	"Smart energy" installations	Annual/hourly net metering scheme?
Gotfred Danielsen	2 adults + 1 child	About 50 years	Blacksmith	PV	Hourly
Lukas & Cathrine Larsen	2 adults + 2 children	In their forties	Electrician & secretary	PV + battery	Hourly
Karin & Emil Petersen	2 adults	In their sixties	Health care assistant & retired workman	PV + battery	Hourly
Simon & Gitte Hansen	2 adults + 2 children	In their fifties	Storehouse clerk & residential social worker	PV + battery	Hourly
Jim Beck	2 adults	About 60 years	Local director	PV + heat pump	Hourly
Hans Frederiksen	2 adult + 1 child	About 60 years	Production manager	PV + heat pump	Hourly
Nikolas Thomsen	2 adults	About 70 years	Inseminator	PV + heat pump	Hourly
Jens & Irene Svendsen	2 adults + 1 child	In their twenties	Haulage contractor & sales assistant	PV + heat pump	Hourly
Jan Olsen	1 adult	In his eighties	Retired technical director	PV + heat pump	Hourly
Bjarne & Theresa Johansen	2 adults	In their seventies	Retired general labourer & head teacher	PV + EV + heat pump	Hourly
Anker & Gry Bertelsen	2 adults	In their sixties	Both retired school teachers	PV + EV + heat pump	Annual
Bjarne & Susanne Andersen	2 adults + 2 children	In their forties	Both professionals (project manager	PV + EV + heat pump	Annual

			and planner)		
Thor & Alberte Brodersen	2 adults	In their fifties	Doctor & nurse	PV + EV + heat pump	Annual

Implications of PVs on household routines

The installation of PVs in the studied households represents an introduction of a new electricity-generating material element. Thus, households are transformed into prosumers (Toffler 1980) and begin engaging in energy making practices (Strengers 2013). In many instances, this had implications on how other everyday practices were performed, which is the focus of this section.

Time shifting mainly for households without childeren

Except from two, all interviewed households on hourly net metering explain that they have changed the timing of everyday practices in order to move some of their electricity consumption to daylight hours. Almost without any exceptions, it is dishwashing and/or laundering that has been time shifted. For these households, it is mainly about increasing the utilization of their own electricity production. As Jim Beck explains:

(…) we also become more conscious about it, at the time we got the solar cells [PVs]… to consume power when we produced it ourselves… (…) So washing [laundering] and dishwashing, it was when the sun was shining…

When asked why they have changed their daily habits, the interviewees' often refer to the economic benefit of synchronising their consumption with the electricity production of the PV. Here, most notice that they are on the "new" net metering scheme with hourly net metering. However, some also like the idea of using their "own" electricity, which seems to relate to a widespread idealization of the notion of being independent and self-sufficient with energy (see also later). Jim Beck, again:

Yes but, it is this mixture… It is about economy, but also this satisfaction with saying… What we are doing know, its something we have produced our own power for… And what's weighting most, I don't really know… (…) We are not part of the old scheme [the annual net metering], so we have to use hour by hour… (…) what we are selling to the grid, we are getting so little for that it is the most logical to use it ourselves.

For the households from the island trial, the idea of time shifting electricity consumption seems to partly originate from, or being corroborated by, the information and instructions that the households got from the distribution system operator and energy supplier managing the trial. Thus, several recalled that it had been emphasised at the information meetings and workshops that it would be an economic benefit to time shift consumption. This also points to the positive role that trial settings seem to play for the participating (trial) households' engagement and active participation in following the scripts that are associated with such trials. Trials represent a unique setting for the participants' active and committed participation through their loyalty to the overall aims and scripts of the trial (Friis 2016).

It appears that time shifting activities are most consistent in households without children living at home and, in some cases, with one or two retired from work. This corresponds with the findings of Nicholls & Strengers (2015) that show limited time shifting flexibility in the everyday life of households with children because their practices are typically highly interrelated and dependent on the close coordination of the individual family members. Also, the temporality of the everyday life and the collective rhythms of school and work hours etc. are limiting the flexibility of shifting activities such as the morning and evening meals. This is also pointed out in Friis & Christensen (2016), who also found dishwashing and laundering (and EV charging) to be the practices most likely to be time shifted.

Time shifting through new routines and strategies for planning

The examples above illustrate that time shifting became quite common for the households we interviewed. However, when discussing time shifting, it became apparent that it was understood, and indeed practiced, differently amongst the households. For some, time shifting became a conscious practice of planning, where new kinds of knowledge devices and technologies became part of balancing energy consumption and production.

One example of this is the couple Karin and Emil Petersen, who are in their late sixties and with Emil being recently retired. About their daily routines related to time shifting dishwashing and laundering, they explain:

Karin: (…) in the evening I ask him about the dishwasher… If it is like we are getting too late in the evening – whether we should wait for the next day [with running the dishwasher] or… (…)

Emil: Also, we have one [mobile phone app] that looks at the weather report… So one can also get an opinion about, if it is cloudy weather today and then sunshine tomorrow… Then it can be worth it just to save it [the dishwashing] for tomorrow and then start when the sun is [shining]…

This couple has established a new and distinct evening routine of planning the timing of dishwashing (as well as laundering). A routine, which involves communication between the wife (carrying out the dishwashing practice) and her husband, who follows the PV electricity production and weather forecast on a daily basis via his smart phone.

Another example of a similar planning routine is from the interview with Jim Beck:

Jim: (…) If it has been cloudy or rainy weather, then we are not washing that day… As we are only two [persons] in the house, we do not need to run the dishwasher every day… (…) we are trying to make it match with that the sun is shinning… (…) and the same with the washing machine…

Interviewer: But how do you make the decision, more specifically… (…) is it something with looking out in the morning and look at the weather or how?

Jim: Yes, yes… We are close to the nature, after all… And one is also listening to the weather forecast…

Embodied and habitual time shifting

However, only few households have developed this kind of new and distinct routines for ongoing planning of the timing of dishwashing and laundering. In most cases, the interviewees explain that the new timing of these activities has become an embodied habit, which they now perform without further reflections in general. An example of this is the couple Jens and Irene, who are in their twenties and are having a young child together. When asked if they find it difficult to move laundering to the daylight hours, they answer:

Irene: No, I don't think it is…

Jens: At first, it was [like]… (…) 'that's something we need to remember tomorrow', but now I think its just… 'Beep, beep, beep' [making the sound of setting the timer of the washing machine], should start in three hours… Or I can also load it before I'm leaving [for work]…

Irene: Yes, and then I'm hanging the laundry to dry [before Ivi leaves home for work or in the afternoon when she arrives from work]…

Jens: And just make it so it starts after she has left [for work]…

However, the time shifting has not become an embodied habit in the everyday life of all households. As Simon explains:

(…) it's not always we are thinking about it… (…) You know, it should be in the back of one's mind (…) and I don't feel [it is], at least not in my case (…).

Several interviewees mention that if they have visitors, the routine of time shifting dishwashing is typically not followed. For instance, if Karin and Emil are having their children and their families on visit, they need to start the dishwasher in the evening.

Gendered patterns of participation

The interviews indicate a gendering with regard to who is paying particular attention to the PV electricity generation and who is most eager to time shift electricity consumption. Without exception, interviewees who regularly monitor data about the electricity generation through mobile phone apps or by direct visual reading of the displays on the PV electricity converters are men. In this respect, our study echoes past research on smart energy technologies in particular (e.g. Hargreaves et al. 2013; Skjølsvold, Jørgensen and Ryghaug 2017), and on domestic energy use more broadly (Tjørring 2016), where highly-educated and technology-interested men are often more engaged in acquiring and using such technologies than their spouses or children.

Also, in several couples it appears to be the man who shows most interest in time shifting the electricity consumption, as illustrated by this dialogue between Jens and Irene following the interviewer's question whether the couple thinks about moving their consumption according to the sunshine:

Jens: I do, at least… It's something I'm thinking about…

Irene: And then, you are rushing around in the home and…

Jens: No, I'm just making sure that if we are having some laundry, that it gets started…

Irene: And then it is me who have to get it started (laughing)…

And later:

Jens: If she is having something that needs to be ironed, then she might as well do it then… Everything that uses power, it should be when the sun is shining…

Interviewer (speaking to Irene): Are you doing it, then?

Irene: Sometimes, yes… (Laughs) Sometimes I just say 'okay, okay, boss'… Or 'okay, okay, darling'… But it is not something I'm devoted to, if I'm going to be honest…

Similarly, Nikolas Thomsen, who follows the PV energy generation regularly, replies to the question whether he and his wife talk about when it is best to consume electricity:

We are talking about it, sometimes… And sometimes she needs a push in order to think [about it]… She is not as aware as I am… She's more like, 'now, we need to get that running, and then we do it at the time when it works best'…

As these quotes indicate, some of the lack of interest from the women might be related to an uneven gender distribution of household chores. It appears as it is still very often the female partner who is carrying out the main part of the daily household chores like laundering and (in the case with Jens and Irene) ironing. Thus, the practical implications of time shifting these practices are felt most hardly by the women, which might also explain why several of the female interviewees are more hesitant with regard to the idea of time shifting. Despite this, most of them welcome the idea that it would be ideal to move electricity consumption to daylight hours. In one case, the female partner has even changed the timing of her cooking, which is definitely atypical for the interviewed households, but at the same time illustrates the diversity. Thus, Theresa Johansen tells:

(…) For instance, if I'm baking in the weekend… Surely, I'm not starting when it's seven in the evening, when it is getting dark… I do it during the day… And you know, it is something that gets built in … So we use the energy while it's here…

Households who did not change

While eight interviewed households had time shifted dishwashing and/or laundering, this was not the case for the other five housholds. Three of these followed the annual net metering scheme, and they all refused the idea of changing the timing of their daily practices, but for various reasons. One couple just had not thought about this as an option, while another couple did not believe that people in general would be willing to time shift their daily habits. The latter couple, Bjarne and Sussanne, associated this with an unreasonable loss of convenience:

Bjarne: But it's never going to succeed, because, we humans are just too stupid… Then we have first got used to flat screens, we are not going back to [old tv sets]… I just simply do not believe in… If it is going to succeed, then it is because one is making the system so it is automatic… It is not something common people can do…

Susanne: How many are washing [their clothes] during the night because it's cheap? You just don't… (…)

Bjarne: I feel that we are [already] thinking much about how we are making our imprint [footprint] on the world, and to us it is a challenge [to be thinking about it]. So, what about those who are not having it on their mind at all…

Susanne: (…) there needs to be a substantial economic saving.

Bjarne: Exactly.

The third household on annual net metering was a couple (Anker and Gry Bertelsen), and here the husband explained that they had actually moved consumption to the night because of considerations regarding the optimization of the electricity system:

During the day, then it's about making all the electricity we have (…) available for the consumers who are needing power during the day – and as we are on annual settlement, it doesn't matter if we are using our power during the day or not, with washing clothes and the dishwasher. Then, we can start it in the evening, just as well, when there's not much run [on the grid]… Then we draw on the wind energy or whatever we draw on at that time…

Finally, the two households on hourly net metering that did not time shift their consumption had both not given it a thought or considered it as an option. However, one of the households had already before the installation of the PVs done their dishwashing and laundering during daylight hours.

Combining PVs with EVs, heat pumps or batteries

In this section, focus is on how the PVs work together with other energy technologies. The aim is to explore possible implications of combining various technologies for everyday practices and electricity consumption patterns.

Electric vehicles

Four households combined PVs with an electric vehicle (EV). Three of those households were on annual net metering, while the fourth followed the hourly net metering scheme. The EV models range from one household with a Tesla over one household leasing a contemporary standard EV (a Renault Zoe) to two households owing older secondhand EV models (Peugoet Ion and a originally modified Citroen C1 combustion engine car). The driving range per battery recharging varies between less than 100 km (Peugout Ion and Citroen C1) and up to more than 300 km (Tesla). All households combine the EV with another conventional car (in one case a hybrid car). Three households had previous experiences with driving EVs from being participants in a former larger Danish demonstration project called *Test an EV*, which has had a positive influence on their interest in buying or leasing an EV.

The interviewees give various reasons for purchasing their EVs. Several mention that it was partly for environmental reasons, while some also think that the EV would work well together with their PVs. This pattern of interest has been reported also in Norway, which has a high diffusion of EVs, but the other way around (Throndsen et al. 2017; Ryghaug and Toftaker 2014). Here, many EV drivers become interested in the potential of microgeneration, such as PVs, in order to be self-sufficient with "fuels". In Denmark, this also relates to a financial incentive, especially for those on annual net metering. With annual excess production of electricity, the electricity consumption needed for recharging is partly or fully covered by the excess production, and in this way more or less free of charge.

All households have established a routine with plugging in and starting the recharging immediately after returning to home from a drive. This appears to have become an embodied routine. Bundling the habit of plugging in the EV with the home arrival simplifies the routine of remembering to start recharging. As all cars are primarily used for commuting (typically by the female partner in the household), this means that recharging in most cases begin in the late afternoon. The implication of this is that it adds additional power consumption to the already existing afternoon peak (the "cooking peak") of households. Also, the EV recharging does not synchronize with the midday peak in PV electricity generation.

For some households the habit of starting recharging upon home arrival also relates to a feeling of security associated with being able to go for possible (unexpected) drives later in the afternoon or evening. For instance, Susanne Andersen explains how their daughter had broken a tooth some time ago and they went to the local hospital in the EV. At the hospital, they were told that they had to go to a hospital in another town, which exceeded the driving range that the remaining power of the EV battery would allow. So, she had to call her husband and ask him to come and pick them up in their conventional car. This had been an unpleasant and inconvenient experience, which is something she wants to avoid again by always plugging in the EV upon arrival at home.

It is interesting to notice that if the aim would be to synchronise electricity consumption and generation on a local level, the combination of EVs and PVs does not appear to be optimal because of the asynchonisity between when the PVs are peaking in their electricity generation (the hours around noon) and when the EVs are typically parked at home (during evening and night). From this perspective, it might be argued that it would be better to have PVs installed at work places so that EVs could be recharged during midday hours rather than in the late afternoon or evening.

The couple Bjarne and Theresa Johnsen actually recognized the asynchronicity between electricity generation and consumption as a problem, and Bjarne had been thinking about the option of storing the excess electricity generated during the midday hours in home batteries with the aim of using the stored electricity for later electricity consumption (including recharging the car):

Our big dream, it is to get a battery, so we can be self-sufficient… And Tesla, [they] have actually done some research into it [refers here to the Tesla Power Wall]… Where one has some battery boxes (…) that you just put up on the wall, actually…

Later in the interview, Bjarne adds that this idea of storing own electricity also relates to a broader vision about being independent of the grid:

But it is sort of the vision, the dream… To get these batteries in the garage over there, and be completely independent of the power station, in fact… So when the big bang comes and everything fail, then we can just switch over to battery operation and heat a pot of water for a pot of coffee or a pot of tea… Really… I was much inspired by these wilderness… Those, who lives entirely in the wild, who are trying to rig up things, both solar cells and batteries, and the like… For mobile phones and perhaps a computer… This primitive way of making power…

Similar thoughts were expressed in the interviews with two other EV households (Thor and Alberte Brodersen and Anker and Gry Bertelsen). We will return to the vision of self-sufficiency in the following, which focuses on experiences with combining PVs with home batteries.

Home batteries

Three households have batteries with a 3 kWh storage capacity installed in combination with PVs. One of the households is intensively engaged in monitoring the energy flows of the home and the battery performance. The other two households have not followed this systematically, partly due to difficulties in accessing the online monitoring system as well as a lack of interest in general.

The household engaged in monitoring the battery performance on an almost daily basis is the couple Karin and Emil Petersen. Or rather, it is Emil who routinously checks his smart phone app showing the electricity flows of the home, including the status of the battery. The couple has established a daily habit of planning dishwashing according to the status of the battery:

Karin: When we have had our supper, then I ask him how it looks with the battery now, because otherwise I can wait to the next day with starting it [the dishwasher]… (…)

Emil: Then I just have a look how much there is on the battery, cause it goes all the way from zero to one hundred per cent.

Karin: If there's nothing on it, then it's not worthwhile turning it [the dishwasher] on. Then, you can wait [until the next day], as well.

Combined with previous quotes from this couple, this illustrates how the couple has established a rather distinct and new evening routine of planning the timing of dishwashing, which was not generally found among the other households (with a few, but less pronounced, exceptions).

Karin and Emil believe that then they got the battery installed (which happened at least a year after the PVs were installed), it lessened the burden of trying to synchronize electricity generation and consumption. When asked whether the battery made a change, Emil answered:

It has probably made it easier with the battery, because (…) then you know that when the sun is shining the entire day, then you know that your battery is charged one hundred per cent. And then, you can actually just start it [the dishwahser etc.] in the evening.

A similar experience was expressed in the interview with Simon and Gitte Hansen, who tells that in the beginning after the installation of their PVs (but before the battery), they were particular engaged in time shifting electricity consumption from evening and night to daylight hours: "*we couldn't save the power, right"* (Gitte). However, they are now less engaged in this. In their own thinking, this is due to two things: that the PVs have lost some of their "novelty value" during the two years that have gone since their installation, but also because they got the battery installed and it partly took over the role of time shifting the consumption.

These examples indicate that households to some extent delegate the activity of optimising the synchronicity of generation and consumption to the batteries. It seems as increased use of batteries in combination with PVs might reduce householders motivation for, and engagement in, time shifting existing electricity-consuming practices like dishwashing and laundering.

Of the ten households without a battery, seven are considering it as ideal to combine batteries with solar power. This is partly related to the idea that the households then could save the excess electricity generation during the midday hours for later use, which would reduce the electricity costs. Hans Frederiksen consider buying batteries and more PVs as one possible solution for the future: *"It is also about making yourself economically independent, when you get older…"*

However, another strong motivation among some interviewees for wishing batteries seems to be the notion of becoming energy self-sufficient and independent of the grid (as indicated previously). This is most strongly expressed by Bjarne Johansen, who links the vision of being independent with being resilient in situations of system breakdown:

So, would there be terrorists smashing something. Yes, then it would be the power grid (…) that [really] (…) could paralyse things. (…) and then it would be wonderful to be able yourself [to provide oneself with power]…

However, despite a widespread interest in increasing self-sufficiency through combining PVs with home batteries, all households without batteries installed consider the existing battery solutions to be too expensive. Nevertheless, the interest in battery solutions appears to be widespread and strong, and this indicates that with declining prices on batteries, combined with the present hourly net metering scheme, it might at some point in the future become economically attractive for households to invest in batteries on a larger scale. In addition, this might be promoted by many (male) householders finding the vision of being (partly) independent of the energy system appealing.

Heat pumps

Nine households combine PVs with heat pumps (air/water, air/air or ground-source heat pumps). All households are satisfied with their heat pumps as well as the combination of heat pumps and PVs. They believe the combination saves them money and they also find heat pumps easy to maintain and regulate (compared to their previous solutions, which for some households included pellet or oil-fired burners). Several also described that the indoor comfort had been improved with the heat pumps, e.g.:

Nikolas Thomsen: I'm almost only seeing benefits… It is rather comfortable to have a constant temperature in the house and it is rather convenient that I don't need to go out and put straw in the boiler. (…) No, there's no challenges…

In economic terms, the combination of PVs and heat pumps is particular attractive for households on annual net metering, but also the households on hourly net metering believed they saved money compared to their previous heating solution.

It appears as if the heat pumps in general involved less active involvement or attention as compared with the previous stories about the interviewees' engagement with PVs, batteries and EVs. None of the households actively manage the electricity demand of their heat pumps on an ongoing basis (similar to time shifting dishwashing, e.g.). Rather, heat pumps seem to run "quitely" in the background, delivering heating to the home. No interviewees reported examples such as lowering night temperatures or deliberately increasing temperatures during the day or in the afternoon in order to optimise the timing of electricity generation and consumption.

Like with the combination of PVs and EVs, there is a degree of asynchronicity between the electricity generation and consumption related to PVs and heat pumps, but this was not something that the interviewees commented on. While the consumption related to heating is in general higher during the night hours (Carmo & Christensen 2016) due to low outdoor temperatures and no passive heating from sunshine, and typically peaks in the morning hours due to a high demand for domestic hot water for showering, the electricity generation of PVs peaks in the hours around noon.

Concluding analysis

Most households on hourly net metering had time shifted some of their energy consuming activities, in particular dishwashing and laundering. A few households even developed new and distinct routines for daily planning of their electricity consumption. The households' active participation in time shifting might appear surprisingly high since other studies typically report limited success, e.g. in relation to time-of-use trials (Nicholls & Strengers 2015; Powells et al. 2014). However, the analysis indicates that this is partly due to the particular characteristics related to PVs and to producing one's "own" electricity. Several interviewees indicate that, besides the economic savings, it is associated with a positive feeling to consume the electricity while it is produced. In this way, the results of this study correspond to previous findings indicating that households find it appealing to consume their own electricity and that microgeneration can trigger a reorientation towards energy as a component of practices (Goulden et al. 2014; Olkkonen et al. 2016). Related to this, the study also found the idea of self-sufficiency to be appealing to several (male) interviewees. Especially the option of combining PVs with batteries was mentioned by many. The idea of self-sufficiency appears to be associated with also the idea of being independent of the energy system and resilient to possible breakdowns. The latter is peculiar, as system blackouts are extremely rare in Denmark.

All in all, this indicates that time shifting in relation to PVs is motivated by a combination of different elements that does not only include financial profit (especially for those on hourly net metering), but also notions like self-sufficiency and resilience. This might also partly explain why typical time-of-use pricing approaches are less effective, as these are typically framed almost solely within an economic rationale emphasising the cost savings that households might get through time shifting.

It appears as the notion of self-sufficiency and consuming one's own electricity can be potentially potent in relation to the combination of PVs and batteries. Today, home batteries are still rather expensive, but if the prices are going to drop significantly within the coming years, this might spur households to acquire batteries to store excess electricity for use in the evening. This could pose a future challenge for the energy system as well as for the politicians in relation tax revenues. On an energy system level, increased self-sufficiency might cause sub-optimization as the PV power capacity installed in households with home batteries will not be available for other sectors that are main consumers during daylight hours (e.g. business and industry sectors). This would create a need for installing additional generation capacity in the grid. Further, households will pay less in network tariffs and energy taxes with increased self-sufficiency, which might lead to a revenue deficit similar to what the Danish politicians faced with the previous annual net metering scheme.

Another system challenge is identified in relation to the recharging of EVs upon home arrival in the late afternoon – i.e. more or less coinciding with, and adding to, the afternoon consumption peak. With increased EV diffusion, this would make the challenge of balancing the grid even more complicated (unless substantial storage or reserve capacity is developed within the energy system, which might be expensive).

A strong gendering is observed across the interviews. Almost without exception, it is the male interviewees that are most interested and engaged in the new technologies as well as the efforts of monitoring generation and planning the time shifting of everyday practices according to the PV generation. In this way, some of the male interviewees appear to reflect Strengers' (2013) notion of the *resource man*. According to Strengers, smart energy technologies are very often designed for the resource man, who represents an *"efficient and well-informed micro-resource manager who exercises control and choice over his consumption and energy options"* (p. 34-35). Besides being gender biased, Strengers criticises this conceptualisation of the user for relying too heavily on a rationalistic perspective that emphasises utility optimization as the main driver behind human action.

However, it should be emphasised that the interviewed households' might represent a group of people more interested in technologies and energy solutions than others, as well as the specific trial context seems to encourage the participants' engagement. In addition, it is only few of the male interviewees who engage in activities that could be termed as strict micro-management, and these are typically challenged by their cohabiter. Thus, the female partners appear less enthusiastic and engaged, which might partly be related to an uneven distribution of the household chores with woman carrying out the major share of the activities.

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