SOLAR PANELS AND HOUSEHOLD ENERGY PROSUMPTION – EXPERIENCES, PRACTICES AND ATTITUDES

Scientific Report from DCE – Danish Centre for Environment and Energy No. 555 2023

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Abstract:	Based on the results from a survey distributed in Denmark, this report examines people's attitudes towards and experiences with solar panels on private homes.

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Preface

The work upon which this report is based was funded by Interreg North Sea Region and co-funded by Department of Environmental Science at Aarhus University. In addition to expressing our gratitude for this funding, the authors would like to thank DENFO – Danske Energiforbrugere/Danish Energy Consumers – and especially its vice chairperson, Louis Boe Carslund-Sørensen, for invaluable assistance in obtaining respondents for our questionnaire survey. We would also like to thank the support at SurveyXact for very thorough advice on clarifying some difficult issues, and not least all the *anonymous* respondents who took time to complete our questionnaire.

Our thoughts also go to the rest of the ACCESS project consortium, to whom this report hopefully will be of some use – as it hopefully will be to other readers as well.

Sammenfatning

Denne rapport fremlægger resultaterne fra en undersøgelse af danske husejeres opfattelser af og erfaringer med solpaneler og integrationen af sådanne i el-nettet. Undersøgelsen var en del af Interreg-projektet *ACCESS, Advancing Communities towards low-Carbon Energy Smart Systems*.

Husholdninger forventes at spille en stadig vigtigere rolle i omstillingen til et energimarked baseret på vedvarende energi. Deres forbrugsmønstre kan bidrage til omstillingen gennem efterspørgsel efter vedvarende energi, og de kan understøtte elnettets kapacitet ved at spare på elektriciteten eller planlægge deres forbrug til de tider på døgnet, hvor der er mindst efterspørgsel. Husholdningerne kan også installere deres egne elektricitetsproducerende anlæg og sælge overskydende el fra disse anlæg til nettet – og dermed indgå i elnettet som såkaldte prosumenter. Energi-prosumenter er husstande og andre aktører, der både producerer og forbruger elektricitet, og som indgår på el-markedet som både forbrugere og producenter.

Formålet med rapporten er at bidrage til forståelsen af private husejeres faktiske og potentielle rolle som energi-prosumenter, herunder især til forståelsen af de husstandsbaserede solpanelers rolle i energisystemet.

Analysen styres af følgende forskningsspørgsmål:

- Hvad motiverer private husstande til at installere solpaneler?
- Hvordan påvirker solpanelerne husholdningernes praksis vedrørende energiforbrug?
- Hvordan opfatter solpanelejerne betingelserne for at sælge til elnettet?
- Hvad er holdningerne til solpaneler, blandt både solpanelejere og ikke-ejere?
- Og hvad er de socio-tekniske betingelser for at opskalere bidraget fra de husstandsbaserede anlæg til den samlede elektricitetsproduktion?

Undersøgelsen er baseret på en online spørgeskemaundersøgelse blandt danske husejere, distribueret i februar-marts 2022 (før energipriserne begyndte at stige efter Ruslands invasion af Ukraine). I alt 1843 respondenter udfyldte spørgeskemaet. Ca. halvdelen af disse var solpanelejere, og blandt de øvrige havde nogle installeret andre små vedvarende energianlæg (såsom solvarme, jordvarme eller mikrovindmøller), mens 43% af respondenterne ikke havde vedvarende energianlæg installeret på eller ved deres bolig.

Resultater: Økonomiske fordele udgør den væsentligste motivation for at installere solpaneler blandt danske husejere, inklusive forventede besparelser på energiregningen og mindre sårbarhed over for svingende energipriser. Klima- og miljøhensyn udgør en anden vigtig motivation for at installere solpaneler, om end resultaterne indikerer, at klimahensyn i fraværet af potentielle økonomiske gevinster ikke i sig selv ville være tilstrækkelig motivation for at tage skridtet til at installere solpaneler. Det understøttes også af, at de tre væsentligste grunde for eventuelt at ville tage skridtet til at installere solpaneler alle er økonomiske, nemlig højere subsidier, bedre husstandsøkonomi og bedre betingelser for at sælge overskudsstrøm til elnettet.

Omvendt tyder undersøgelsen på, at lokale aspekter, dvs. at lokal lagring eller handel med energi, ikke er en vigtig bevæggrund for at installere solpaneler.

Survey-resultaterne viser, at solpanel-ejere i nogen grad søger at tilpasse deres elektricitetsforbrug tidsmæssigt til produktionen fra deres eget anlæg. Men denne tilpasning er også integreret i hverdagspraksisser, og tilpasningen varierer med forskellige typer af apparater. Apparater som f.eks. opvaskemaskiner eller bilbatterier bruges eller oplades ofte, når solpanelet genererer strøm – fordi disse apparater har tidsindstillingskapacitet, fordi det ganske enkelt ikke kolliderer med daglige rutiner, og fordi energibesparelserne er betydelige, mens generne er små. Brug eller genopladning af computere og mobiltelefoner samt brug af komfur og ovn styres i højere grad af praktiske hensyn. Hvor økonomiske fordele udgør den vigtigste begrundelse for at tilpasse energiforbruget – med klimahensyn som en væsentlig sekundær begrundelse – er den dominerende begrundelse for ikke at tilpasse sit forbrug, at en sådan tilpasning ikke passer ind i de daglige rutiner. Som nævnt blev undersøgelsen gennemført før energipriserne begyndte at fluktuere, og det er muligt, at flere respondenter i dag ville tilpasse deres forbrug til tidspunkter, hvornår der produceres fra eget anlæg i lyset af den forøgede opmærksomhed på energipriser.

Hvad angår interessen i prosumption, dvs. salg af overskudsstrøm til elnettet, viser undersøgelsen, at mange respondenter var utilfredse med de nuværende priser og betingelser for at sælge til nettet. Mange af respondenterne installerede deres solpaneler, da betingelserne var mere favorable, faktisk så favorable at det offentliges omkostninger blev væsentligt højere end forventet, og i 2012 stemte det danske Folketing for at ændre betingelserne, men denne ændring har genereret omfattende utilfredshed blandt solcelleejerne.

Undersøgelsens fund peger på følgende betingelser for at opskalere produktion af elektricitet på husstandsniveau. For at få husejere til at installere solpaneler (og andre vedvarende energi-anlæg), skal det være økonomisk muligt for dem at klare investeringen, og det skal give en rimelig økonomisk fordel, såfremt brugen af solpaneler på private hjem skal nå videre end de frontløbere, der er mindre motiverede af og mindre begrænsede af økonomiske overvejelser. Sådanne økonomiske fordele omfatter besparelser i energiudgifter og/eller en god pris for at sælge overskudsstrøm til andre forbrugere/nettet og/eller tilskud til investering i solpaneler.

Løfterne om økonomiske gevinster kan og bør dog med suppleres ved at appellere til andre faktorer. Disse kan være klimahensyn, men kan også være andre samfundshensyn som f.eks. energiforsyningssikkerhed.

Endelig kan det tænkes, at den generelle offentlige holdning til solpaneler også påvirker mulighederne for at opskalere brugen af solpaneler. Her viser undersøgelsen massiv offentlig accept af, at der installeres solpaneler på offentlige bygninger, virksomheder og private boliger, mens et langt mindre flertal ville acceptere placering af solpaneler på marker i det åbne landskab, og et betydeligt mindretal ville være imod en sådan placering. Så selv om landbrugsjord nok udgør den mest omkostningseffektive placering af solpaneler (IEA 2020), er der stor sandsynlighed for, at en sådan placering ville skabe konflikt (og allerede har skabt konflikter), ikke mindst i Danmark, som er relativt tæt befolket.

Summary

This report presents results from a study of Danish homeowners' perceptions of and experiences with solar panels and their integration in the wider electricity grid. The study is part of the Interreg project *ACCESS, Advancing Communities towards low-Carbon Energy Smart Systems*.

Households are expected to play an ever more important role in the transition towards an energy market based on renewables. Their consumption patterns can assist the transition through demands for renewable energy and contributing to electricity grid capacity by conserving electricity or planning electricity use for off-peak hours. And they can install electricity or heat producing facilities to sell to the grid, as prosumers.

The aim of this report is to provide insight on the actual and potential role of private homeowners as energy prosumers, especially the role of solar panels on private residences in the energy system. Its guiding research questions are:

- What are the motivations for private households to install solar panels?
- How do they influence energy consumption practices of their owners?
- What are conditions for grid connection perceived by solar panel owners?
- What are the attitudes towards solar panels, among both solar panel owners and non-owners?
- And consequently, what are the socio-technical conditions for upscaling household based co-generation of electricity?

The study is based on an online survey among Danish homeowners, distributed in February-March 2022 (before energy prices started to increase as a result of the Russian invasion of Ukraine). The questionnaire was completed by 1843 respondents, approximately half of which were solar panel owners. Among the rest, some had other renewable installations, while 43% of the respondents had no such installations in their homes.

Findings: Economic benefits are the key motivation for the installation of solar panels on private homes, including expected savings on the energy bill and reduced vulnerability towards fluctuating energy prices. Concern for climate and environment is also an important motivation for solar panel installation, although it is reasonable to suggest that without the potential for economic benefit, climate concern would not be enough for householders to take the step. This is supported also by the fact that the top-three conditions for taking the step to install micro-renewables all concern economics, i.e. better subsidies, better household economy and better conditions for selling surplus power. In contrast, community aspects, i.e. storing or trading energy in a local energy community, does not appear to be an important driver for solar panel installation.

The results from our survey indicate that solar panel owners to some extend do try to adjust their electricity consumption so that it matches production from their own installation. But this adjustment is also always integrated in daily practices, and it depends upon the specific appliances. Appliances such as dishwashers and car batteries are frequently used and charged when solar panels generate power – because there are timer functions on the appliances, because it simply is not at odds with the daily routines to do so, and because

energy savings are tangible while inconveniences are insignificant. Use and charging of electronics such as computers and use of cooking facilities is more likely to be decided by convenience. Whereas the main reason for adjusting electricity consumption is the economic benefit – with environmental concern as an important secondary reason – the dominant reason for *not* adjusting electricity consumption is that such an adjustment does not fit into the daily routines. Again, the survey was conducted prior to the onset of the price fluctuations over the last year, and it is possible that more respondents would adjust their consumption now given heightened awareness about energy prices.

As for interest in prosumption, i.e. selling surplus power to the grid, the survey shows that many of the respondents were dissatisfied with the current prices and conditions for selling to the grid. Many of the respondents installed solar PV, when conditions were more favourable, in fact so favourable that costs soared and the Danish parliament voted in 2012 to change these conditions.

Our findings point to the following preconditions for upscaling of household co-generation of electricity. For homeowners to install solar panels, it must be economically feasible and provide a reasonable economic benefit – assuming that any upscale will have to reach beyond the nerdy frontrunners who are less motivated and less limited by economic considerations. Such economic benefits may consist in savings on household energy expenses and/or in good prices for selling surplus power to other consumers/the grid and/or in subsidies for the investment in solar panels.

But the prospect of economic benefit must ordinarily go hand in hand with appeals to other factors. Those other factors can be widespread climate concern, but other shared societal concerns such as energy security.

Finally, the general public's attitudes regarding solar panels may also condition the upscaling potential. Here the study suggests massive public acceptance of solar panel installation on public, business, and private buildings, while a much smaller majority would accept locating solar PVs in agricultural fields and a significant minority oppose such a location. Hence, while open fields may be the most cost-effective location for solar panel facilities (IEA 2020), such a location is likely to – and has – caused controversy, at least in Denmark, which is a relatively densely populated country.

1 Introduction

In this report, we will present and analyse results from a study of Danish homeowners' perceptions of and experiences with solar panels – often referred to as photovoltaic or PVs – and their integration in the wider electricity grid. The study is part of the Interreg project *ACCESS, Advancing Communities towards low-Carbon Energy Smart Systems*. While the overall project is testing different forms of decentralized energy production, storage and distribution, involving business buildings and parking houses etc., this report focuses on householders' co-generation of electricity, exploring also the preconditions for scaling-up their contribution to the overall energy system.

The role of householders in the energy transition is receiving increasing interest in research as well as in policy, as the urgent mitigation of climate change through green transition of European energy provision must consider all forms of sustainable energy production, including various forms of distributed and decentralized energy production from building based facilities. For instance, the Danish Parliament has recently decided to quadruple power production from land based windmills and solar panels by 2030 (Regeringen 2022). Although, this political agreement focuses on large-scale energy facilities in the open landscape, it also lays out aims to promote installation of solar panels on transport infrastructure and roofs of business and office buildings, public institutions, and private homes. The agreement also contains initiatives to build out the grid and to develop flexibility schemes.

Likewise, as part of the REPowerEU plan, the European Commission in May 2022 adopted a solar energy strategy (European Commission 2022a), which aims for four-fold increase in solar voltaic installations between 2020 and 2030. This means installation of over 320 GW solar photovoltaics by 2025 and almost 600 GW by 2030 (European Commission 2022b). Installation of solar PV on residential, public, commercial and industrial rooftops is one of three initiatives in the strategy. Thus, it is estimated that rooftop PV can provide up to 25 pct. of the Union's electricity consumption – exceeding the current share of gas (European Commission 2022b).

This is in line with the 2019 EU Directive on common rules for the internal electricity market (EU 2019/944) which grants a very important role to European consumers in the future energy market, by positioning consumers at the core of the green energy transition and by encouraging their active participation in the market (see also COM(2015)). There is a broad spectrum of ways in which the consumers' role can be – and indeed is being – fulfilled.

They can reduce their electricity and general energy consumption in a number of ways, technologically and by changings everyday practices. They can, more or less assisted by smart technologies, plan their electricity consumption to take place at times of peak production and/or low prices, thereby also reducing grid congestion. *And* they can install electricity and heat producing facilities at their homes and properties such as photovoltaic solar panels, micro wind turbines and solar heating systems.

Consumers thereby become *pro*sumers or *co-generators*, in that they both *consume* electricity (and heating), which is generated elsewhere and transmitted through various distribution grids, and at the same time *produce* electricity

and/or heating. If they produce more electricity than they consume, it can be distributed back into the common power grid or perhaps transmitted directly to other consumers. (For a general reflection on the concept and practices of energy prosumption, see for instance Ellsworth-Krebs & Reid 2016, Humphreys & Grayson 2008).

This kind of prosumption has increased in Europe over the past two decades. Due to various promotion schemes, increase in solar panel installations was very rapid in the years between 2009 and 2013 and seems to be rising again from 2019 (Jäger-Waldau et al. 2019). Similar trends have been seen in Denmark. As explained in Hansen, Jacobsen & Gram-Hanssen (2022), sales of photovoltaic systems boomed in Denmark around 2012. Prior to 2011, sales were very low bordering on non-existent, and when, towards the end of 2012, the hitherto very favourable scheme for se-selling excess power changed, sales of PV systems to private homes stabilized at a much lower level.

Local energy communities is another way in which consumers can be involved in the energy transition. Such energy communities can have varying forms and sizes, but they are in principle, and in contrast to the household based forms of prosumption, *communal* solutions where community-based organisations develop and manage energy production, distribution and storage facilities, which provide some or all of the community's energy needs or even produce enough energy to export out of the community.

Energy communities that organize collective and citizen-driven energy actions has for some years been expected to be central for the development of the energy market – as the Commission stated in 2015: "Collective schemes and community initiatives have been emerging with increasing frequency in a number of Member States. More and more consumers engage in collective self-generation and cooperative schemes to better manage their energy consumption" (European Commission, 2015). This report does however not investigate community energy projects per se, but the results from our study are relevant for the community aspect of citizen involvement in the energy transition.

The aim of this report is to provide insights on the actual and potential role of private homeowners as energy prosumers, especially the role of solar panels on private residences in the energy system.

- What are the motivations for private households to install solar panels?
- How do they influence energy consumption practices of their owners?
- What are conditions for grid connection perceived by solar panel owners?
- What are the attitudes towards solar panels, among both solar panel owners and non-owners?
- And consequently, what are the socio-technical conditions for upscaling household based co-generation of electricity?

In the following, we will present some key insights from previous studies of homeowners' attitudes towards solar panels as well as their uses of these panels. This is followed by an account of the set-up of our study, a presentation and analysis of our results, and a conclusion.

2 Sociological aspects of solar panels

Before presenting the results from our own study, it is relevant to summarize some of the key issues that have surfaced in previous studies of householders' uses of, experiences with and attitudes towards solar panels on private properties as these issues suggest both drivers of and potential barriers for accelerating the energy transition through integration of local energy prosumers. Without claiming to present a comprehensive literature review, we will in the following outline the most important of these key issues – which in turn informed the design of our empirical study. Findings in previous studies revolve mostly around two core topics regarding socio-technical conditions for household-based energy prosumption. (A) What are the motives and the conditions for households to engage in energy co-generation by acquiring solar panels? (B) How is domestic energy generation integrated in the daily practices of households, and how do householders want to engage with their facilities? Our summary below is focused on the same issues.

Motivations

There is not one single conclusion to be derived from the studies included in this review regarding motivating factors for people's involvement in energy co-generation. On the contrary, studies show a variety of motivations, which include the following:

- Economy
- Environmental concern
- Technical interest
- Independence/autonomy
- Community/regionality
- Building aesthetics

All studies do find that economic motivations are important. Thus, Colasante, D'Adamo & Morone (2021) conclude from their survey in Italy that the primary motivation for respondents to become prosumers was monetary. The expected savings in the energy bill were critical, but the likelihood of receiving a subsidy also strongly affected respondents' willingness to install co-generation facilities. In a similar vein, Inderberg, Tews & Turner (2018) conclude from their study in Germany, Norway and the UK that changes in support schemes have been influential for the development of prosumption in all three countries. And Palm (2018) conclude from a study of two waves of solar panel installation in Sweden that favourable subsidies, together with more profitable conditions for selling micro generated electricity to the grid, became a key factor in the second wave of solar panel installations.

However, while economy is an important factor – and in several studies appears to be the most important factor in household energy decisions – it rarely stands alone. All the quoted studies show that in addition to economic concerns, there are always concurrent and diverse motivations (e.g. Hackbarth & Löbbe 2020; Mechlenborg et al. 2020; Kalkbrenner & Roosen 2016). What differs in the conclusion of these studies is the relative importance of the varying concerns and motivations.

In an older study from Great Britain, Balcombe, Rigby & Azapagic (2013) conclude that although environmental benefit appears to be a significant motivation to install solar panels, consumers do not seem willing to pay extra for that. In a more recent study, Sloot, Jans & Steg (2019) investigated the importance of financial, environmental, and communal motives for involvement in initiatives to install solar panels, and across three studies in three different countries, environmental and financial motives were mostly rated as equally important, and in some instances environmental motives were even rated as more important. And Wolske (2020) compares motivations amongst higher income and lower to medium income households in California, where the latter had received a photovoltaic system for free through a non-profit organisation. Results from this study suggest that high and low-income solar adopters are more alike than not. Both groups are drawn to novel goods and have strong pro-environmental norms, so even when solar panels are highly subsidized, they may be most attractive to people who fit the profile of early adopters of sustainable forms of energy co-generation, i.e., having strong pro-environmental norms and being tech interested.

Community

Especially when it comes to the issues of grid independence and community attachment as motivating factors for installing co-generation facilities, the literature shows diverse results.

Thus, in their comparative study, Winther, Westskog & Sæle (2018) found that people in Germany were motivated to become prosumers by the prospect of increased independence from the central grid, whereas Norwegian interviewees expressed a motivation to help ease the pressure on the central electricity system through prosumption; in other words, they could assist the societal energy grid rather than detach themselves from it.

In a German study of willingness to participate in local renewable energy projects, community identity was found to be a weak motivation for participation (Kalkbrenner & Roosen 2016). Similarly, in the three studies compared in Sloot, Jans & Steg (2019), respondents consistently rated communal motives *less important* than financial and environmental motives.

On the other hand, the most recent and most comprehensive study of participation in electricity trading directly between household co-generators and other consumers indicate a strong positive influence of community, local self-sufficiency and 'regionality' on the willingness to participate (Hackbarth & Löbbe 2020; Mengelkamp et al. 2019). In this particular study, respondents are – in addition to environmental concern – mainly motivated by the ability to *share generation and consumption of energy in their local area and become more independent from their energy provider*. Similarly, a study of a community energy project on the Danish island of Samsø shows a strong element of community spirit in the local residents' support for and engagement in the project (Papazu 2016; Sperling 2017).

The varying findings regarding the significance of community attachment may be due to varying national contexts and cultures. Another explanation may be locality, i.e. where prospective participants live, whether it is in rural or (sub)urban areas, more or less detached from or integrated in energy grids and other infrastructures, threatened by socio-economic marginalisation or situated in an economic and residential centre.

Barriers and enablers

Entwined with the motivations of solar panel owners are a number of barriers to and enablers for the installation and use of energy prosumption technologies. Barriers and enablers that are constituted by organizational, administrative and societal contexts for the implementation of these technologies.

In an Australian study of small island residents and their approaches to the installation of household batteries for their photovoltaic facilities, it became evident that individual cost minimization is not the only determining factor for the success of such initiatives (Ransan-Cooper et al. 2020). Other factors in households/technology interaction are quite critical for the implementation and integration of prosumption technologies. The study identified a range of negative emotions when householders experienced confusion about the operation of their system, whether it was perceived as inflexible, impractical or just difficult to operate. Moreover, the actors who had initiated the installation of household batteries and who could explain and interpret them – i.e., the organizational context for the installation of this technology – seemed unavailable or at least difficult to reach. The study suggests that such negative household emotions can significantly hinder the adoption and function of new energy technologies.

Another study also suggests that technical complexity can exceed the competences of even first mover households and can strain their willingness to use time and energy to achieve new competences (Baborska-Narozny et al. 2016). It mentions how a family who had invested in solar panels never really understood the converter – partly because it was not properly installed – and gave up on using their panels.

Conversely, households with co-generation facilities tend to have a higher education, mainly within technical disciplines or, if none of these, have a non-higher educational *technical* background, for instance in building maintenance or in the energy sector. Thus Winther, Westskog & Sæle (2018) observed that when taking the initiative to obtain solar panels, the individual householders had been driven by a personal interest in solar technology, and they were often professionally involved with energy.

In a different study, Bach, Hopkins & Stephenson (2020) find that intermediaries such as building professionals (e.g., electricians and architects) can play an important role in influencing homeowners' purchase decision-making and assisting them in any difficulties they may experience when starting to use the facility. As Inderberg, Tews & Turner (2018) conclude from their comparative study, the presence of a third-party installing market is a significant catalyst for mass increase in prosumption. The actors in that market, electricians, installers, producers of solar panels, the associated administrative bodies, etc., appear to have a separate effect that boosts prosumption by delivering expertise, advice, technical solutions and by facilitating the procedures for becoming a prosumer. That point is supported by Rai, Reeves & Margolis (2016), who even conclude that households' consideration to install solar panels frequently are installer drive.

However, the boosting of effect installers does not exist in a vacuum; it interacts with the wider context where decisions to install solar panels also are inspired by input from media and from neighbours and other social networks (Rai, Reeves & Margolis 2016; Jacobsen, Hansen & Gram-Hanssen 2019).

Integrating technologies in household practices

People have different ways of integrating new technologies and new procedures in their home, their household practices and their daily lives. This is an important issue, not just for the acquisition and installation of co-generation facilities but also for the optimal use of them and consequently the maximum contribution to carbon-free energy provision.

It is a well-established finding that the kind of energy systems that developed in the second half of the 20th century rendered energy consumption automated and invisible for consumers (Gram-Hanssen 2010, Shove & Warde 2002). The services and functions that need energy – such as heating and cooling, refrigeration, washing and other household appliances, lighting, entertainment, communication, etc. – are of course visible and tangible, pertaining directly to the functions of everyday life, although also often automated, but the consumption of energy can easily become an invisible service. This is potentially altered when people install facilities for co-generation.

The literature shows that there are different approaches to and effects of these new phenomena in people's home and their daily life.

Most studies presented here outline one or both of the following observations: (A) a continuum in household responses from what could be called a minimum adoption to a maximization strategy. (B) a distinction between those who want to 're-automate' the operations of their new installation and make energy as unnoticed as possible and those who turn careful hands-on management of the new technology into a nerdy activity, a hobby of sorts, perceiving it as a way of obtaining and enacting new skills.

A minimal adoption of micro generation facilities does – as the term indicates – not allow for an optimal use of the facility in terms of allocating as much of the household's energy consumption as possible to the times of the day where energy is produced (Mechlenborg et al. 2020). There will be some adoption, for instance through acquisition of energy-efficient, energy A-marked equipment and smaller changes in everyday life, but household members will not significantly disrupt their daily lives or their perception of what constitutes a good life. It is, however, an interesting finding from this Danish study that the level of minimal adoption could be conditioned by the method of accounting, i.e. whether trading surplus power to the grid is accounted on a yearly basis at a fixed rate or on an hourly basis at a flexible rate. Respondents suspected that the latter system would have a significant effect on their electricity bill, and it made them reconsider the impact on their daily life of their PV facility (Mechlenborg et al. 2020).

At the other end of the continuum, we see householders who seek to optimize their use of energy produced from their own solar panel (or other facility) and minimize their use of grid energy. They may apply technical solutions – with timers and batteries – but they also plan and initiate activities to take place when the sun is up, and they even alter their daily routines. These routines are as Galvin (2020) emphasize, developed within a complex *geo-sociotechnical system* including house, solar technology, grid technology, energy policy actors and regulatory regimes. The biggest problem for solar panel owners is to align their needs and regulatory restrictions with solar rhythms.

But as Hansen & Hauge (2017) conclude from their Danish study, solar panel owners gradually become skilled practitioners and prosumers. People relate

to their environment in new ways and construct new practices according to the movements of the sun. Similarly, Winther, Westskog & Sæle (2018) conclude that when solar panels were introduced into their everyday lives, most households started to use certain appliances at different times during the day, running appliances when the sun was shining. They also found that there is an embedded *economic* rationale for this rescheduling of their household practices; the energy bill is reduced and the investment is returned more quickly.

For some solar panel owners, it becomes a sport or a hobby to monitor their own electricity production and their use of grid power and it also becomes a hobby and even a challenge to manage household life according to these energy prosumption requirements and to develop the necessary competences. The same is the case when respondents hunt savings on their energy bill; these also seem to be pursued for the sport and the challenge as much as for the actual economic gain (Mechlenborg et al. 2020).

The effect on overall electricity consumption is, however, a different matter, and the quoted studies differ in their findings. Some studies have observed a rebound effect from photovoltaics, also known as solar rebound, i.e. a reaction in the household where the now free energy from solar panels is coupled with higher overall energy consumption, for instance through the acquisition of more equipment that consumes energy (Galvin 2020, 2022).

Hansen & Hauge (2017) find that households that have invested in solar panels may gradually become more skilled prosumers but they tend also to increase their overall electricity consumption, although not their consumption of power from the grid. Thus, a study from Germany by Frondel et al. (2022) finds that solar panel adoption does not change the amount of electricity taken from the grid by the involved households. In contrast, Winther, Westskog & Sæle (2018) found in their comparative study no support to the thesis that self-production may lead to increased consumption, although none of their respondents believed that their total electricity consumption had been reduced.

Householders' propensity for time shifting their electricity consumption according to the sun's movements – and for reducing their consumption of power from the grid – is influenced by several factors. These include the composition of their everyday life and the ways in which they engage with their installation. Strong environmental concern as well as strong orientation towards financial gain will prompt householders towards an optimization of their use of power from their own solar panels (Hansen et al. 2019).

Among these different factors, the accounting scheme may also constitute an important influence, i.e. the accounting scheme for surplus electricity. This is a key finding from a study from Denmark, where there is a significant difference between on the one hand solar panel owners who are hourly or immediately accounted for the difference between production and consumption and on the other hand those who are annually accounted (Hansen et al. 2019; Jacobsen, Hansen & Gram-Hanssen 2019). Their study shows that those who are hourly and immediately accounted are more inclined to time-shift. Maybe because the hourly/immediate accounting promotes an ongoing attention towards electricity prosumption in the household's daily practices and contributes to the nerdy engagement with the photovoltaic installation. And maybe because financial benefits from the installation depends on active time shifting when accounting is immediate/hourly.

3 Study and respondents

In order to provide knowledge about householders' perceptions of and experiences with solar panels, we conducted a survey among Danish householders.

Design and formulation of questions was informed by input from our literature review. In particular, we were inspired by and copied large parts of the questionnaire used in the study reported in Jacobsen, Hansen & Gram-Hanssen (2019). This resulted in questions about motivations for having solar panels, practices for daytime electricity consumption, use of excess power from panels, reasons for *not* having solar panels, plans for acquiring micro renewables, and general perceptions of solar panels. The full questionnaire can be seen in Appendix 1.

The survey was distributed in February-March 2022 as a link to an online questionnaire. We wanted to be sure to reach a sufficiently large population of solar panel owners and at the same time target a nationally representative population of residents in single-family houses (excluding residents in apartment buildings because they will have very different access to installing co-generation facilities). Consequently, we applied two different means of distribution:

- Through an interest group/NGO called Danish Energy Consumers, *DENFO*, the membership of which consists predominantly of solar panel owners but also other owners of other forms of co-generation. Approximately 740 respondents, most of which were solar panel owners, but not all.
- Through the online polling panel of a research agency called Userneeds, targeting two sub-populations.
    - *Userneeds rep*: a nationally representative population of residents in single-family houses; approx. 1000 respondents, some of which happened to have facilities for co-generation on their property.
    - *Userneeds focused*: a targeted population of residents with solar panels intended as an addition to counter a potential bias in the DENFO-population; 100 respondents.

The questionnaire was completed by 1843 respondents in total, and an additional 71 respondents answered parts of it. Approximately half of the respondents were solar panel owners. Among the rest, some had solar heating, geothermal facilities or even micro wind turbines, and 43 % of the respondents had no solar panels or other micro renewables on their house or property.

Socio-demographic distribution of respondents

The distribution along socio-demographic variables in this survey does not match that of the general population in Denmark, but this should not be expected when the target population is residents in single-family houses. However, when comparing the age profile of our survey respondents with that of the residents in single-family houses in Denmark, some considerable imbalances in the survey population become obvious.

In this study, we applied age ranges of 15 years, which are different from the age ranges of 10 years applied in Statistics Denmark's online StatBank, so the comparison is a bit rough, but illustrative nonetheless. Of residents in single-family houses in 2020, 44 % were younger than 50 years and 56 % were older (DST.dk, BOL201). As can be seen in FIGURE 1, the 'Userneeds rep' sub-population is representative for residents in single-family houses: 43 % were younger than 50 years and 57 % were older. But the 'DENFO' sub-population is not representative, 90 % of them were 50 years or older, and consequently the older age segments also are significantly over-represented in the entire survey population with 71 % in our study versus 56 % in Denmark in general. Consequently, some age-bias – whatever that may entail – is expected in the compiled results.

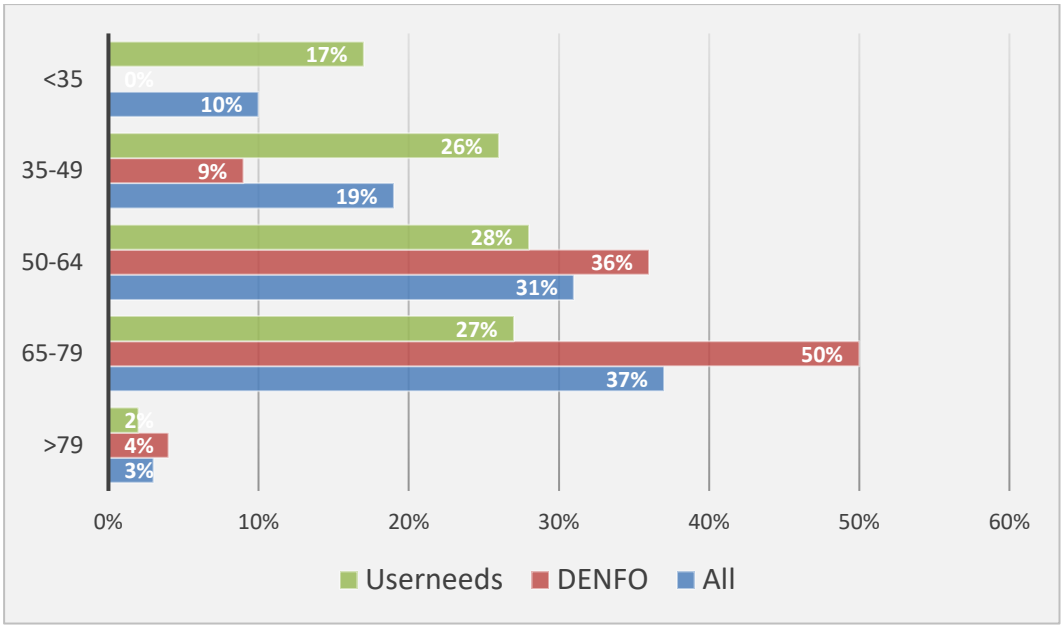

Figure 1 Age distribution of survey population.

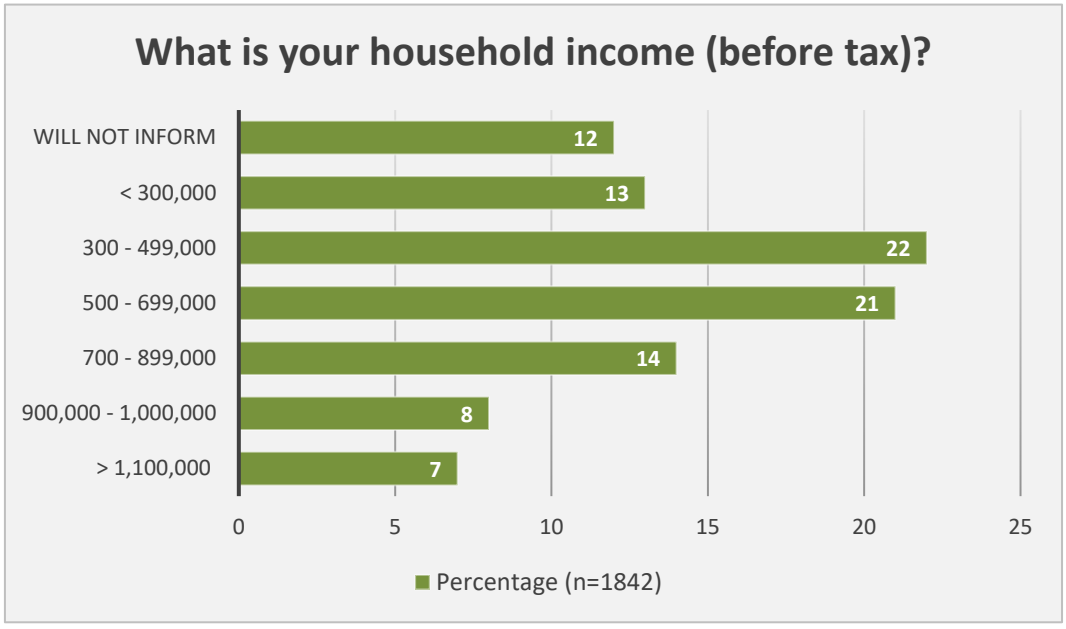

Figure 2 Income level of survey population.

We also asked respondents about their occupational experience, more specifically whether they had work experience in one or more of 11 suggested fields, including 'as craftsperson', 'in health care', 'in law' etc. The reason we asked about 'occupational experience' is that we expected that experience, current or previous, from e.g. technical or economic fields might impact the respondent's interest in or comfort level with decisions related to energy presumption. Almost half of the respondents, 46 %, answered that they had occupational experience as craftsperson and/or in engineering and technical fields. That is not representative for the entire population, but it may be indicative for solar panel owners. Regarding household income, there seems to a wide distribution in the survey population (as can be observed in Figure 2), although probably with a lower average income than would be expected among residents in single-family houses. This may however be due to the over-representation of retired people (older than 65) who generally have lower incomes.

4 Results

Motivations

Of all solar panel owners in the survey, 91 % had acquired the facility themselves. Their motivations for doing so were not limited to only one, but rather to a set of key motivations. Chief among those is, nonetheless, the economic benefit. We asked the following question: "How important (on a scale from 1 to 5) were the following reasons, when you chose to have solar panels installed?" As can be seen in Figure 3, *saving on the running energy costs* was a very important reason for 71 % of the respondents and important for an additional 19 %[1]. But at the same time, *climate concern* was very important for 54 % and important for an additional 21 %. Reduced vulnerability vis-à-vis fluctuating energy prices was also a key motivation, whereas the potential increase in property value was unimportant for most.

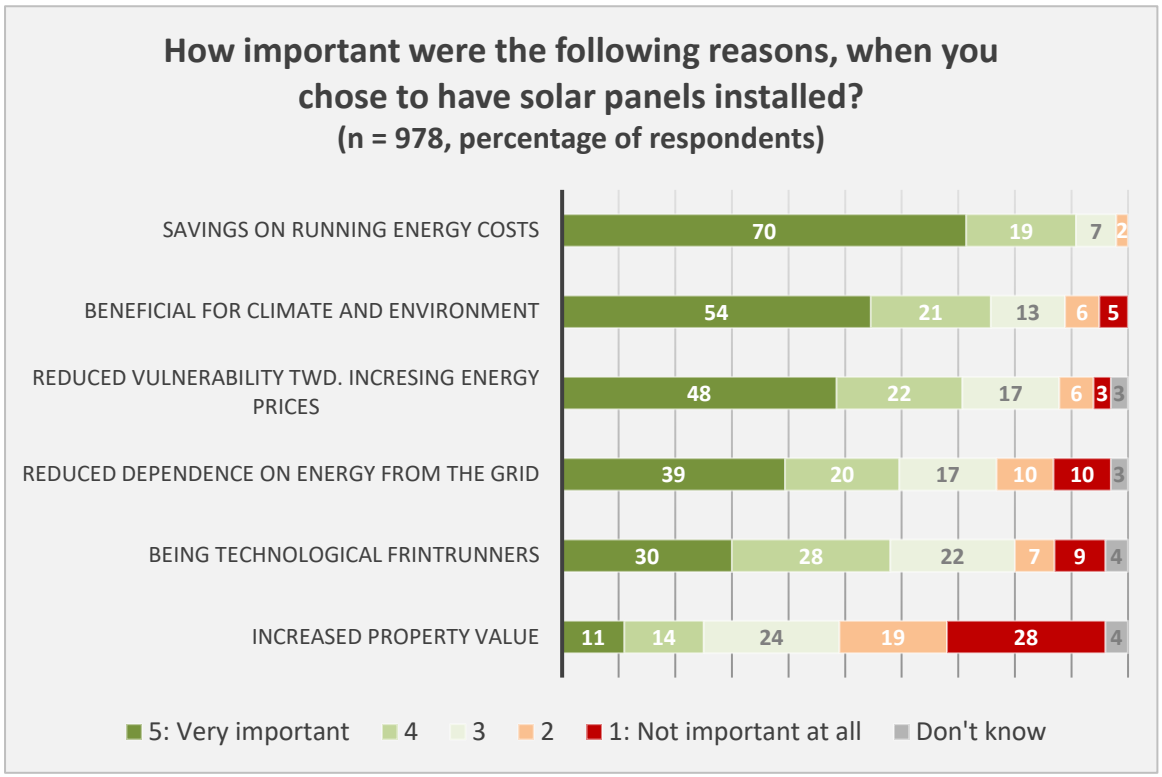

Figure 3 Motivations for acquiring solar panels.

The prevalence of the economic motivation as well as the prominence of the abovementioned other concerns – including climate concerns – is mirrored in respondents' replies to some of the other questions in the survey, such as their motivation for shifting electricity provider and their motivations for timing their electricity consumption to the daylight hours, where they have power from their own facility.

[1] The survey was conducted just as the focus on energy prices was increasing due to the Russian invasion of Ukraine, but the question addressed past installations of micro renewables, so we do not expect the level of economic motivation to be significantly skewed due to the timing of survey.

Timing of electricity consumption

On that issue, survey results indicate that solar panel owners indeed do adjust some of their electricity consumption to exploit better the power production from their own photovoltaic facility. Thus, a clear majority of 75 % indicate that they to a high or at least to some extent adjust their electricity consumption to the daylight hours. This practice does however depend on the device (see Figure 5). We asked how often the respondents adjust their usage or charging of some specific devices to match the power production from their own solar panels, and it turned out that dishwashers and washing machines are most popular for this particular exercise, but also charging of car batteries for the minority of respondents that have electric vehicles or plug-in hybrids. On the other hand, usage of cooker and water heater and charging of computer and mobile phone are not customarily timed according to the solar panels' production. People want to cook supper in the evening, to take baths whenever it is convenient, and to charge computer and mobile phone batteries whenever it is necessary.

As mentioned, people's motivation for this practice is predominantly economic. 85 % indicate that they adjust their consumption because of the economic benefit, but approximately 50 % indicate that environmental concern and autonomy in energy provision are also important concerns. Conversely, respondents' reasons for *not* adjusting their electricity consumption mainly revolve around issues of impracticality – as can be seen in Figure 4.

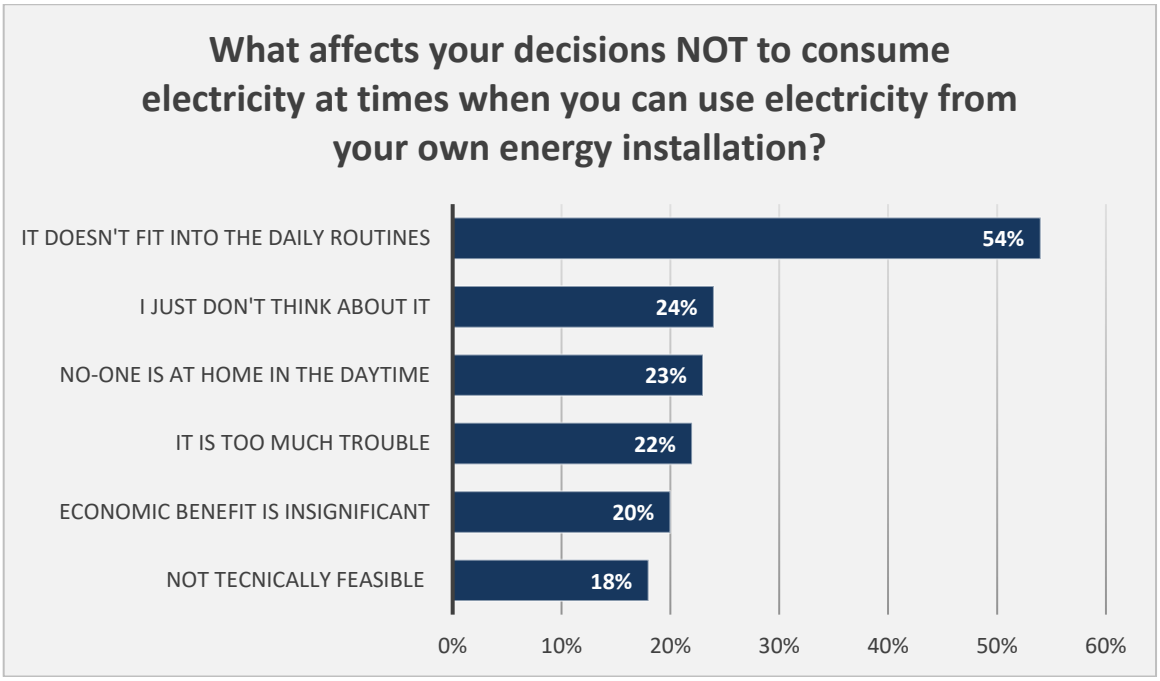

Figure 4 Reasons for not adjusting electricity consumption to daytime hours.

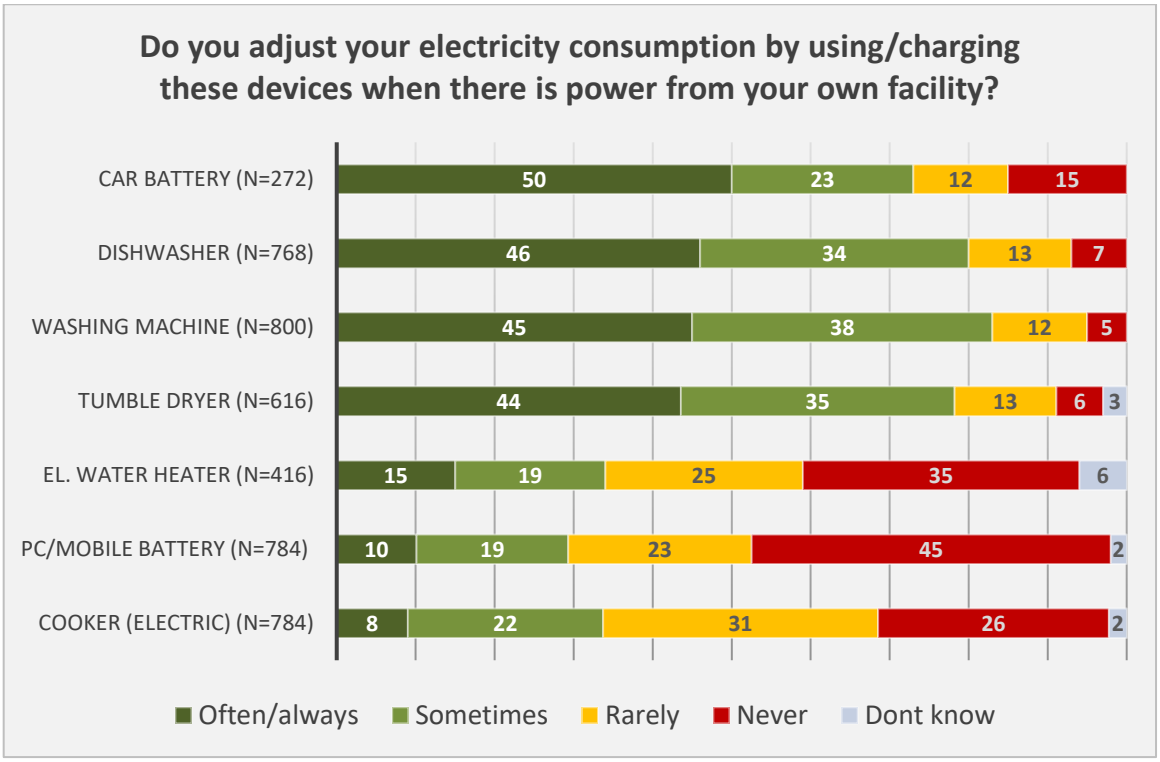

Figure 5 Timing of electricity consumption.

Excess power – selling to the grid

A key issue in household electricity prosumption – and a key question for any kind of energy prosumption and for distributed energy production and smart grid development in general – is how excess power from solar panels and other energy prosumption facilities is used. There is a range of different options, when households produce more energy from their own facilities than they can use immediately themselves. They can simply sell/distribute it to the general electricity grid, through their electricity provider. That is the dominant solution in Denmark, and the key issue is the conditions under which prosumers are connected to the grid and the price they can get for their excess power.

Another potential solution for prosumers is to sell and distribute excess electricity directly to specified customers, either through a more or less automated peer-to-peer exchange or through some sort of energy community in their local area. A third option is to store excess electricity on a battery in the household or through a shared storage solution at community level, presumably on a battery, but potentially also as hydrogen (derived through electrolysis) or some sort of heating storage or whichever technical solution that may be relevant and accessible.

Almost all respondents, *92 %* of the surveyed solar panel owners, *sell their excess electricity to the grid*. A few, 6 % store it on a household battery, possibly as an addition to their grid connection, and a few, less than 2 % indicate that they do not produce excess power. A substantial majority counting 70 % of those who sell their surplus power to the grid are either very (51 %) or moderately (19 %) dissatisfied with the settlements that govern their grid connection and with the resale rates that they are offered (see Figure 6 and Figure 7).

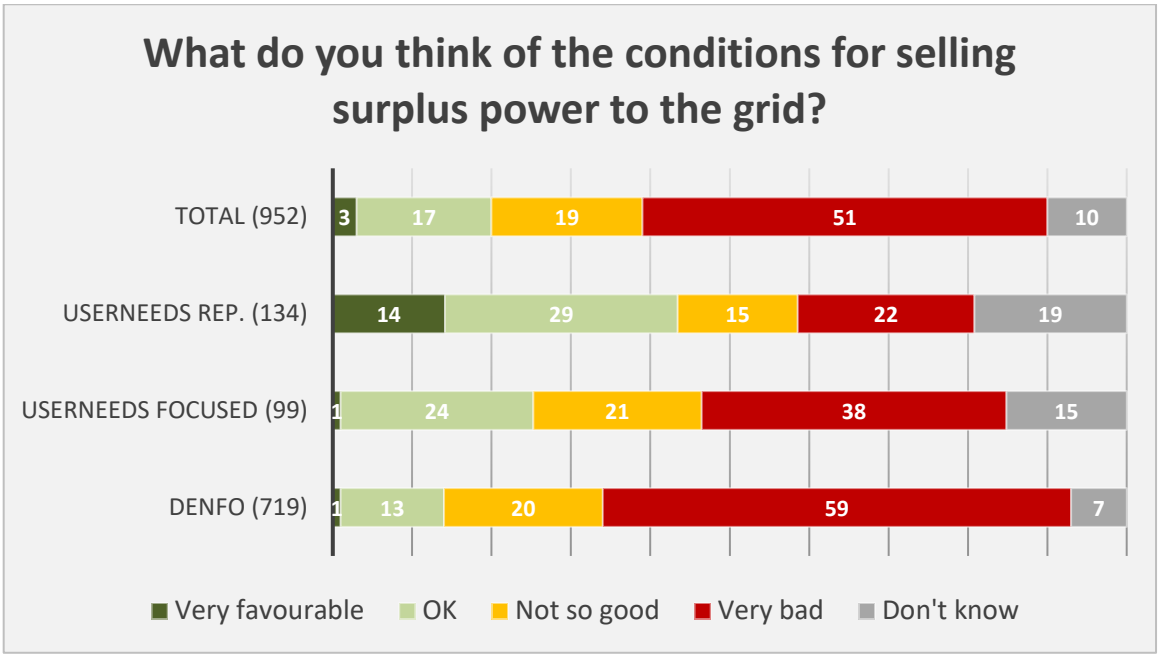

Figure 6 Dissatisfaction with resale schemes correlated with survey sub-populations.

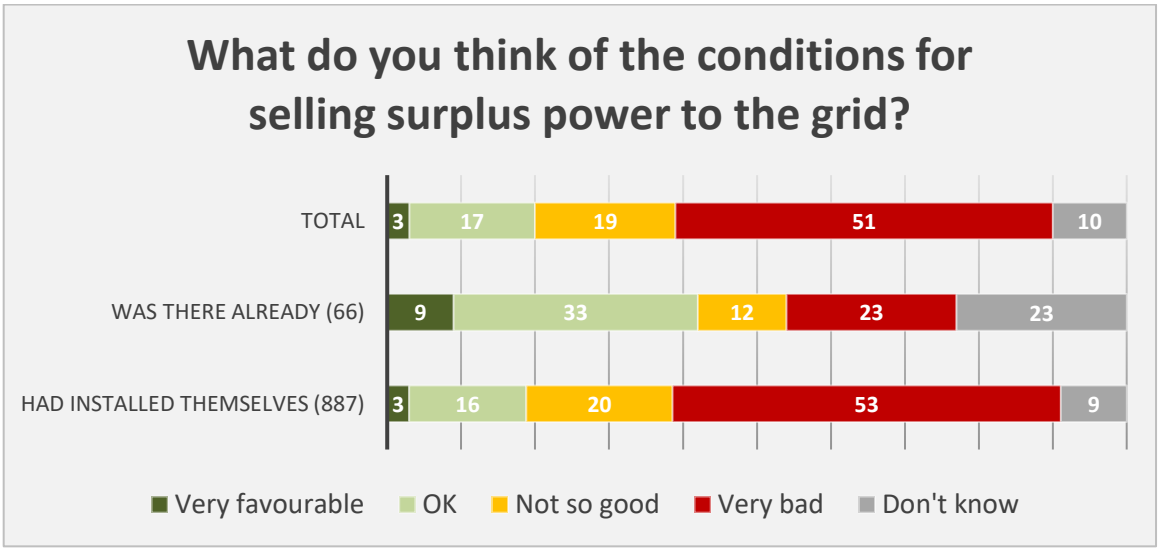

Figure 7 Dissatisfaction with resale schemes correlated 'who installed?'

There are, at the national Danish level, different schemes regulating grid connection for household prosumers, depending among other factors on when their facility was installed, but dissatisfaction is prevalent across the different schemes. There are, however, other notable variations in disapproval among the different respondent groups. Thus, the respondents from DENFO are considerably more dissatisfied with the resale schemes than the respondents from Userneeds are (see Figure 6). By recruiting respondents through an NGO/interest group, we may have reached a more dissatisfied segment of solar panel owners – those who have been so frustrated that they joined an interest group. Similarly, we can see that respondents who have installed their facility themselves are more displeased with the resale schemes than those who have moved into a house where panels were already installed.

Respondents were given the option to elaborate why they were unhappy with the conditions for selling surplus power to the grid, and almost all of them did. Three main complaints, partly overlapping, saturated the respondents' replies:

- Respondents found prices for selling to the grid too low; some add that the difference between the price for buying and the price for selling electricity is too unfavourable.
- Respondents simply state that conditions for selling to the grid were better before.
- People feel deceived because conditions for selling to the grid have been altered contrary to what they believe was promised before they got their facility installed. Some of these complaints use quite strong language, such as a barfing emoji and some swear words in capital letters and utterances like "The government has screwed us over" and "I hate [a named former minister]".

These complaints warrant further explanation. In 2012, the Danish government, backed by all parties in parliament except the Liberal Alliance Party, stopped a hitherto favourable scheme for private solar panel owners trading their surplus power production to the grid. Households and other owners of electricity production installations with a capacity of *less* than 6 kW could – in a manner of speaking – store their surplus power on the grid, i.e., whatever amount of kWh of electricity from their solar panels they did not consume themselves at the time of production, they could transmit to the grid and then get the same amount back at a later time, presumably during the winter, without paying for it. In other words, they would only pay for their net electricity consumption.

Any facility purchased before the end of 2012 could be included in this scheme, which, it was promised, would persist until 2032. But that promise did not keep. Changes have been made in the conditions for trading excess power from private solar panels, also for facilities purchased before ultimo 2012. Thus, starting in 2019, all private solar panel owners must pay market price either on an hourly basis or instantaneously for all the electricity, they buy from the grid for their own consumption, and they get market price for all electricity they sell. Some taxes and fees are paid only for the net consumption but others, depending on the specific arrangement and on time of purchasing the facility, are paid for each kWh bought and sold (vivaenergi.dk, ens.dk, greenmatch.dk, nrgi.dk).

It is assessed by the Danish Energy Agency that these changes only will increase expenses for solar panel owners by 200-500 DKK per year (ens.dk), although recent increases in energy prices may render this assessment obsolete. Nevertheless, some respondents indicated that the changing conditions had ruined the overall economy of their investment; an assessment that was made prior to the acute rise in energy prices after Russia's attack on Ukraine. Regardless of the severity of economic loss caused by changing resale conditions, the sense of deception was strong among the many respondents who wrote in their comments to the survey's open question.

Excess power – other solutions

When asked, if they would be interested in any *different usage of their excess electricity*, respondents favoured storage in a household battery over the other suggested options. 59 % would be interested in electricity storage at home, whereas 31 and 36 % respectively were interested in using a community facility for electricity storage or selling directly to other consumers or (see Figure 8). It should be noted that 13-14 % of respondents answer 'don't know' to the two latter options. They probably are not sure what these options entail.

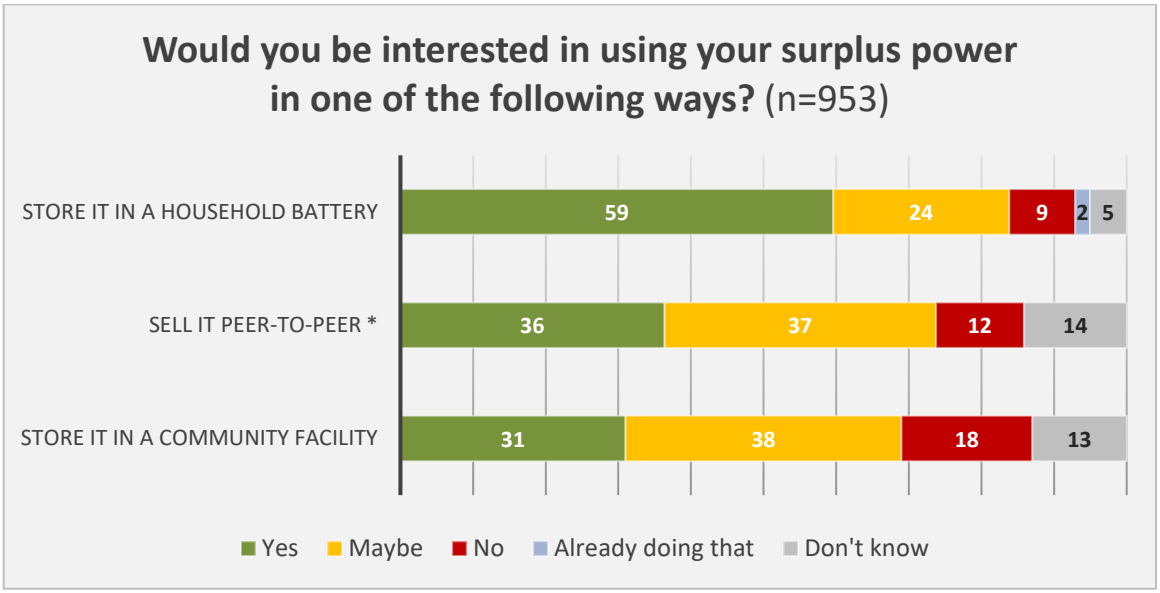

Figure 8 Alternative uses.

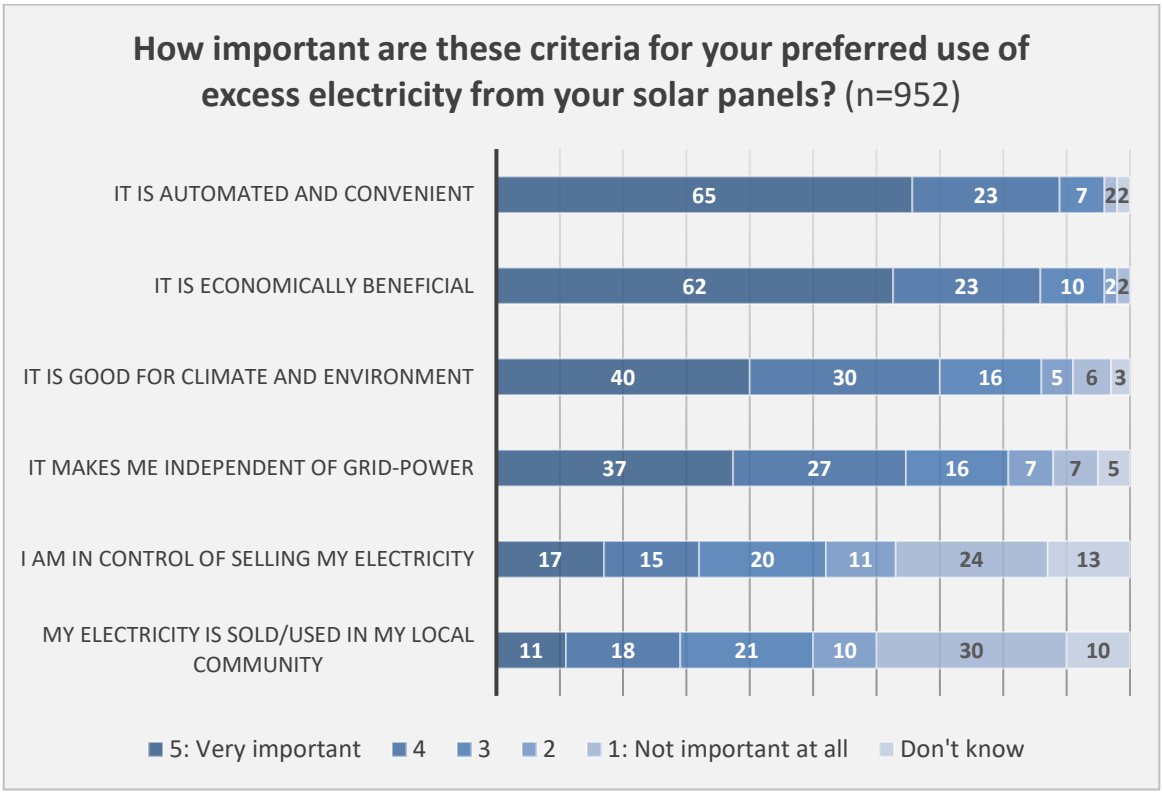

Figure 9 Criteria for use of excess electricity.

Of particular interest are the criteria respondents apply in their assessment of different schemes for using excess electricity from their solar panels. As can be seen in Figure 9, two criteria stand out as more important. Thus, *88 %* of respondents find it either very important (65 %) or important (23 %) that usage of their excess electricity takes place *automatically* and with no inconvenience for themselves, while *85 %* find it very important (62 %) or important (23 %) that it is *economically beneficial* for their household. Also environmental and climate concern is an important criterion, whereas *community focus* is of no particular concern for the respondents. Only 29 % find it important while *40 % find it unimportant*.

Overall satisfaction

Regardless of the misgivings about resale rates and grid connection, solar panel owners are overwhelmingly happy with their installation. We posed more or the less the same question in different ways, and the result was very clear – as can be seen in Figure 10. Almost all respondents agree that they are happy with their solar panels; almost 75 % agree that they are proud of it, and almost no one indicates that they are tired of it.

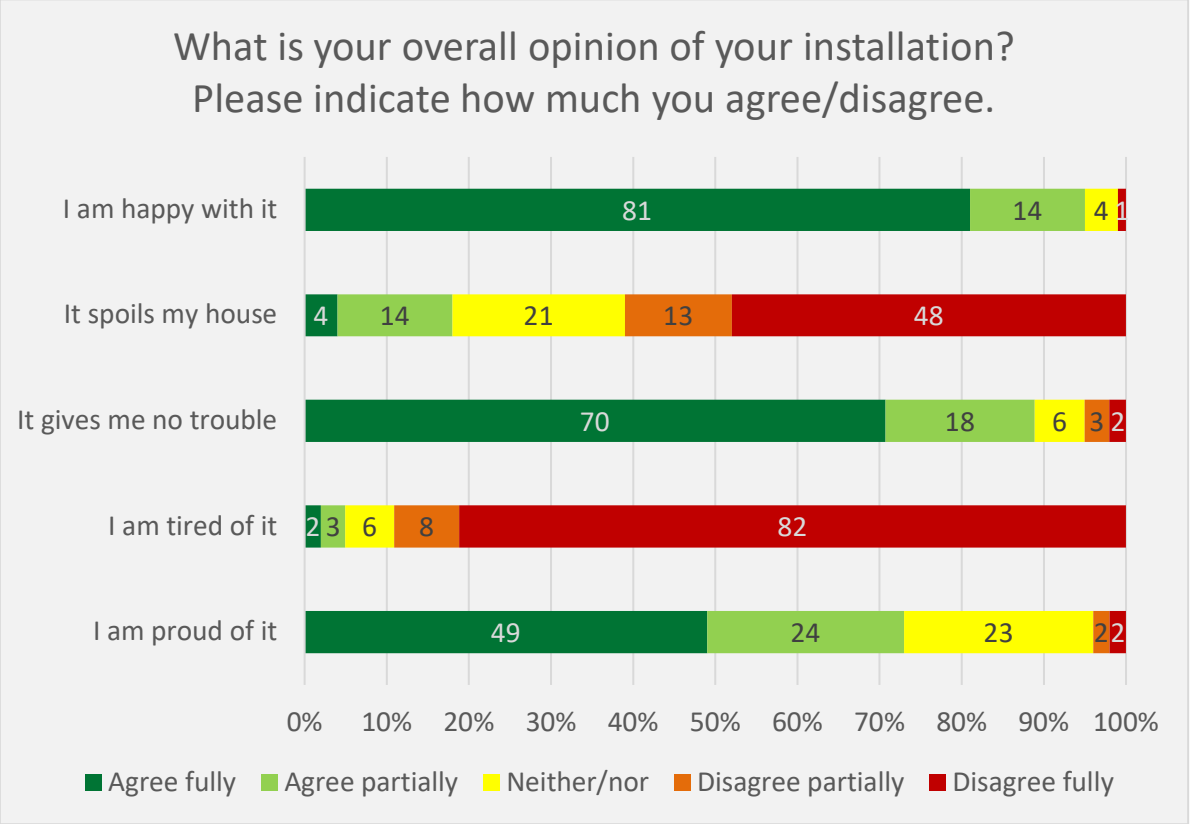

Figure 10 Overall opinion of installation.

Is there demand for increased household energy prosumption?

We have so far looked into the responses of those who already own solar panels. But when assessing the potential for upscaling, it is also relevant to probe any plans respondents may or may not have for acquiring solar panels or other micro-renewables and look into the general attitudes – among owners and non-owners alike – towards such facilities.

We asked if respondents considered having solar panels, micro wind turbines, solar heating and/or ground source heat pumps installed (in addition to whatever installations they already possessed). A sizable majority, 71 %, had no intentions to have any of the suggested facilities installed, while 29 % did consider acquiring such facilities. Notably, much of the interest in solar panels and other forms of energy prosumption was indicated by respondents who already had some such facility. Of those survey-respondents who had no micro-renewable facilities at the time of asking, 21 % considered acquiring such facilities, whereas 32 % of the study's solar panel owners and a whopping 46 % of the solar heating owners harboured such intentions (see Figure 11).

For the minority of respondents who do consider having new or additional facilities installed, a combination of several motivations sustains these considerations, in particular concern for climate and environment, the benefits of increased grid independence and the benefits of reduced daily energy expenses (see Figure 12).

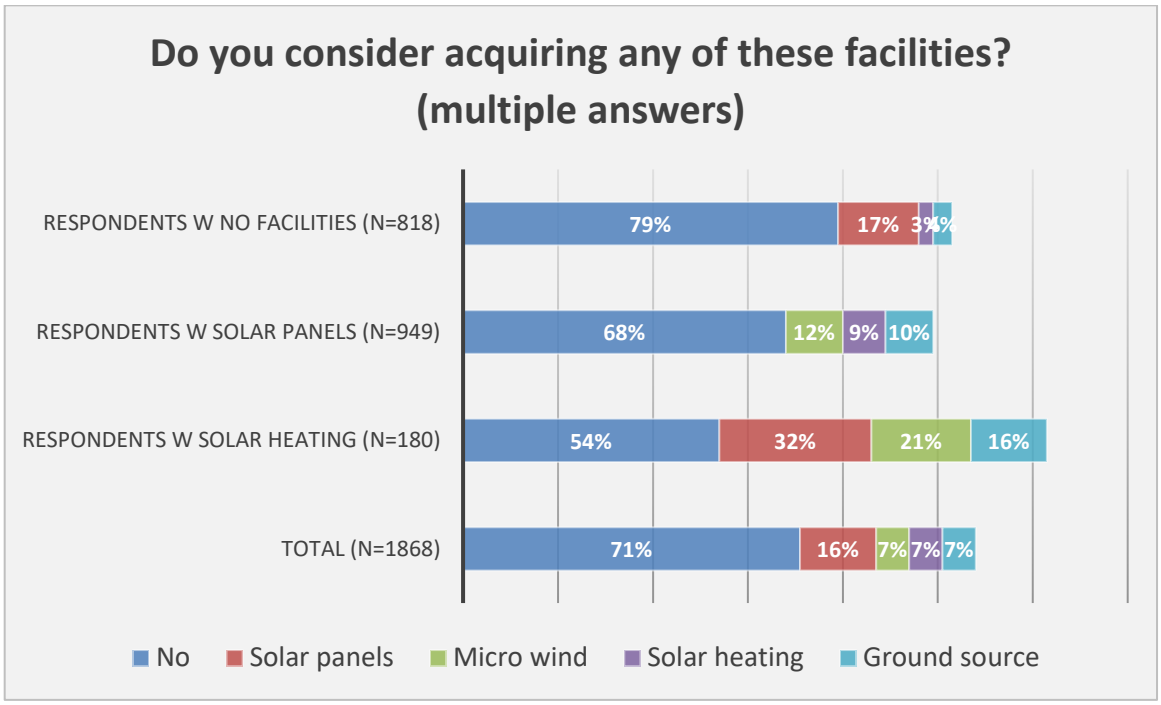

Figure 11 Considering micro-renewables.

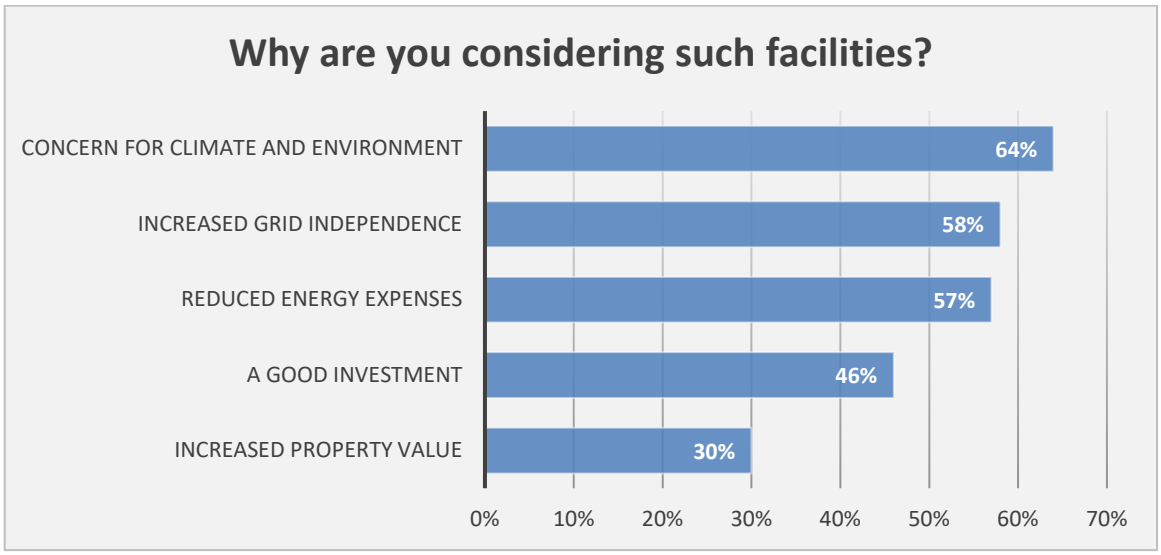

Figure 12 Reasons for considering new/additional facilities.

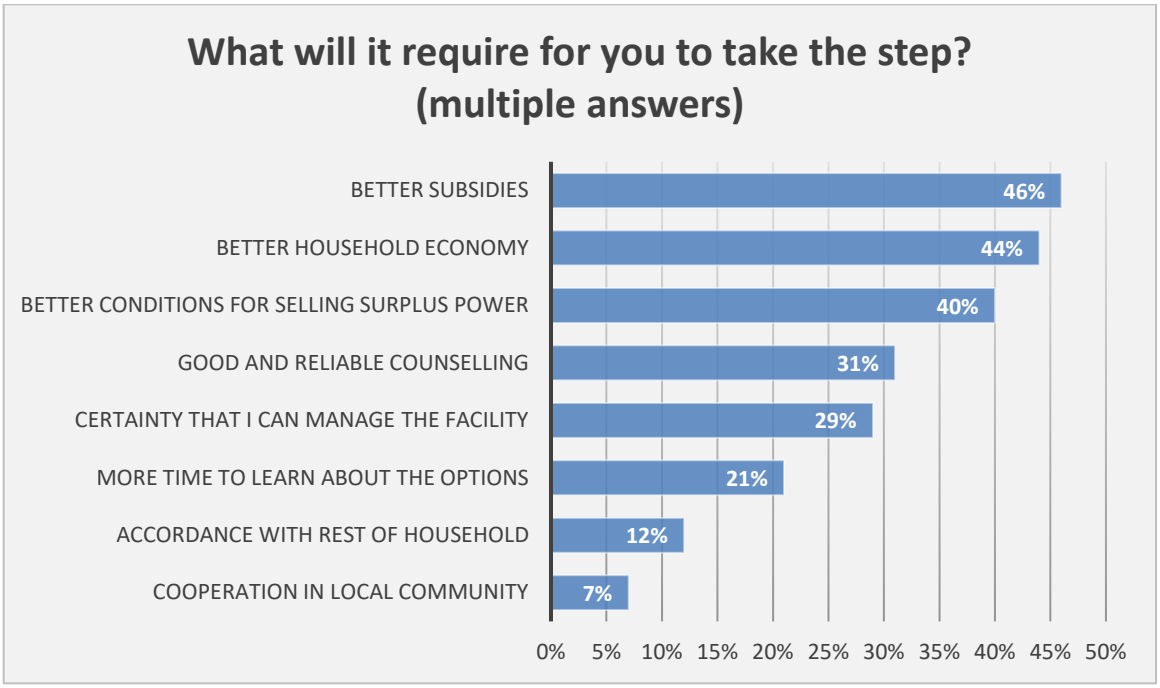

Figure 13 Requirements for taking the step.

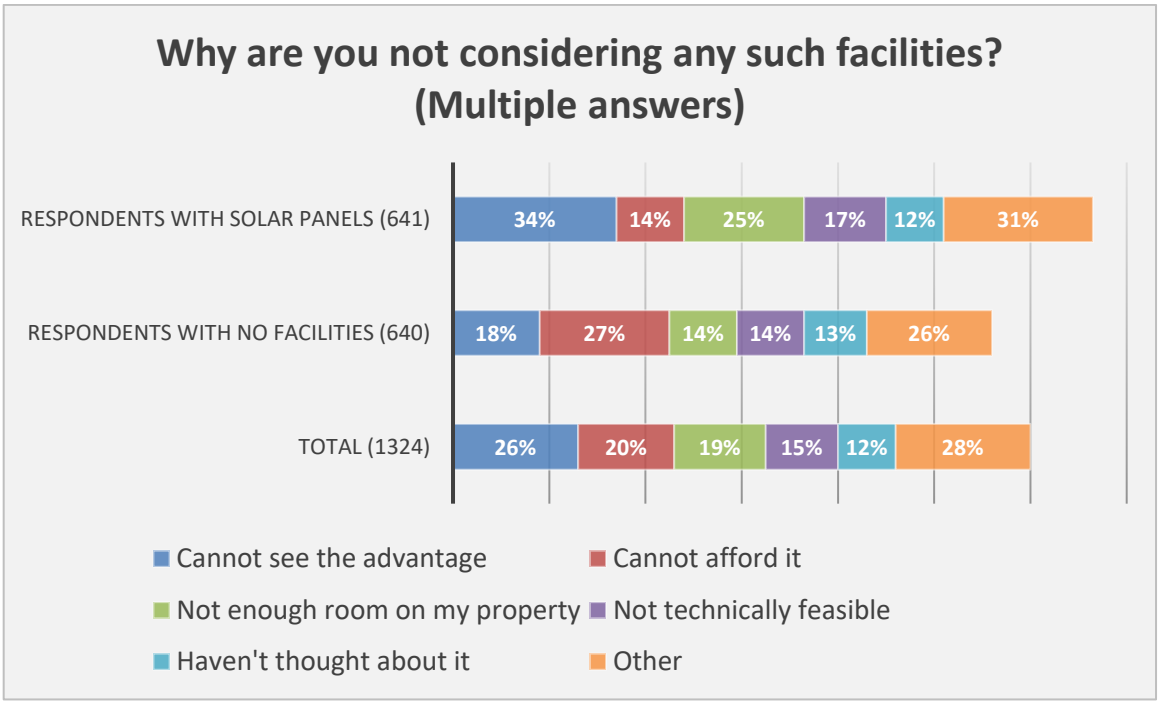

Figure 14 Reasons for not wanting micro-renewables.

Having considerations and intentions is one thing, actually having new/additional energy prosumption facilities installed is another, so we also asked what it will require for these households to take the step. Again, we see a combination of several factors, chief among which are a need for subsidies, a need for better household economy so they can afford the installation, and a need for better conditions for selling surplus power (Figure 13).

For the majority of respondents who did *not* consider any acquisition of energy prosumption facilities, there was a variety of reasons for not having such intentions. Thus, 26 % cannot see the advantage, and 20 % indicate that they cannot afford it, while the reply 'other reasons' was indicated by 28 %. In turn,

this reply covers a variety of reasons: that people are connected to district heating (and implicitly believe that they do not need any additional energy sources), that they are tenants in their accommodation, that they find conditions and rates for selling excess electricity much too unbeneficial, and also that they do not trust the authorities/politicians to maintain reasonable grid connection schemes.

A closer analysis reveals some interesting differences between those who do and those who do not already have solar panels on their property. Not surprisingly, a larger share, more than a third, of those who already possess micro renewables answer that they cannot see any advantage in adding another facility to their property. But it is interesting that only 18 % of those who have no facilities indicate that they cannot see the advantage. Instead, a larger share of those respondents, 27 %, indicate that they cannot afford it (see Figure 14).

Community attachment – or not

When presented with various statements regarding household energy, solar panels etc., almost half the respondents (49 %) agreed fully or partially that energy provision should be rooted in the local community. But 32 % were indifferent, 9 % answered "don't know", and when respondents were asked more practice-oriented questions, community attachment turned out to be among the lesser concerns. Thus and as already mentioned, storage in a community battery is the least favoured alternative to selling surplus power to the grid, and local usage is not important for many respondents in their assessment of different schemes for selling excess electricity (see fig. 3-4). Similarly, when non-panel owners are asked what they believe is the best use of excess electricity from panels, storage in a local facility is the least favoured option – indicated by 20 %, in contrast to the 46 and 49 % who believe that storage in a household battery and trading to the grid are the better options.

We see that some solar panel owners, 20 % of the respondents, believe they have inspired neighbours to acquire solar panels, and 10 % say they have been inspired themselves. But that is different from community energy where residents in a local area (an island, a village, a district) develop common solutions and common facilities. When neighbours inspire each other, they are still establishing individual solutions with connections to the national grid.

Location of solar panels

Solar panel owners and non-owners alike seem to welcome the installation of solar panels in most of the built environment. We asked respondents for their opinion about various locations, and most suggestions were met with strong approval, except location at fields/in the open landscape. There was however still approval of this location, but from a markedly smaller majority, and more than a third of the respondents opposed such a location (see Figure 15). A further interpretation of this result would suggest that location of solar panels in (agricultural) fields is likely to attract more protests and more conflict than any other location, and whatever disapproval the immediate neighbours to a solar panel farm may express is likely to resonate with a larger public.

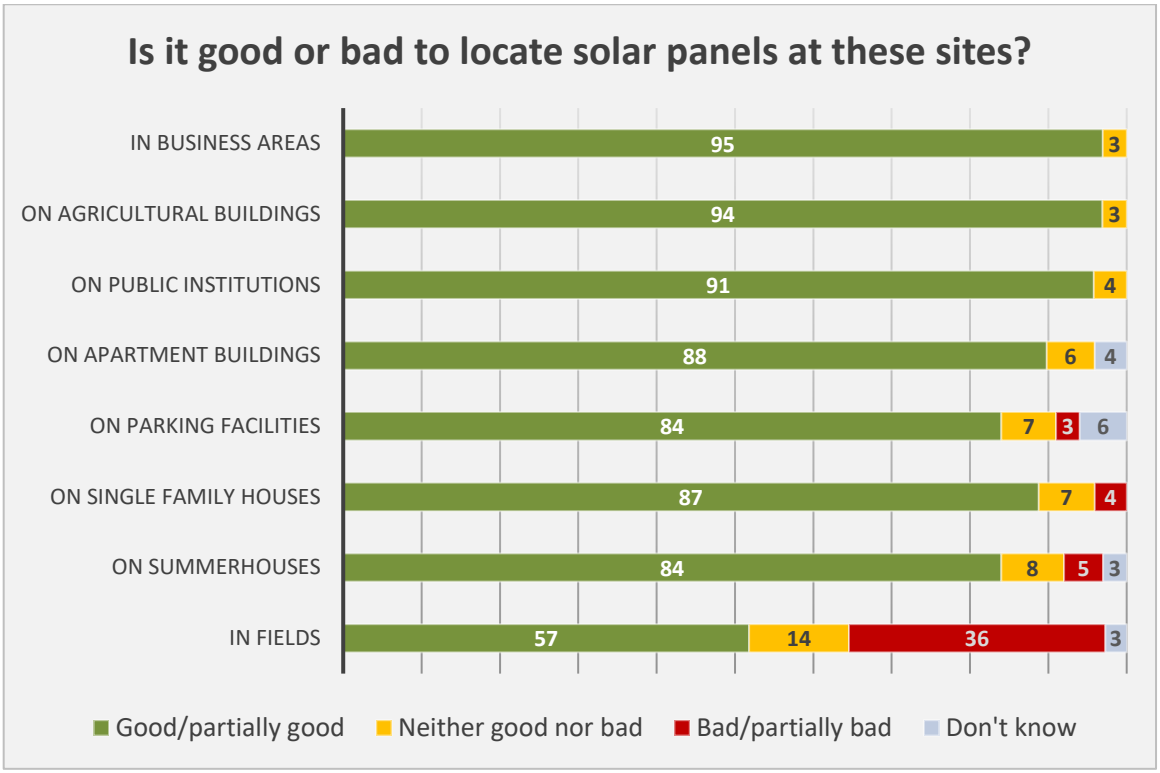

Figure 15 Solar panel location.

5 Conclusion

The objective of this report was to present the results from a survey conducted in February 2022 in Denmark regarding uses and perceptions of solar panels. We now return to the questions posed in the introduction for a summary and discussion of these results.

We asked the following questions

- What are the motivations for private households to install solar panels
- How do solar panels influence energy consumption practices of their owners?
- How are conditions for grid connection perceived by solar panel owners?
- What are the attitudes towards solar panels, among both solar panel owners and non-owners?
- And consequently, what are the socio-technical conditions for upscaling household based co-generation of electricity?

Motivations: The findings from our study regarding householders' reasons for acquiring solar panels resemble results from most other studies, not least the similar Danish studies (Mechlenborg et al. 2020, Jacobsen, Hansen & Gram-Hanssen 2019). The potential benefits for household economy are a major motivation for the installation of solar panels on private homes, especially because of the expected savings on the energy bill, but reduced vulnerability towards fluctuating energy prices is also an important reason and also counts as an economic benefit. Based on our findings, it is fair to say that without this potential for improved household economy, there would be little drive for installing photovoltaics on private homes. However, similar to other studies, our results also indicate that economic incentives rarely stand alone. Thus, concern for climate and environment is also clearly an important motivation for solar panel installation among this study's respondents, although it is reasonable to suggest that without the potential for economic benefit, climate concern would not be enough for householders to take the step. This is supported also by the fact that the top-three conditions for taking the step to install micro-renewables all concern economics, i.e. better subsidies, better household economy and better conditions for selling surplus power.

It should be noted that our survey was conducted prior to the Russian attack on Ukraine and the ensuing steep incline in energy prices (an incline that recently has changed to a matching price decline).

In other words, it is fair to expect that for householders to make the major investment of acquiring solar panels and endure the hassle of having them installed there is not and cannot be just one motivating factor. Reasonable benefits for household economics must go hand in hand with wider considerations, chief among which are climate concern, but national and regional energy security may potentially also constitute such a wider consideration.

That said, our study does not indicate that ***community attachment*** is an important driver for solar panel installation. The importance of community attachment is assessed in quite different ways across the various studies mentioned in this report. This may reflect differences in the wider context in terms

of geographical location, proximity to and integration in energy infrastructures, criteria in various subsidy regimes, trust in national governments and energy/utility companies, and other factors. Our study does not allow a thorough analysis of the impact of all these different factors on the importance of community attachment, but it does indicate that 'community solutions' has not until now been the favoured solution for homeowners challenged by the climate crisis, fluctuating energy prices and energy insecurity.

Integration in household practices: The ways in which household electricity consumption is arranged during the day is an important issue for a widespread implementation of energy production from wind and sun, whether it is large-scale wind and solar farms or micro installations at private homes. It is important from a societal perspective so that electricity consumption can be optimally matched with peak production (and storage capacities). And it is important from the perspective of individual households so that they can optimize the benefits from their facility.

The results from our survey indicate that solar panel owners to some extend do try to adjust their electricity consumption so that it matches production from their own installation. But this adjustment is also always integrated in daily practices, and it depends upon the specific appliances and activities for which energy is consumed. Thus, dishwashers, washing machines, tumble dryers and car batteries are frequently used and charged during the daytime when there is power from the panels – because there are timer functions on the appliances, because it simply is not at odds with the daily routines to do so, and because energy savings are tangible while inconveniences are insignificant.

Conversely, most respondents want to recharge computers and mobile phones whenever it is needed, they take baths (using electric water heaters) when it is convenient for them, and they want to cook and dine in the evening as usual, regardless of the sun's movement on the sky. Whereas the main reason for adjusting electricity consumption is the economic benefit – with environmental concern as an important secondary reason – the dominant reason for *not* adjusting electricity consumption is that such an adjustment does not fit into the daily routines. Again, the survey was conducted prior to the onset of the price fluctuations over the last year, and it is possible that more respondents would adjust their consumption now given heightened awareness about energy prices.

Grid connection: Just as timing of electricity-consumption is important for the overall energy system and the individual households alike, so is the issue of grid connection. Most solar panel owners may at times produce more power than they consume themselves and that surplus is mostly distributed to the grid. The prices and conditions that are applied can be a factor in how well the decentralized energy production from micro renewables contributes to the energy system. Similarly, individual households are potentially affected by the conditions for grid connection, in terms of their inclination to acquire solar panels and the ways in which electricity from such panels are used as part of the households' daily routines.

In our study, the conditions for grid connection appeared to be a sore issue. As noted, the majority of respondents with solar panels were members of an association, and this *may* constitute a bias, because people may have joined that association out of discontent. Whatever bias there may be, the study

shows a considerable majority being dissatisfied with the prices and conditions for selling their surplus power to the grid. Their dissatisfaction appears mainly to be the result of those changes that have been imposed by the Danish government and the distribution companies. When solar panel owners acquired their installation, conditions were more favourable, and now that conditions have changed, they feel betrayed, and quite a few also believe that the potential for reimbursement of and benefit from their investment has deteriorated considerably.

An overwhelming majority of the surveyed solar panel owners are still content with their installation; their grievances about betrayed promises and resale rates have not affected this contentment. Moreover, respondents with solar panels or solar heating are more likely to be interested in acquiring new installations than respondents with no micro renewables. The governmental breach of the original grid connection rules has, in other words, not necessarily discouraged people's interest in micro renewables. However, for respondents to take the step and acquire additional micro renewables, better conditions for selling surplus power can be one determinant.

General attitudes: There are at least two aspects of the general public's attitude towards solar panels: (a) people's acceptance or disapproval of solar panels as an energy source and of their presence in urban and rural landscapes, (b) people's inclination to have solar panels installed on their own homes and properties.

Judging from our survey there seems to be massive public acceptance of solar panels and their installation on a variety of buildings and surfaces. With one exception. Whereas a huge majority favours locating solar panels on all kinds of public, business and private buildings, it is a much smaller majority who would accept locating PVs in agricultural fields, and a large minority are opposed to such a location. So even though open fields are the most cost-effective location for solar panel facilities (IEA 2020), such a location is likely to cause local controversy and is not necessarily optimal from a social, cultural and political perspective.

It is outside the scope of this study to assess whether decentralized energy production from micro renewables on individual homes/properties is a technically and economically useful contribution to the general energy system. To the extent that is the case, the question is how the installation of solar panels on private homes can be scaled up. Alternatively, it may simply be deemed preferable to provide good preconditions for the citizens to include micro renewables in their household's energy mix, even if the contribution of those household-based micro renewables is somewhat less than important for the overall energy system. If that is the case, the question remains, what are the best conditions for increased installation of solar panels and the like?

Our findings point to the following preconditions. For homeowners to install solar panels, it must be economically feasible and provide a reasonable economic benefit – assuming that any upscale will have to reach beyond the nerdy frontrunners who are less motivated and less limited by economic considerations. Such economic benefits may consist in savings on household energy expenses and/or in good prices for selling surplus power to other consumers/the grid and/or in subsidies for the investment in solar panels.

But the prospect of economic benefit must go hand in hand with appeals to other factors. Those other factors can be widespread climate concern, other shared societal concerns such as energy security, and – depending on the specific circumstances – a strong community attachment or a strong local incentive to devise local solutions.

To understand further the preconditions for developing photovoltaic and other micro-renewable installations on private homes, it is important to deepen the analysis of not just householders' practices around acquisition and usage of energy installations, but also the framing of such installations – in the general public, in the discourses of policy actors, and in the householders' own perceptions of their installations.

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Appendix 1: Questionnaire

QUESTIONS INSPIRED BY AND PARTLY COPIED FROM STUDY REPORTED IN JACOBSEN, HANSEN & GRAM-HANSSEN (2019).

Mange tak for at du vil besvare dette spørgeskema

Det er udarbejdet af forskere ved Aarhus Universitet og handler om energiforbrug og energiproduktion i privatboliger.

Du deltager **anonymt** i denne undersøgelse, og vi bruger og opbevarer dine besvarelser i **anonymiseret** form (helt i overensstemmelse med reglerne for databeskyttelse, de såkaldte GDPR-regler). For at du kan komme videre til spørgsmålene, har vi først brug for at du giver dit samtykke nedenfor. Forskerne bag undersøgelsen kan kontaktes på lkp@envs.au.dk

Efter spørgeskemaets sidste spørgsmål bliver du bedt om at afslutte besvarelsen. Det er vigtigt for at du kan deltage i lodtrækningen om et gavekort.

☐ Ja, jeg deltager gerne

Hvis du ikke ønsker at deltage, lukker du bare vinduet.

Hvordan bor du?

☐ I kollegie- eller klubværelse
☐ I lejlighed
☐ I rækkehus/klyngehus
☐ I villa/parcelhus
☐ På landejendom
☐ I haveforeningshus eller sommerhus som helårsbolig
☐ Andet
☐ Ønsker ikke at svare

Er der et eller flere af disse energianlæg på din bolig eller den tilhørende grund?

☐ Solpaneler/solcelleanlæg til elproduktion
☐ Mikrovindmølle til elproduktion
☐ Solvarmeanlæg
☐ Jordvarmeanlæg
☐ Ingen af delene

Hvem har fået anlæggene installeret [Aktivering: Hvis ikke 'ingen af delene']

☐ Jeg selv/min husstand har fået installeret mindst ét af anlæggene
☐ Anlægget/anlæggene var der allerede, da jeg/vi flyttede ind

Hvor vigtige var følgende grunde, da I valgte at få installeret jeres anlæg? [Aktivering: Selv fået installeret]

	1 Slet ikke vigtig	2	3	4	5 Meget vigtig	Ved ikke
Det forøger ejendommens værdi	(1)	(2)	(3)	(4)	(5)	(6)
Det gør os mere uafhængige af energiforsyning udefra	(1)	(2)	(3)	(4)	(5)	(6)
Det er godt for klima og miljø	(1)	(2)	(3)	(4)	(5)	(6)
Vi sparer på de løbende energiudgifter	(1)	(2)	(3)	(4)	(5)	(6)
Det gør os mindre sårbare overfor stigende energi-priser	(1)	(2)	(3)	(4)	(5)	(6)
Vi kan godt lide at være på forkant med ny teknologi	(1)	(2)	(3)	(4)	(5)	(6)

Havde det betydning, da du/I valgte bolig, at der er et sådant anlæg på ejendommen? [Aktivering: Var der da de flyttede ind]

- ☐ Det trak ned, men jeg/vi valgte huset alligevel
- ☐ Det gjorde ingen forskel
- ☐ Vi/jeg ser det som en fordel, at der er sådan et anlæg

Hvor vigtige er følgende grunde til, at du/I opfatter det som en fordel, at der er et sådant anlæg på ejendommen? [Aktivering: Ser det som en fordel]

	1 Slet ikke vigtig	2	3	4	5 Meget vigtig	Ved ikke
Det forøger ejendommens værdi	(1)	(2)	(3)	(4)	(5)	(6)
Det gør os mere uafhængige af energiforsyning udefra	(1)	(2)	(3)	(4)	(5)	(6)
Det er godt for klima og miljø	(1)	(2)	(3)	(4)	(5)	(6)
Vi sparer på de løbende energiudgifter	(1)	(2)	(3)	(4)	(5)	(6)
Det gør os mindre sårbare overfor stigende energi-priser	(1)	(2)	(3)	(4)	(5)	(6)
Vi kan godt lide at være på forkant med ny teknologi	(1)	(2)	(3)	(4)	(5)	(6)

Har du eller overvejer du at anskaffe en varmepumpe til din bolig (luft-til-luft eller luft-til-vand)?

- ☐ Ja
- ☐ Nej, men vi overvejer
- ☐ Nej
- ☐ Ved ikke

Råder din husstand over ét eller flere af disse transportmidler? (Gerne flere svar)

- ☐ Elbil
- ☐ Plugin hybridbil
- ☐ Elcykel
- ☐ Andre elektriske køretøjer (fx scooter, løbehjul)
- ☐ Ingen af delene

I hvor høj grad tilpasser din husstand elforbruget efter belastning og pris på elnettet ved at flytte elforbrug til om natten?

- ☐ I meget høj grad
- ☐ 4
- ☐ 3
- ☐ 2
- ☐ 1 Slet ikke
- ☐ Ved ikke

Har du nogensinde skiftet elforsyningsselskab?

- ☐ Ja, mindst én gang
- ☐ Nej, aldrig
- ☐ Kan ikke huske / ved ikke

Hvorfor skiftede du selskab? (Eventuelt flere svar) [Aktivering: Mindst én gang]

- ☐ Fordi jeg kunne spare penge
- ☐ Fordi miljøprofilen var bedre på det nye selskab
- ☐ Fordi jeg flyttede
- ☐ Andre grunde (skriv evt. hvilke) _____
- ☐ Ved ikke / kan ikke huske

Hvorfor ikke? (Eventuelt flere svar) [Aktivering: Nej aldrig]

- ☐ Har bare aldrig tænkt på det
- ☐ Der har ikke været bedre tilbud
- ☐ Det er for besværligt at sætte sig ind i selskabernes tilbud
- ☐ Vil gerne men har ikke haft tid
- ☐ Andre grunde (skriv evt. hvilke) _____
- ☐ Ved ikke

I hvor høj grad tilpasser du og din husstand elforbruget efter, hvornår der er strøm fra husstandens eget solcelleanlæg ved at flytte elforbrug til dagtimerne? [Aktivering: Har solcelleanlæg]

- ☐ I meget høj grad
- ☐ 4
- ☐ 3
- ☐ 2
- ☐ Slet ikke
- ☐ Ved ikke

Tilpasser du og din husstand jeres elforbrug ved at lægge brugen/opladningen af disse apparater, når der er strøm fra eget anlæg? [Aktivering: Hvis 5-2]

	Altid	Ofte	Af og til	Sjældent	Aldrig	Har ikke apparatet
Opvaskemaskine	(1)	(2)	(3)	(4)	(5)	(6)
Vaskemaskine	(1)	(2)	(3)	(4)	(5)	(6)
Tørretumbler	(1)	(2)	(3)	(4)	(5)	(6)
El-vandvarme	(1)	(2)	(3)	(4)	(5)	(6)
Opladning af elbil	(1)	(2)	(3)	(4)	(5)	(6)
Opladning af computer/ mobil	(1)	(2)	(3)	(4)	(5)	(6)
Elkomfur og -ovn	(1)	(2)	(3)	(4)	(5)	(6)

Hvad har betydning for, at du/din husstand lægger elforbrug på tidspunkter, hvor du/I kan udnytte strømmen fra eget anlæg? (Afkryds alle relevante svar) [Hvis 5-2]

☐ Det giver en økonomisk fordel
☐ Det er det bedste for miljøet
☐ For så vidt muligt at være selvforsynende med strøm
☐ Der er nogen hjemme i dagtimerne
☐ Det passer ind i husstandens dagligdag
☐ Der er tekniske muligheder såsom timer-funktion
☐ Intet af ovenstående / ved ikke

Hvad har betydning for, at du/din husstand IKKE lægger elforbrug på tidspunkter, hvor I kan udnytte strømmen fra eget anlæg? (Afkryds alle relevante svar) [Aktivering: Hvis 3-1]

☐ Det passer ikke ind i husstandens dagligdag
☐ Det er for besværligt
☐ Der er ikke nogen hjemme i dagtimerne
☐ Det er ikke teknisk muligt (der mangler timer-funktioner)
☐ Den økonomiske gevinst er ubetydelig
☐ Vi har et husstandsbatteri
☐ Kan ikke se nogen grund til at gøre det
☐ Intet af ovenstående

Har din husstands elforbrug ændret sig siden du/I har fået solceller? [Har solcelleanlæg]

☐ Vi bruger mere el
☐ Vi bruger mindre
☐ Vi bruger cirka det samme
☐ Ikke sikker, men vi tænker mere over hvornår vi bruger el
☐ Ved ikke

Hvor ofte aflæser du solcelleanlæggets produktion? [Har solcelleanlæg]

☐ Her dag
☐ Hver uge

☐ Hver måned
☐ Hvert kvartal
☐ Hvert år
☐ Aldrig
☐ Det er ikke muligt at aflæse
☐ Ved ikke

Hvad gør du, hvis der er overskydende strøm fra dit eget anlæg, altså strøm du/I ikke selv bruger? (Eventuelt flere svar) [Har solcelleanlæg]

☐ Sælger den til nettet
☐ Lagrer den hos mig selv i et separat husstandsbatteri
☐ Lagrer den i et lokalt fællesanlæg
☐ Andet (skriv gerne hvad) _____
☐ Ved ikke

Hvilken afregningsordning har du for anlæggets overskydende produktion? [Har solcelleanlæg]

☐ Timebaseret nettoafregning
☐ Øjebliksbaseret nettoafregning
☐ Årsbaseret nettoafregning
☐ Andet (hvad) _____
☐ Ved ikke

Tror du, at et skift til time- eller øjebliksafregning vil få dig til i højere fra at tilpasse dit elforbrug til dit eget anlægs produktion? [Hvis årsbaseret]

☐ Ja, helt sikkert
☐ Måske
☐ Formentlig ikke
☐ Nej, helt sikkert ikke
☐ Ved ikke

Hvad synes du om betingelserne for salg til nettet? [Har solcelleanlæg]

☐ Meget fordelagtige
☐ OK
☐ Ikke så gode (skriv evt. hvorfor) _____
☐ Alt for dårlige (skriv evt. hvorfor) _____
☐ Ved ikke

Kunne du være interesseret i at bruge din overskydende strøm på en anden måde, end du gør i dag, f.eks. på én af følgende måder? [Har solcelleanlæg]

	Ja	Måske	Nej	Gør jeg allerede	Ved ikke
Sælge den direkte til andre el-forbrugere (frem for bare til nettet)	(1)	(2)	(3)	(4)	(5)
Lagre den i et lokalt fællesanlæg	(1)	(2)	(3)	(4)	(5)
Lagre den i mit eget husstands-batteri	(1)	(2)	(3)	(4)	(5)

Hvor vigtige er følgende forhold for dig, når det gælder brugen af overskydende strøm fra dit anlæg?

	5 Meget vigtigt	4	3	2	1 Slet ikke vigtigt	Ved ikke
At det gavner min husstands økonomi	(1)	(2)	(3)	(4)	(5)	(6)
At det gavner klima og miljø	(1)	(2)	(3)	(4)	(5)	(6)
At strømmen sælges/bruges i mit lokalområde	(1)	(2)	(3)	(4)	(5)	(6)
At det foregår automatisk og uden besvær for mig	(1)	(2)	(3)	(4)	(5)	(6)
At det gør mig uafhængig af energiforsyning udefra	(1)	(2)	(3)	(4)	(5)	(6)
At jeg styrer om min el skal sælges, til hvem og hvornår	(1)	(2)	(3)	(4)	(5)	(6)

Hvad synes du alt i alt om dit solcelleanlæg? Angiv hvor enig/uenig du er i disse udsagn.

	Helt enig	Delvist enig	Hverken/ eller	Delvist uenig	Helt uenig
Jeg er tilfreds med anlægget	(1)	(2)	(3)	(4)	(5)
Det skæmmer bygningen/ grunden	(1)	(2)	(3)	(4)	(5)
Det giver mig intet besvær	(1)	(2)	(3)	(4)	(5)
Jeg er træt af det	(1)	(2)	(3)	(4)	(5)
Jeg er stolt af det	(1)	(2)	(3)	(4)	(5)

Overvejer du og din husstand at få installeret et eller flere af disse anlæg (altså ud over det/de anlæg I eventuelt allerede har)?

- ☐ Solpaneler/solcelleanlæg
- ☐ Mikrovindmølle
- ☐ Solvarmeanlæg
- ☐ Jordvarmeanlæg
- ☐ Ingen af delene

Hvad får dig/jer til at overveje en sådan installation? (Gerne flere svar) [Aktivering: Har ikke anlæg, vil gerne]

- ☐ Det er en god investering
- ☐ Det er godt for klima og miljø
- ☐ Det vil gøre min husstand mere uafhængig af energiforsyning udefra
- ☐ Det vil begrænse de løbende energiudgifter
- ☐ Det vil øge ejendommens værdi
- ☐ Det er godt at være på forkant med den teknologiske udvikling
- ☐ Andet (skriv gerne hvad) _____
- ☐ Ved ikke

Hvad skal der til, for at du tager skridtet og får installeret et sådant anlæg? (Gerne flere svar) [Aktivering: Har ikke anlæg, vil gerne]

- ☐ En bedre husstandsøkonomi, så der er råd til investeringen
- ☐ Samarbejde i lokalområdet
- ☐ Bedre tilskud fra det offentlige eller forsyningsselskabet
- ☐ Bedre vilkår for salg af overskydende strøm fra mit anlæg
- ☐ Enighed med resten af husstanden
- ☐ Jeg skal være sikker på at jeg kan styre og vedligeholde anlægget
- ☐ Bedre tid til at sætte sig ind i tingene
- ☐ God og pålidelig rådgivning
- ☐ Andet (skriv gerne hvad) _____
- ☐ Så interesseret er jeg heller ikke
- ☐ Ved ikke/intet af ovenstående

Hvorfor ikke? (Gerne flere svar) [Aktivering: Har ikke anlæg, vil ikke have ét]

- ☐ Kan ikke se nogen fordel ved det
- ☐ Har ikke råd
- ☐ Jeg tror ikke det giver nogen betydelig klimagevinst
- ☐ Jeg er bekymret for at jeg skal bruge tid på anlægget
- ☐ Det er grimt
- ☐ Der er ikke plads på min ejendom
- ☐ Det er ikke teknisk muligt på min ejendom
- ☐ Har bare aldrig tænkt over det
- ☐ Andet (skriv gerne hvad) _____
- ☐ Ved ikke

Husstande med solpaneler kan ikke altid bruge den strøm, de selv producerer. Hvad synes du man skal gøre med den overskydende strøm? (Eventuelt flere svar) [Aktivering: Har ikke solcelleanlæg]

- ☐ Sælge den til elnettet/forsyningsselskabet
- ☐ Sælge den direkte til beboere og virksomheder i lokalområdet
- ☐ Lagre den på et batteri i husstanden
- ☐ Lagre den på et fælles batteri i lokalområdet
- ☐ Det er jeg ligeglad med
- ☐ Ved ikke

Er der solcelleanlæg på ejendommene i dit kvarter?

- ☐ Kun på min egen ejendom
- ☐ Både på min og på andres ejendomme
- ☐ Ikke hos mig, men på én eller flere andre ejendomme
- ☐ Nej, det er der ikke
- ☐ Ved ikke

Har du oplevet noget af følgende i forbindelse med solcelleanlæg i dit kvarter? (Eventuelt flere svar) [Aktivering: Solpaneler i kvarteret]

- ☐ Jeg har inspireret mine naboer til at installere solcelleanlæg
- ☐ Jeg er blevet inspireret af mine naboer til selv at installere solcelleanlæg
- ☐ Naboer har klaget over mit solcelleanlæg
- ☐ Naboer har klaget over andres solcelleanlæg
- ☐ Jeg har selv klaget over andres solcelleanlæg
- ☐ Jeg kan ikke lide solcelleanlæggene i mit kvarter, men har ikke klaget
- ☐ Ingen af delene

Er det efter din mening godt eller skidt at placere solpaneler på disse steder?

	Godt	Delvist godt	Hverken eller	Delvist skidt	Skidt	Ved ikke
På parcelhuse og rækkehuse	(1)	(2)	(3)	(4)	(5)	(6)
På sommerhuse	(1)	(2)	(3)	(4)	(5)	(6)
På etageejendomme til beboelse	(1)	(2)	(3)	(4)	(5)	(6)
I erhvervs- og industriområder	(1)	(2)	(3)	(4)	(5)	(6)
På landbrugsbygninger	(1)	(2)	(3)	(4)	(5)	(6)
På offentlige institutioner	(1)	(2)	(3)	(4)	(5)	(6)
På parkeringsanlæg	(1)	(2)	(3)	(4)	(5)	(6)
På marker	(1)	(2)	(3)	(4)	(5)	(6)

Hvor enig eller uenig er du i følgende?

	Helt enig	Delvist enig	Hverken eller	Delvist uenig	Helt uenig	Ved ikke
Det er pænt med solpaneler på privatboliger	(1)	(2)	(3)	(4)	(5)	(6)
Jeg stoler på mit elforsyningsselskab	(1)	(2)	(3)	(4)	(5)	(6)
Energiforsyning skal være lokalt forankret	(1)	(2)	(3)	(4)	(5)	(6)
Jeg kan godt lide at nørkle med boligens tekniske anlæg	(1)	(2)	(3)	(4)	(5)	(6)
Jeg holder øje med energiforbruget i min husstand	(1)	(2)	(3)	(4)	(5)	(6)
Jo mindre jeg til daglig skal beskæftige mig med min energiforsyning, jo bedre	(1)	(2)	(3)	(4)	(5)	(6)

Til sidst har vi nogle spørgsmål om din baggrund, hvorefter du får mulighed for at tilmelde dig lodtrækningen om gavekort.

Hvor gammel er du?

☐ Yngre end 35
☐ 35-49
☐ 50-64
☐ 65-79
☐ Ældre end 79
☐ Vil ikke oplyse

Hvad er dit køn?

☐ Kvinde
☐ Mand
☐ Andet/Vil ikke oplyse

Hvad er din årlige husstandsindkomst (før skat)?

☐ Under 100.000
☐ 100 - 299.000
☐ 300 - 499.000
☐ 500 - 699.000
☐ 700 - 899.000
☐ 900.000 - 1.100.000
☐ Over 1.100.000
☐ Ved ikke
☐ Ønsker ikke at oplyse

Har du erhvervserfaring inden for ét eller flere af disse områder?

☐ Håndværk

- ☐ Ingeniør og teknik
- ☐ IT
- ☐ Industri
- ☐ Sundhed og pleje
- ☐ Børnehave og vuggestue
- ☐ Undervisning
- ☐ Handel og service
- ☐ Forskning
- ☐ Design og kreative fag
- ☐ Jura og økonomi
- ☐ Andet
- ☐ Vil ikke oplyse

SOLAR PANELS AND HOUSEHOLD ENERGY PROSUMPTION – EXPERIENCES, PRACTICES AND ATTITUDES

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