Demanding, distributing and selling energy flexibility: How dynamic tariffs entered the Danish electricity market and what to do next

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Abstract

Dynamic electricity pricing, in which tariffs vary during the day, has gained more attention over recent decades. In Denmark, the expansion of renewable and fluctuating energy production, primarily in the form of wind power, has increased the need for energy demand flexibility, and with a full rollout of smart meters, dynamic electricity pricing appears as an apparent solution. However, a successful (further) implementation of time-varying electricity rates in Denmark depends on households adopting, accepting and acting on dynamic price signals.

The concept of energy flexibility plays an essential role here, but different actors emphasize different aspects of flexibility. For grid companies, who distribute electricity, flexibility is a way to limit or postpone investments. For retailers, who sell electricity, flexibility helps promote products and introduces cost-reflecting prices. Finally, for households, who demand energy, flexibility needs to reflect everyday rhythms and practices.

In this paper, we review the initial implementation of dynamic electricity pricing in Denmark. First, focusing on *demanding* energy flexibility, we describe the modest effect of dynamic pricing and the (modest) adoption of such products based on previous studies. Then, taking social and material contexts into account, we suggest that flexible *practices* better encapsulate energy demand flexibility rather than flexible *consumers*, and that price signals work through changing the meaning of household practices. Second, focusing on *distributing* and *selling* energy flexibility, we outline the role of grid companies and retailers, and include general descriptions of products on the market today.

Finally, we comment on the preliminary and future promotion of time-varying products as well as suggest recommendations for future energy policy and research on dynamic electricity pricing.

Introduction

The transition to more renewable energy production such as wind and solar generates a need for more demand flexibility. Dynamic electricity pricing, signalling when production costs are lower or when grid loads are higher, is a popular tool for providing more flexibility on the demand side (Torriti, 2015).

The increased need for energy flexibility is also a concern in Denmark. Dynamic electricity tariffs have entered the Danish market in recent years as many energy retailers have introduced Real Time Pricing (RTP) products and some grid companies have introduced Time-of-Use (ToU) tariffs. This development is closely associated with the rollout of smart meters to all Danish households, as well as the goal of a smart energy system (Klima-, Energi- og Bygningsministeriet, 2013).

In this paper, we detail the current status of dynamic electricity pricing in Denmark from the viewpoint of grid companies and retailers. In addition, we conceptualize the relationship between dynamic pricing and (flexible) energy demand. This enables us to discuss the current situation and provide suggestions for future marketing and research.

Dynamic electricity pricing in Denmark has focused on smart grid infrastructure and technology solutions, whereas demand flexibility has been given less attention. However, the current implementation of dynamic tariff structures must address what *flexible demand* is and how households *respond,* as well as understanding the assumptions about demand-response that dynamic pricing products are designed on.

Based on international research, we start by answering two questions: What is flexible electricity demand and how do households respond to dynamic electricity pricing? We then look into the Danish case by first describing the grid companies' efforts to generate more energy flexibility, focusing on time-varying tariffs, and, second, by describing how electricity retailers have commercialized dynamic pricing.

1. Dynamic electricity pricing and flexible demand

In the 1920s, the Danish electricity company NESA introduced dynamic peak pricing with tariffs overnight that were almost half the daytime price (Olesen and Thorndal, 2004). This was probably to accommodate limitations on the production and supply side. After the Second World War, economic growth led to a substantial increase in energy demand, which was met by expanding production and connecting with neighbouring countries (Olesen and Thorndal, 2004). In the 1980s, flexible demand was once again put on the agenda when NESA proposed that the costs of expanding infrastructure could be reduced by levelling out load patterns (Hansen et al., Forthcoming). In the 2000s, the Danish transmission system operators Eltra and Elkraft suggested that flexible electricity demand could help stabilize market prices and increase energy security during peak periods (Hansen et al., Forthcoming). Also in the 2000s, interest in flexible demand reached the political level when the Minister for Energy suggested adjusting demand to accommodate more renewable energy production from wind power, and smart meters were prioritised as a prerequisite for flexibility. The idea of a smart grid also started to dominate the agenda following two reports from Danish Energy and the Danish Transmission System Operator (Dansk Energi and Energinet.dk, 2012, 2010).

This history can be summarized in three periods. First, a period when electricity pricing followed energy supply (for international examples of this, see Decker (2020)). Second, a period when increasing energy demand was met by increasing production. The development from the first to the second period illustrates a shift from energy demand *reflecting* (natural) rhythms in energy production and supply, for example via price signals, to energy production and supply *meeting* demand through a 'predict and provide' strategy, which potentially generates even greater energy demand (Coutard and Shove, 2019). Finally, in the third and current period, we probably need to re-establish parts of the strategy where energy demand *reflects* the intermittent fluctuations and other limitations of (renewable) energy production. Such a strategy is well-known in other industries, for example telecommunications, hotels, and car hire (Strengers, 2019). This brief historical outline helps us remember what used to be the normal and how it is possible to change. One place to start is with a discussion of what flexible energy demand is, and the relationship between price signals and energy-demanding practices.

1.1 What is flexible energy demand?

The concept of *energy demand flexibility* plays a central role in the transition to an energy system based on more renewables, and dynamic pricing is often seen as the primary solution (Torriti, 2015). However, conceptualizations of energy *flexibility* differ across technical and social science perspectives. Moreover, *flexibility* tends to be understood differently by different actors in the energy sector (Blue et al., 2020). As illustrated in Figure 1, grid companies, distributing electricity, focus on flexibility as a quality of energy systems. Retailers, selling electricity, focus on marketing flexibility, and households, demanding energy, focus on everyday rhythms and daily practices.

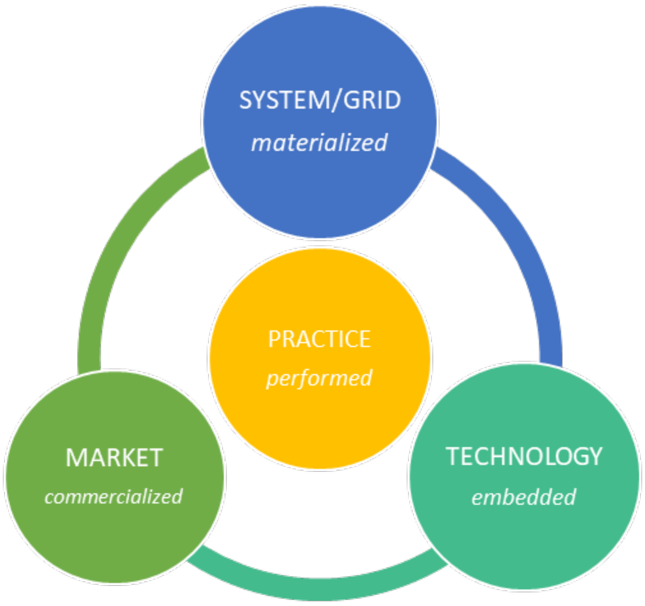

Figure 1. Different roles of energy flexibility (inspired by Blue et al. (2020), 'practice' added).

This paper includes the perspectives on energy flexibility of the different actors (households, retailers and grid companies), which primarily refers to energy flexibility as commercialized (for sale) and performed, but also touches on energy flexibility as materialized in energy systems and embedded in technologies.

Where dynamic price schemes are marketed as flexible (or similar framings), how should we then understand the demand response? The terms 'flexible demand/consumption' or 'flexible consumers' are often used. It has also been suggested that households' capacity, or lack thereof, to time-shift consumption can be described as a flexibility capital (Powells and Fell, 2019), which can be used to highlight social inequality in demand-response initiatives (Fell, 2019). This approach appear sympathetic to take into account household differences and useful as long as demand-response is not individualized. Both sociological and economic accounts build on an understanding of individual behaviour as constrained. This could, for example, refer to biases that hinder 'good' decisions (Thaler and Sunstein, 2012), or to the so-called value-action gap, which problematizes a one-sided focus on the individual consumer (Southerton, 2006), or the role of materiality in reproducing and changing social practices (Shove et al., 2012), or (energy) consumed without conscious reflection and awareness (Warde, 2005). Others have pointed to similar underlying (mis)understandings of consumers as predominantly rational actors who wish to, and are able to, optimize consumption patterns based on information (Hargreaves, 2017; Strengers, 2013), especially concerning economic interests (Strengers, 2019).

However, an approach that focuses on changing energy demand through encouraging and informing individual choices and decision-making risks overestimating households' ability to change their electricity consumption patterns. Dynamic pricing uses cost as a lever of behavioural change, and there is no doubt that price is an important instrument, but far from being the only factor stimulating behavioural changes, especially in contexts where economic incentives are low, for example because of lower overall prices.
Instead, as energy-demanding practices are inherently dynamic, but at the same time inelastic, and individual agency is only one driver for change (Blue et al., 2020; Shove et al., 2012; Warde, 2017), we propose that *flexible practices* better frames how households respond to dynamic pricing (see also Nyborg, 2015).
This shifts attention from the *elasticity of prices* to the *elasticity of social practices*. Focusing on changing social practices takes into account how individual action is *routinized*, because of boundaries of social relations and material surroundings, and *habitual*, because of the embodiment of the practitioners' previous experience (Jacobsen and Hansen, 2019). From this perspective, demand response, and thereby energy demand flexibility, reflect the elasticity of social practices performed by households, rather than individual decision-making.

Moreover, the practice approach entails that:

1. Electricity is consumed through the performance of everyday practices. Thus, electricity is not consumed for its own sake, but for the services and practices that it provides (Shove and Walker, 2014; Warde, 2005). This does not, however, need to contradict other theoretical accounts. This could be done by zooming in on specific doings that provide more or less room for flexibility. In this case, it could be cleaning practices (Smale et al., 2017), such as the use of washing machines and dishwashers (Friis and Christensen, 2016; Gram-Hanssen et al., 2020).

2. Demand for electricity occurs through the performance of everyday practices that are reconfigured by material surroundings, e.g. electrical appliances and infrastructure, relations to others, e.g. family and friends, and social norms, e.g. how to cook and travel (Shove et al., 2012).
3. Electricity consumers perform routinized energy-demanding practices differently, for example referring to social differences in competences (e.g. technical know-how), practical understandings (e.g. frugality), and engagement (e.g. importance of activity) (Warde, 2005).
4. The timing of energy-demanding practices is closely related to the rhythm and organization of everyday routines, for example 'hot' and 'cold' spots (Southerton, 2020, 2003) and 'family peaks' (Nicholls and Strengers, 2015), as well as societal rhythms, e.g. opening hours and the working day (Blue et al., 2020).

In summary, the (in)elasticity of energy demand is better understood as reflecting (in)flexible practices rather than (in)flexible consumers. This perspective emphasizes how the timing of energy-demanding practices are influenced by technologies (or other factors), social norms (relations to others), and everyday rhythms.

1.2 How do households respond to dynamic electricity pricing?

Time-varying electricity pricing serves two primary purposes: 1) to shift energy use from periods of peak demand to periods of lower demand, and 2) reducing energy demand at certain peak load periods (Torriti, 2015, p. 14). Worldwide, a number of time-varying electricity rates exist, including time-of-use pricing, critical peak pricing, real-time pricing, and their variants. They present varying risk-reward trade-offs to consumers and different degrees of price volatility and uncertainty. For example, real-time pricing is associated with the greatest price volatility and uncertainty, while time-of-use pricing is a less risky option but also (potentially) less rewarding. Clearly, the extent of the financial reward or loss depends on the willingness and ability of the household to shift consumption from higher-priced hours to lower-priced hours. In Denmark, two time-varying electricity rates have been applied (definitions based on Faruqui et al. (2012) and Torriti (2015)):

1. **Time-of-Use** (ToU) tariffs charge customers differently according to time periods during the day, typically on-peak and off-peak periods. *Super peak ToU* is a variation where the on-peak period is shorter, often only four hours.
2. **Real-Time Pricing** (RTP) charges customers according to the real-time cost of electricity in the form of hourly or half-hourly fluctuating prices.

Studies on the effects of ToU and RTP (table 1) indicate that households tend to respond to some degree to dynamic pricing schemes. However, the effect size and type of response vary significantly across contexts and pricing schemes. It is very important to underline some precautions when attempting to create such an overview: the context matters, and the results are sensitive to methodological design, sample size, sampling, type of data, and consumer options, among others.

With that in mind, it appears demand response increases as the ratio of peak to off-peak prices increases, but at a diminishing rate. Moreover, it appears that consumers tend to reduce rather than time-shift electricity demand, and tend to respond more in warmer climates, where the presence of air conditioning offers more potential and incentive for load shifting. Finally, it appears that different technologies can help increase the gains from dynamic pricing.

Table 1. Overview of studies on the effect of ToU or RTP programs on household electricity consumption across countries.

Author(s)	Country	Type	Result
Bartusch et al., 2011	Sweden	ToU	Peak shaving: 0.1–2.5%
Faruqui and Sergici, 2010	USA	ToU	Peak shaving: 3-6%
Burns and Mountain, 2021	Victoria, Australia	ToU	Elasticity: 0.2%
Darby and McKenna, 2012	Ireland	ToU	Demand reduction: 2.5% Peak demand reduction: 8.8%
Torriti et al., 2010	France	ToU	Peak demand reduction: 15-45%
Torriti et al., 2010	Oslo, Norway	ToU	Peak demand reduction: 10%
UK Power Networks, 2014	London, Great Britain	ToU	Demand reduction: 3.2%
Torriti, 2012	Trento, Italy	ToU	Demand increased by 13.69%
Faruqui et al., 2017	USA	ToU	Peak shaving: 4.6%
Faruqui, 2010	USA	RTP	Peak shaving: 10-14%
Allcott, 2011	USA	RTP	Peak shaving: 5-14%
Yousefi et al., 2011	USA	RTP	Peak shaving: app. 5%

In Denmark, only few small-scale studies investigating household responses to dynamic electricity pricing have been carried out. Recently, Bejan et al. (2021) used a randomized field experiment to compare the responses of 93 households to dynamic pricing and time-of-use tariff incentives. They found that ToU tariffs are twice as successful in inducing electricity demand reductions than dynamic pricing, because their stability and predictability better reflect the regularity and daily habits of households. The positive response of households to ToU rates was also found in a trial conducted in 2019 by Radius, a Danish grid company. In the trial, customers (households and businesses) reduced consumption by 3.4% on average following the introduction of ToU tariffs with peaks from 5pm to 8pm during winter (Radius Business Management, 2019). A questionnaire study of Danish private owners of photovoltaic systems (PVs) also suggested that households are able to time-shift electricity consumption. Around half of the PV owners said they had time-shifted their energy-demanding activities to benefit from their own electricity production and every sixth had time-shifted to night (Gram-Hanssen et al., 2020; Hansen et al., 2019).

The results suggest that households respond to dynamic electricity rates. However, as the results in general indicate small or modest effects, this review also suggests that other factors or instruments are important in order to change everyday practices and the timing of energy demand. One explanation of the modest response to dynamic pricing might be that price signals have to 'break through' the rigidity of the timing and organization of everyday practices (as described in the previous section). In other words, the price signal 'works' when it succeeds in reconfiguring the meaning of energy-demanding practices (Christensen et al., 2020; Hansen, 2018; Strengers, 2019). For example, laundering practices serve multiple purposes and interconnect with the timing of other household practices (Anderson, 2016). Therefore, dynamic price signals have to penetrate not only the routinized timing of laundering, but the everyday rhythms constructed by several household practices. In line with this, Strengers (2019) suggests that the primary importance of dynamic tariffs is their variability and dynamism. This entails a focus on the duration, frequency and regularity of pricing rather than the pricing itself, for example based on price points and utility maximization. The main question is then how "temporalities of electricity pricing intersect with the routines and rhythms of everyday life" (Strengers, 2019, p. 185). This emphasizes how price is one instrument (among others) that sustains or potentially changes the organization of everyday practices, and thereby the timing of energy demand.

While the response to dynamic pricing is modest and varies across contexts, the same is the case for consumers' willingness to choose such products. According to a review of studies on the adoption of dynamic pricing products, it appears that consumers generally have some interest in time-varying electricity rates, and that ToU rates are more popular than real-time pricing (Nicolson et al., 2018). Generally, there is a trade-off between the complexity of the tariff model and the engagement of households in demand-response programmes. Insights from behavioural economics help explain these trends. Since people often rely on simple heuristics when making decisions, they tend to avoid the complexity and uncertainty associated with dynamic pricing. Also, individuals are typically risk-averse and tend to emphasize losses more than gains; the potential loss of financial and other benefits during on-peak periods is more important than the potential gains during off-peak periods. Finally, individuals tend to stick to the default options ('status-quo bias'). This helps explain the reluctance of individuals to switch to another electricity product, and, when automatically enrolled, only a few decide to opt out.

In relation to this, certain recommendations about the design of such products recur in different studies (see for example Kessels et al. (2016) and Faruqui et al. (2012)):

1. **Simplicity is crucial:** The price signal needs to be easy for the customer to understand. More complex rate structures such as real-time pricing should be introduced gradually and strategically or they will result in rate shock and a low adoption rate.
2. **Short on-peak periods:** The on-peak period should be as short as possible, but of course long enough to cover peak loads in the energy system.
3. **Clear price differences:** The product should include substantial price differences, for example between peak periods and the rest of the day. This is especially crucial in countries where the variable component of the electricity price represents only a small percentage of the final electricity price paid by customers.
4. **Enabling technologies and information help:** Demand response typically increases in the presence of enabling technology (e.g., in-home display) that makes electricity consumption 'visible' and increases consumer learning and awareness of price events, and how behaviours translate into consumption.

2. Dynamic electricity pricing in Denmark

The Danish energy system is characterized by a large wind power supply and high tax rates. However, a brief introduction to the Danish electricity market and energy system should start with the basics (for more information, see for example Kitzing et al. (2016)). The Danish electricity system basically consists of three parts:

1. Power **production** primarily coming from large central power plants, offshore wind parks and grid connections to neighbouring countries.
2. The **transmission grid** transporting electricity from production to distribution around the electricity system.
3. The **distribution grid** delivering electricity from the transmission grid to households.

In 2019, wind power constituted almost half of the energy supply to Danish households (Energistyrelsen, 2020a), and the percentage is expected to increase considerably in the future (Energistyrelsen, 2020b). This means the Danish energy system is strongly dependent on wind power, and thereby has a significantly fluctuating electricity supply (Katz, 2014), which is set to intensify in the future.

The three parts (production, transmission and distribution) are also reflected in electricity bills, which can be divided into four categories based on estimates from Elpris.dk[1]:

1. Supply tariff to **retailers** (app. 16.7%).
2. Distribution grid tariff to **grid companies** (app. 13.8%).
3. Transmission (and system) tariff to **TSO**[2] (app. 4.6%).
4. Different **taxes** (app. 64.9%), including a PSO element, electricity tax and value-added tax (VAT).

In this paper, we focus on payment for the supply and distribution of electricity, which together are the focus of dynamic pricing in the current Danish system.

Since 2003, Danish households have been able to freely choose a retailer, but grid companies have a monopoly within their given geographical area (Kitzing et al., 2016). This means that all customers have the opportunity to choose a retailer with a dynamic pricing product, which makes approximately 16.7% of the electricity bill dynamic, and if they live in a grid area that has time-varying tariffs, the dynamic portion will increase to approximately 30.5%, or almost one-third of the electricity bill.

Andersen and colleagues (2017, 2013) give aggregate figures for the hourly electricity consumption for 2010 and 2012, respectively, based on meter-data from about 4,500 clients in five customer categories (households, agriculture, industry, private services, and public services). The figures on households indicate average morning peak hours between 8am and 10am, and average evening peak hours between 6pm and 8pm. Trotta (2020) uses hourly electricity consumption data for 2017 from a sample of 15,433 households and employs cluster analysis to segment households in relation to their hourly electricity load patterns. The results indicate four distinct groups characterized by different timings and magnitudes of electricity use. On average, morning peak hours range between 7am and 9am, while evening peak hours range between 4pm and 6pm. Common to all three studies is the variation in electricity demand between seasons, and between weekdays and weekends.

In summary, the Danish electricity system is strongly reliant on intermittent electricity production from wind power, the electricity billing system leaves little room for dynamic pricing (around 22% in the best cases), and the morning peak in household demand falls between 7am to 9am and the afternoon peak between 4pm and 6pm (with large variations across sectors representing different everyday rhythms of energy demand).

2.1 Danish grid companies' efforts to create more energy flexibility

Three primary developments make household energy demand flexibility a key issue for Danish grid companies (see Hansen et al. (Forthcoming)). These are: 1) the future expansion of wind power, and consequently a more fluctuating energy supply, 2) increased electricity demand following electrification, especially with a future increase in the adoption of electric vehicles (EVs) and heat pumps, and 3) the increase in decentralized electricity production units, for example residential PVs, causing a two-way power flow. These three developments are crucial for the transition of the electricity system to more renewable energy, which is part of ensuring the political goal of a more sustainable society. Despite these challenges, the (future) electricity grid

[1] It is important to stress that these are estimates based on average prices and that they are comprised of several payments, for example *distribution grid tariff* compiles the grid access charge and local grid tariff, while the supply tariff compiles a fixed charge and a price per unit kWh consumed. Moreover, the public service obligation (PSO element) varies quarterly. In summary, the final electricity bill changes over time and depends on the amount of electricity consumed and the chosen product.
[2] The Transmission System Operator (TSO) in Denmark is Energinet.dk (https://energinet.dk/El).

still has to transport electricity safely, effectively and stably in periods with no wind (or a lot of wind) and when Danish households adopt EVs, heat pumps, and PVs to a larger extent.

A common feature of these challenges is to balance demand and supply, which underlines the need for energy demand flexibility. To address these challenges, Danish grid companies have initiated a range of initiatives. These primarily include:

1. Maintaining, modernizing and expanding the electricity grid (and related systems and technologies).
2. Participation in demonstration and research projects. By putting the energy grid and its competencies at the disposal of researchers, the grid companies have contributed to the development of innovative solutions to future problems.
3. Digitalization and demand side management, for example SCADA systems (Nordic Council of Ministers, 2017).
4. Introducing time-varying grid tariffs.

As this paper focuses on dynamic electricity pricing, we provide examples of how grid companies have introduced time-varying grid tariffs. Danish grid companies' interest in dynamic pricing is relatively new, and the focus has been on reducing the afternoon peak from 5pm to 8pm, when the electricity grid has the largest challenges and least capacity. Therefore, all dynamic tariffs have been ToU tariffs; or rather super ToU tariffs as the peak period only lasts for three hours.

Although only seven grid companies have time-varying tariffs out of a total of 36 (as registered in February 2021), these are estimated to cover more than 80% of Danish households (De Frie Energiselskaber and Kile Kommunikation, 2020).

Table 2. Overview of grid companies' ToU tariffs. All prices include VAT. Peak periods refer to the winter months from October to March.

Grid company[3]	Off-peak 8pm to 5pm (¢/kWh)	On-peak 5pm to 8pm (¢/kWh)	Diff. (¢/kWh)	Peak/off-peak Ratio[4]
Radius[5]	3.18	8.48	5.30	2.7
Cerius[6]	2.07	6.40	4.33	3.1
Konstant[7]	2.20	6.24	4.04	2.8
N1 (tidl. Evonet)[8]	2.31	7.33	5.02	3.2
N1 Randers[20]	1.97	5.08	3.11	2.6
N1 Hillerød[20]	1.06	3.99	2.93	3.8
TREFOR[9]	1.04	5.09	4.05	4.9

It should be noted that the peak/off-peak ratios are large, and the peak periods short and simple. Thus, several of the recommendations from previous studies (see section 1.1 above) are implemented in these price products. However, as grid companies cover just 15% of the electricity bill and do not have direct contact with consumers in the same way as retailers, it is conceivable that only few households know that grid tariffs are dynamic and that the electricity grid benefits from lower loads in peak hours. Findings from a representative survey of energy consumers conducted by a private trade association and a private communication company support this: 67% responded that they know electricity is more expensive during peak hours and only 12% had time-shifted consumption to access cheaper energy (De Frie Energiselskaber and Kile Kommunikation, 2020).

2.2 Danish electricity retailers' marketing of dynamic tariffs

The energy retailers' main task is to deliver electricity to end-users. They are responsible for the final contact with households, and therefore their task is also to meet the needs and wishes of energy consumers if they want to keep current customers or attract new ones. At the beginning of 2021, dynamic pricing seems to be increasingly important for the task. Dynamic pricing, together with other new opportunities following a full rollout of smart meters to Danish households in 2021, is a growing arena of competition for customers, not least

[3] Based on prices for private customers, also called C-customers.
[4] Known as *peak to off-peak price ratio.*
[5] https://radiuselnet.dk/elkunder/priser-og-vilkaar/tariffer-og-netabonnement/
[6] https://cerius.dk/priser-og-tariffer/tariffer-og-abonnementer/gruppe-c/
[7] https://konstant.dk/net/priser-og-vilkaar/nettariffer-og-abonnementer/
[8] https://n1.dk/priser-og-vilkaar
[9] https://trefor.dk/elnet/priser

those households with PV, EV, heat pumps or strong environmental engagement. The smart meters enable remote hourly metering of electricity use, which can be matched to hourly wholesale prices.

Previously, customers with *variable pricing schemes* would pay a profiled price. For instance, the Nord Pool Spot day ahead index consists of hourly prices determined by supply-demand equilibrium per hour. However, as retailers were previously unable to extract hourly customer consumption data, households would typically pay a monthly average day-ahead price with an added profile premium, and the premium would be calculated based on the consumption profile of an average customer. This effectively removed any customer incentive to shift consumption out of peak/expensive hours in order to cut electricity expenditures. Up to this point, dynamic pricing on the retail side was limited to a select few products, of which several required a 'camera' of sorts to be installed facing the electricity meter in order for hourly consumption to be logged.

Reviewing electricity retail products from the electricity price overview website elpris.dk (in English meaning *electricity price*) operated by the Danish Utility Regulator, we identified 18 products (app. 10%) that included dynamic pricing. Two challenges occurred in identifying dynamic pricing products. First, ticking the box with flexible metering (in Danish, flexafregning) on elpris.dk will not leave you with a list of dynamically priced products; it will leave you with a list of products which retailers, upon registering said products, have deemed available for customers with flexible metering, referring to hourly rates. Second, there is confusion with product names. Certain product names may insinuate dynamic pricing through words such as 'flex', 'variable', and 'spot', but they do not always feature dynamic pricing but rather monthly or quarterly prices. While these are dynamic compared with fixed price products, in which prices are typically locked in for up to three years, they have no price variation over the course of a day. On the other hand, more creatively named products may feature dynamic pricing but offer little clue to this through the product name. For instance, ElbilEnergi, a SEAS-NVE Strømmen A/S power product, features two price slots – one slot from 6am to 10pm and another slot from 10pm to 6am – thereby making it dynamically priced whereas the product name alone simply indicates that it is somehow tailored to EVs.

However, despite the variety of names for dynamic pricing products, almost all refer to relatively simple RTP price structures that charge the consumer according to the real-time costs of electricity production on an hourly basis. One exception is Modstrøm (in English meaning countercurrent) that offers 'klimapakken' (the climate package) with free electricity during the night and RTP the rest of the time. Most of these RTP products are accompanied by a similar product relating to 'climate' and refer to supporting renewable energy production via certificates. This recent development has also led to new niche actors focusing on specific segments, such as EV or PV owners, or specific services, such as data visualisation or climate action.

With different names for nearly identical products, unclear product descriptions, and lacking access to information on consumption, it can be difficult for customers to choose the product that best fits their demands and wishes. This is probably not intentional, but rather is an illustration of a new field for marketing dynamic electricity products, as well as for customers to demand such products. However, the expected increase in EVs and heat pumps, which forms part of Denmark's political goals (The Danish Ministry of Energy, Utilities and Climate, 2018), has the potential to increase awareness of and engagement in dynamic pricing products. In addition, services focusing on automation, simplicity or climate consciousness stand to become more important.

Discussion

Dynamic electricity pricing has made its entry into the Danish energy market especially within the last decade. This entry has been closely linked to a full rollout of smart meters as part of the political goal of a smart grid to accommodate a future energy system based on more renewable, intermittent energy production.

Seven grid companies, estimated to cover more than 80% of Danish customers, have time-varying tariffs with substantial differences between peak periods (5pm to 8pm during winter) and off-peak periods. This can be characterized as super ToU tariffs as the peak period is relatively short. Whereas grid companies primarily see dynamic pricing as a way to ensure more energy flexibility to limit or postpone investments, electricity retailers focus on the new market opportunities that dynamic pricing provides in combination with smart meters. Thus, grid companies have only applied ToU grid tariffs, whereas the retailers, with a few exceptions, have offered RTP tariffs.

There seems to be an underlying assumption in Denmark that the implementation of dynamic electricity pricing will affect the timing of electricity demand. Several studies support this by identifying small to modest effects of dynamic pricing (especially ToU) on timing. However, contrary to that narrative, energy-demanding practices are generally described as rigid and inflexible (Torriti, 2015) and energy consumers may not see the benefits of changing to a time-varying price product, and therefore, rarely ask for it (Darby and McKenna, 2012). Moreover, the Danish electricity billing system leaves little room for dynamic pricing (app. 20% retail, 20% grid company, and the rest for levies and taxes (Kitzing et al., 2016) and small numbers of households have electric heating and EVs. Overall, this paints a rather pessimistic picture of the potential for dynamic pricing in Denmark. However, electricity demand is expected to change dramatically in the future with more heat pumps and EVs (Danish Energy Agency, 2019) and studies on PV prosumers suggest that households may be willing and able to time-shift everyday practices (Gram-Hanssen et al., 2020; Hansen et al., 2019). In addition, after a full rollout of smart meters, households have (presumably) technologies to postpone electricity use or start them automatically if dynamic price products are on the market. Therefore, more research in a specific context, such as the Danish electricity market, is needed.

In a Danish context, two questions especially need to be asked:

1. **Products:** *Are the financial gains for households too little?* At least for households without heat pumps or an EV, consumption is not large enough (Andersen et al., 2017) when only 22% or less of the electricity bill can be dynamic (Katz, 2014; Katz et al., 2018). Measures strengthening the price signal, such as dynamic taxation, are needed (Katz et al., 2018; Kitzing et al., 2016).
2. **Demand:** *Do households want to engage in responding to dynamic price signals (and are they able to)?* Denmark has generally high living standards (Larsen et al., 2017) and high energy security (World Energy Council, 2020), while the homes many functions (Gram-Hanssen and Darby, 2018) as well as harried everyday lives and rigid routines further make change less likely (Friis and Christensen, 2016; Nicholls and Strengers, 2015; Southerton, 2020). Instruments other than those based on financial incentives should therefore be considered, and could involve a new narrative of dynamic electricity pricing.

There are also several other aspects to consider, for example whether ToU tariffs could be a staging post before RTP (Darby and McKenna, 2012; Kitzing et al., 2016), and the role of automation especially for RTP (Darby and McKenna, 2012).

This calls for more research investigating how willing Danish households are to choose dynamic pricing retailers, which types of household tend to choose such products, for example households with EV and/or heat pumps, and to what degree households respond to ToU grid tariffs and RTP supply tariffs. Some research has already been conducted, but to inform demand-side strategies and develop market products, such studies need to be conducted over a representative sample covering more household groups than pilot studies. Moreover, future research needs to consider whether other instruments of change, for example smart technologies, feedback and energy efficiency, maybe in combination with financial incentives, would have a stronger effect on energy consumption patterns.

At the same time, we need to discuss how to understand the influence of dynamic pricing and the specific potential in the Danish context. The risk is that overestimating the potential for energy demand flexibility, for example households' ability, options, and willingness to change the timing of their everyday practices, may lead to false hopes and predictions for the energy industry and policy.

Recommendations

Based on this outline of dynamic pricing products in Denmark, we suggest five recommendations:

1. **How households consume electricity during the day should be given more attention.** Much of the discussion focuses on technology and price, but ultimately energy demand flexibility requires households to reduce consumption or time-shift everyday practices. A better understanding of the mechanisms of changing (and reproducing) these practices could be key to ensuring more demand response.
2. **Broaden the target from flexible consumers to flexible practices**. Consumer behaviour is constrained by several factors, and focusing on practices would take the mediating role of technologies and social norms better into account.
3. **We need to know more about how Danish households respond to dynamic price signals.** More evidence is needed on the relation between dynamic price signals and timing of energy demand based on a representative sample of Danish households. We cannot rely on results from (smaller) demonstration projects and trials. This also entails more knowledge about what type of energy demand and which activities it is possible to time-shift or reduce (and what is not).
4. **What a dynamic pricing product is (and is not) should be clearer.** Many terms and names are used for similar products and lack of information on products makes it difficult for consumers to navigate the market.
5. **Different perspectives on energy flexibility should be taken more into account.** Grid companies and retailers have different purposes with demand flexibility and do not always use the same terms, for example for dynamic pricing products. Households probably have a third way of talking about, and perceiving, demand flexibility.

From a future residential electricity demand perspective, the likely increasing market penetration of heat pumps, energy efficiency measures, and EVs will pose new challenges and opportunities for peak periods and overall demand reduction. Making the existing residential building stock more efficient is a necessary prerequisite for exploiting the full potential of heat pumps. Upgrading the thermal properties of buildings not only allows overall demand reduction, but also acts as a key enabler for heat pump flexibility by positively affecting the switch-off times. New products could be designed for more specific energy demands, for example directed households with EVs and/or heat pumps. Future energy pricing products should ideally have clearly defined descriptions and names, easy access to various types of information, stronger price signals, and might also focus on other meanings, such as CO_2 footprint.

The load shift potentials from increased electricity demand driven by heat pumps (and EVs) will also depend on energy tax reform, which has recently been put on the agenda of the Danish Ministry of Climate, Energy and Utilities (2018). To stimulate an active response to time-varying electricity rates, taxes and levies on electricity will need to be rebalanced to match its carbon intensity decrease, while fairly allocating costs across customer groups. Alternatively, or in combination with this regulatory reform, taxes and levies on electricity could have some degree of fluctuation over time following wholesale electricity prices. These measures would make electricity price signals more visible, incentivize fuel substitution between gas and electricity for heating, and encourage an active response to demand-side programmes. Alongside energy-efficient retrofits and stronger price signals, replacing old with new appliances and a wider introduction of smart digital technologies (for example, real-time information displays) in homes may contribute to peak electricity reduction.

The success or failure of time-varying electricity rates in reducing peak demand and supporting the integration of renewable energy in the supply mix depends on the complex interaction of many factors. Because of the inelasticity of electricity demand and rigidity of everyday practices, there is no silver bullet. Technologies, well-designed and implemented policies, and stronger price signals play an essential role in enabling the competitive advantage that dynamic pricing can confer. However, we argue that an optimal strategy aiming at reducing peak demand should better account for user practices, why electricity is used at certain times, where the most potential for flexibility arises, and how to induce changes in everyday practices using other levers than price. Only then can the hope for synergies between the combined impact of different measures be successfully realized.

References

Allcott, H., 2011. Rethinking real-time electricity pricing. Resource and Energy Economics, Special section: Sustainable Resource Use and Economic Dynamics 33, 820–842. https://doi.org/10.1016/j.reseneeco.2011.06.003

Andersen, F.M., Baldini, M., Hansen, L.G., Jensen, C.L., 2017. Households' hourly electricity consumption and peak demand in Denmark. Applied Energy 208, 607–619. https://doi.org/10.1016/j.apenergy.2017.09.094

Andersen, F.M., Larsen, H.V., Boomsma, T.K., 2013. Long-term forecasting of hourly electricity load: Identification of consumption profiles and segmentation of customers. Energy Conversion and Management 68, 244–252. https://doi.org/10.1016/j.enconman.2013.01.018

Anderson, B., 2016. Laundry, energy and time: Insights from 20 years of time-use diary data in the United Kingdom. Energy Research & Social Science 22, 125–136. https://doi.org/10.1016/j.erss.2016.09.004

Bartusch, C., Wallin, F., Odlare, M., Vassileva, I., Wester, L., 2011. Introducing a demand-based electricity distribution tariff in the residential sector: Demand response and customer perception. Energy Policy 39, 5008–5025. https://doi.org/10.1016/j.enpol.2011.06.013

Bejan, I., Jensen, C.L., Andersen, L.M., Hansen, L.G., 2021. Inducing flexibility of household electricity demand: The overlooked costs of reacting to dynamic incentives. Applied Energy 284, 116283.

Blue, S., Shove, E., Forman, P., 2020. Conceptualising flexibility: Challenging representations of time and society in the energy sector*. Time & Society 0961463X20905479. https://doi.org/10.1177/0961463X20905479

Burns, K., Mountain, B., 2021. Do households respond to Time-Of-Use tariffs? Evidence from Australia. Energy Economics 7.

Christensen, T.H., Friis, F., Bettin, S., Throndsen, W., Ornetzeder, M., Skjølsvold, T.M., Ryghaug, M., 2020. The role of competences, engagement, and devices in configuring the impact of prices in energy demand response: Findings from three smart energy pilots with households. Energy Policy 137, 111142. https://doi.org/10.1016/j.enpol.2019.111142

Coutard, O., Shove, E., 2019. Infrastructures, Practices and the Dynamics of Demand, in: Infrastructures in Practice - The Dynamics of Demand in Networked Societies. Routledge, New York.

Danish Energy Agency, 2019. Denmark's Energy and Climate Outlook 2019 87.

Dansk Energi, Energinet.dk, 2012. Smart grid i Danmark 2.0 - Implementering af tre centrale anbefalinger fra smart grid netværket.

Dansk Energi, Energinet.dk, 2010. Smart Grid i Danmark.
Darby, S.J., McKenna, E., 2012. Social implications of residential demand response in cool temperate climates. Energy Policy, Special Section: Fuel Poverty Comes of Age: Commemorating 21 Years of Research and Policy 49, 759–769. https://doi.org/10.1016/j.enpol.2012.07.026
De Frie Energiselskaber, Kile Kommunikation, 2020. Veje til øget fleksibilitet i det danske energisystem.
Decker, K.D., 2020. Reorienting the Economy to the Rhythms of Nature: Learning to Live with Intermittent Energy Supply. American Journal of Economics and Sociology 79, 877–905. https://doi.org/10.1111/ajes.12333
Energistyrelsen, 2020a. Energistatistik 2019.
Energistyrelsen, 2020b. Basisfremskrivning 2020 – Danmarks Klima- og Energifremskrivning.
Faruqui, A., 2010. The Ethics of Dynamic Pricing. The Electricity Journal 23, 13–27. https://doi.org/10.1016/j.tej.2010.05.013
Faruqui, A., Hledik, R., Palmer, J., 2012. Time-Varying and Dynamic Rate Design, Global Power Best Practice Series. Regulatory Assistance Project.
Faruqui, A., Sergici, S., 2010. Household response to dynamic pricing of electricity: a survey of 15 experiments. Journal of regulatory Economics 38, 193–225.
Faruqui, A., Sergici, S., Warner, C., 2017. Arcturus 2.0: A meta-analysis of time-varying rates for electricity. The Electricity Journal 30, 64–72. https://doi.org/10.1016/j.tej.2017.11.003
Fell, M.J., 2019. Just flexibility? Nat Energy 1–2. https://doi.org/10.1038/s41560-019-0510-3
Friis, F., Christensen, T.H., 2016. The challenge of time shifting energy demand practices: Insights from Denmark. Energy Research & Social Science 19, 124–133. https://doi.org/10.1016/j.erss.2016.05.017
Gram-Hanssen, K., Darby, S.J., 2018. "Home is where the smart is"? Evaluating smart home research and approaches against the concept of home. Energy Research & Social Science 37, 94–101. https://doi.org/10.1016/j.erss.2017.09.037
Gram-Hanssen, K., Hansen, A.R., Mechlenborg, M., 2020. Danish PV Prosumers' Time-Shifting of Energy-Consuming Everyday Practices. Sustainability 12, 4121.
Hansen, A.R., 2018. Heating homes: Understanding the impact of prices. Energy Policy 121, 138–151. https://doi.org/10.1016/j.enpol.2018.06.021
Hansen, A.R., Friis, F., Jacobsen, M.H., Gram-Hanssen, K., 2019. Three forms of energy prosumer engagement and their impact on time-shifting electricity consumption, in: ECEEE 2019 Summer Study Proceedings. Presented at the ECEEE Summer Study.
Hansen, A.R., Trotta, G., Thybo, G.W., Grundvad, J., Hoelgaard, P.H., Green, G.A., Andersen, J.L., Forthcoming. Energifleksibilitet til salg: Hvordan dynamiske priser indtog det danske elmarked.
Hargreaves, T., 2017. Beyond energy feedback. Building Research & Information 0, 1–11. https://doi.org/10.1080/09613218.2017.1356140
Jacobsen, M.H., Hansen, A.R., 2019. (Re)introducing embodied practical understanding to the sociology of sustainable consumption. Journal of Consumer Culture 1469540519846213. https://doi.org/10.1177/1469540519846213
Katz, J., 2014. Linking meters and markets: Roles and incentives to support a flexible demand side. Utilities Policy 31, 74–84. https://doi.org/10.1016/j.jup.2014.08.003
Katz, J., Kitzing, L., Schröder, S.T., Andersen, F.M., Morthorst, P.E., Stryg, M., 2018. Household electricity consumers' incentive to choose dynamic pricing under different taxation schemes. WIREs Energy and Environment 7, e270. https://doi.org/10.1002/wene.270
Kessels, K., Kraan, C., Karg, L., Maggiore, S., Valkering, P., Laes, E., 2016. Fostering Residential Demand Response through Dynamic Pricing Schemes: A Behavioural Review of Smart Grid Pilots in Europe. Sustainability 8, 929. https://doi.org/10.3390/su8090929
Kitzing, L., Katz, J., Schröder, S.T., Morthorst, P.E., Andersen, F.M., 2016. The residential electricity sector in Denmark: A description of current conditions. Department of Management Engineering, Technical University of Denmark.
Klima-, Energi- og Bygningsministeriet, 2013. Smart Grid-Strategi - fremtidens intelligente energisystem. Klima-, Energi- og Bygningsministeriet.
Larsen, J.N., Christensen, T.H., Engberg, L.A., Friis, F., Gram-Hanssen, K., Hansen, J.R., Jensen, J.O., Madsen, L.V., 2017. Denmark, in: Pareja-Eastaway, M., Winston, N. (Eds.), Sustainable Communities and Urban Housing: A Comparative European Perspective, Routledge. Routledge Studies in International Real Estate. Routledge, pp. 99–119.
Nicholls, L., Strengers, Y., 2015. Peak demand and the 'family peak' period in Australia: Understanding practice (in)flexibility in households with children. Energy Research & Social Science, Special Issue on Smart Grids and the Social Sciences 9, 116–124. https://doi.org/10.1016/j.erss.2015.08.018

Nicolson, M.L., Fell, M.J., Huebner, G.M., 2018. Consumer demand for time of use electricity tariffs: A systematized review of the empirical evidence. Renewable and Sustainable Energy Reviews 97, 276–289. https://doi.org/10.1016/j.rser.2018.08.040
Nordic Council of Ministers, 2017. Demand side flexibility in the Nordic electricity market, TemaNord. Nordic Council of Ministers. https://doi.org/10.6027/TN2017-564
Nyborg, S., 2015. Pilot Users and Their Families: Inventing Flexible Practices in the Smart Grid. Science & Technology Studies 28, 54–80. https://doi.org/10.23987/sts.55342
Olesen, B., Thorndal, J., 2004. Da danske hjem blev elektriske 1900-2000. Kvindemuseets Forlag.
Powells, G., Fell, M.J., 2019. Flexibility capital and flexibility justice in smart energy systems. Energy Research & Social Science 54, 56–59. https://doi.org/10.1016/j.erss.2019.03.015
Radius Business Mangement, 2019. Effekt af tidsdifferentierede elnet-tariffer: Analyse af timedata for udvalgte kunder. Radius.
Shove, E., Pantzar, M., Watson, M., 2012. The Dynamics of Social Practice : Everyday Life and how it Changes. Sage, London.
Shove, E., Walker, G., 2014. What Is Energy For? Social Practice and Energy Demand. Theory Culture Society 31, 41–58. https://doi.org/10.1177/0263276414536746
Smale, R., van Vliet, B., Spaargaren, G., 2017. When social practices meet smart grids: Flexibility, grid management, and domestic consumption in The Netherlands. Energy Research & Social Science 34, 132–140. https://doi.org/10.1016/j.erss.2017.06.037
Southerton, D., 2020. Time, Consumption and the Coordination of Everyday Life, Consumption and Public Life. Palgrave Macmillan UK. https://doi.org/10.1057/978-1-349-60117-2
Southerton, D., 2006. Analysing the Temporal Organization of Daily Life: Social Constraints, Practices and their Allocation. Sociology 40, 435–454. https://doi.org/10.1177/0038038506063668
Southerton, D., 2003. `Squeezing Time' Allocating Practices, Coordinating Networks and Scheduling Society. Time Society 12, 5–25. https://doi.org/10.1177/0961463X03012001001
Strengers, Y., 2019. Prices as instruments of demand management : Interpreting the signals, in: Shove, E., Trentmann, F. (Eds.), Infrastructures in Practice - The Dynamics of Demand in Networked Societies. pp. 184–197. https://doi.org/10.4324/9781351106177-19
Strengers, Y., 2013. Smart Energy Technologies in Everyday Life. Palgrave Macmillan.
Thaler, R.H., Sunstein, C.R., 2012. Nudge: Improving Decisions About Health, Wealth and Happiness. Penguin UK.
The Danish Ministry of Energy, Utilities and Climate, 2018. Energy Agreement 19.
Torriti, J., 2015. Peak Energy Demand and Demand Side Response. Routledge. https://doi.org/10.4324/9781315781099
Torriti, J., 2012. Price-based demand side management: Assessing the impacts of time-of-use tariffs on residential electricity demand and peak shifting in Northern Italy. Energy, Integration and Energy System Engineering, European Symposium on Computer-Aided Process Engineering 2011 44, 576–583. https://doi.org/10.1016/j.energy.2012.05.043
Torriti, J., Hassan, M.G., Leach, M., 2010. Demand response experience in Europe: Policies, programmes and implementation. Energy 35, 1575–1583. https://doi.org/10.1016/j.energy.2009.05.021
Trotta, G., 2020. An empirical analysis of domestic electricity load profiles: Who consumes how much and when? Applied Energy 275, 115399. https://doi.org/10.1016/j.apenergy.2020.115399
UK Power Networks, 2014. Low Carbon London Project Progress Report.
Warde, A., 2017. Consumption. Palgrave Macmillan UK, London. https://doi.org/10.1057/978-1-137-55682-0
Warde, A., 2005. Consumption and theories of practice. Journal of consumer culture 5, 131–153.
World Energy Council, 2020. World Energy Trilemma Index 2020. World Energy Council, London.
Yousefi, S., Moghaddam, M.P., Majd, V.J., 2011. Optimal real time pricing in an agent-based retail market using a comprehensive demand response model. Energy 36, 5716–5727. https://doi.org/10.1016/j.energy.2011.06.045

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