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Households' hourly electricity consumption and peak demand in Denmark

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HIGHLIGHTS

- Modelling of the contribution of appliances to households' hourly consumption.
- New services will require additional production and transmission capacities.
- Results from a new experiment giving households' incentives to shift demand in time.
- Demand flexibility may reduce required capacity enlargements.
- Incentives targeting new services will be particularly important.

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ABSTRACT

The electrification of residential energy demand for heating and transportation is expected to increase peak load and require additional generation and transmission capacities. Electrification also provides an opportunity to increase demand response. With a focus on household electricity consumption, we analyse the contribution of appliances and new services, such as individual heat pumps and electric vehicles, to peak consumption and the need for demand response incentives to reduce the peak.

Initially, the paper presents a new model that represents the hourly electricity consumption profile of households in Denmark. The model considers hourly consumption profiles for different household appliances and their contribution to annual household electricity consumption. When applying the model to an official scenario for annual electricity consumption, assuming non-flexible consumption due to a considerable introduction of electric vehicles and individual heat pumps, household consumption is expected to increase considerably, especially peak hour consumption is expected to increase.

Next the paper presents results from a new experiment where household customers are given economic and/or environmental incentives to shift consumption to or away from specified hours. The experiment focuses on the present classic consumption and shows that household customers do react to incentives, but today the flexibility of the classic consumption is limited. Considering electric vehicles and individual heat pumps, for an individual household, the consumption of each of these technologies roughly doubles the household's consumption and considerably increases their potential for flexibility. Thus, in order to introduce incentives for demand flexibility, while considering reducing peak consumption, policy makers should initially focus on households that have a heat pump and/or an electric vehicle.

1. Introduction

In Denmark, annual peak consumption generally occurs on a workday in January between 6 p.m. and 7 p.m. when households account for approximately 35% of total electricity consumption Andersen et al. [1]. In addition, due to the introduction of electric vehicles and individual heat pumps Beaten et al. and Arias and Bae [2,3] household electricity consumption is expected to increase considerably. Furthermore, if demand is not flexible, peak consumption, in particular, is expected to increase. Various solutions have been proposed to address this challenge. Among others, flexibility and demand response that changes/shifts consumption in response to incentives are listed as relevant options D'hulst et al. and Nolan et al. [4,5]. To understand the potential of such measures, it is necessary to investigate the size and the variability of energy consumption of individual devices. For example, in the household sector, miscellaneous appliances have different consumption patterns and total energy demand Mansouri et al. [6], and tailored-measures (e.g. demand response) that target one device rather

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than another may result in different outcomes.

The literature includes various studies that investigate hourly consumption profiles. Andersen et al. [1] analyse hourly consumption profiles for aggregated categories of Danish customers (residential, agriculture, industry, private services and public services) and use the profiles to develop a projection model for the aggregated national hourly consumption. Using the same model, Østergaard et al. [7] investigate how structural changes affect the need for production capacity in the Danish electricity system. Also, using hourly consumption data for Danish customers, Andersen et al. [8] analyse how categories of customer contribute to consumption in local areas. The authors further develop a model for long-term projections of the hourly load at transformer stations in the west of Denmark.

Focusing on the residential sector in Finland, and assuming technical data for the availability and use of different household appliances, Paatero and Lund [9] develop a model that generates representative hourly consumption profiles for groups of household customers. The model is used to analyse demand-side management strategies such as reducing peak load by shifting and/or reducing the electricity consumption of different appliances. Similarly, Gottwalt et al. [10] present a model that generates load profiles for German households and the authors analyse demand response to hourly pricing.

Combining time-use statistics from studies in Sweden and technical data for appliances, Widén et al. and Widén and Wäckelgård [11,12] develop a model which generates hourly electricity consumption profiles for groups of households and analyse how changing appliance efficiency and consumer behaviour affect the aggregate load profiles of groups of households. Lastly, focusing on residential load profiles and related flexibility, Sadeghianpourhamami et al. [13] propose two systematic methodologies for modelling individual customer behaviour and evaluate the proposed models in terms of the accuracy of the generated profiles. Sandels et al. [14] propose a simulation model that forecasts electricity load profiles for a population of Swedish households who live in detached houses. The model focuses on appliance usage, domestic hot water (DHW) consumption and space heating.

Consumption profiles for individual household appliances are important for identifying the factors that influence domestic consumers' power usage patterns Riddell et al. [15]. At the European scale, data can be obtained from the EURECO and REMODECE projects. The EURECO project Sidler et al. [16], which was completed in 2012, focused on average daily load curves for different appliances in the following four EU countries; Denmark, Greece, Italy and Portugal. The REMODECE project [17,18], which metered daily load profiles for different household appliances and was completed in 2008, had a broader scope and presented profiles that were valid for eight EU countries. In Jacobsen and Juul [19], profiles for individual appliances are adjusted to Danish conditions taking into account seasonal variations and daylight influence, see Ginden and Feilberg, and Zimmermann [20,21]. Jacobsen and Juul [19] includes consumption profiles for 24 categories of appliances,[1] and a Danish profile for electric heating is calculated from the statistics Paneldata [22]. The weight of different appliances in the total household consumption in Denmark can be extrapolated from the statistics used in the Danish household model "Elmodel bolig" [23]. Finally, statistics on aggregated Danish household profiles are available from [22].

The potential for flexibility in Denmark, considering control and storage of the electricity consumption and the service supplied by different appliances, is evaluated in Kwon and Østergaard [24]. Despite the fact that today households are charged the same price per kWh irrespective of the time-of-use (which means they have no incentive to be flexible), there is still potential for flexibility. For example, considering classic household consumption, electricity used for heating, cooling and washing is considered to have some flexibility, while electricity used for e.g. lighting, cooking and entertainment is assumed to be inflexible. In the future, both the charging of electric vehicles and consumption by individual heat pumps are expected to offer substantial demand flexibility.

The flexibility of individual household appliances has been assessed in different studies: Finn et al. [25] analyse dishwashers, Zehir and Bagriyanik [26] focus on refrigerators, Darby and McKenna [27] study washing equipment, and Dupont et al. [28] focus on the effects of demand response from both white goods and electric vehicles in the Belgian energy system.

With regards to an economic approach to demand response, there is a considerable amount of literature that analyses the effects of time-of-use and real-time pricing. A review of empirical short-term price elasticities of electricity demand is provided by US Department of Energy [29], while an analysis of demand response to hourly prices in Denmark is found in Møller and Andersen [30]. Another line of relevant literature concerns consumer behaviour, experimental economics and motivations for households' demand response. Using a field experimental design, Jensen et al. [31] find that offering households free of charge auto-power off plugs significantly reduces electricity consumption in households, while Gleerup et al. [32] find that giving household feedback on electricity consumption via text messages and e-mails reduced energy consumption by 3%. In other field experiments, Sexton et al. and Matsukawa [33,34] estimated the effect of installing continuous-display electricity-use and cost monitors in households. The former found that exposing customers to time-of-use tariffs and providing current cost information can cause a significant shift in consumption from peak to off-peak periods with a lower price, while the latter discovered that the installation of electricity monitors reduced electricity consumption significantly.

This paper focuses on household consumption and develops a model for hourly electricity consumption. The model is based on data for hourly consumption profiles and the annual consumption of household appliances, which is extrapolated from a forecast-model developed by the Danish EPA Elmodel bolig [23].

Based on the hourly model and assuming non-flexible household consumption, the authors analyse how the aggregated Danish hourly electricity consumption is expected to develop. Furthermore, the study focuses on demand flexibility and analyses results from an experiment that was performed in collaboration with the Danish energy company SydEnergi [35]. In the experiment, household customers are given economic and/or environmental incentives to shift consumption to or away from particular time slots. Information concerning desirable actions in particular time slots is sent as text messages to private mobile phones.

Finally, by combining the model projections and the results from the experiment, the authors evaluate the need for incentives that target household demand flexibility.

The paper is structured as follows. Section 2 provides a brief presentation of the data for hourly consumption profiles. Section 3 presents the model, while Section 4 shows how different appliances contribute to the aggregated household consumption profile. Section 5 analyses the flexibility within classic consumption and Section 6 analyses the new categories of consumption. Finally, Section 7 concludes the paper.

2. Data for hourly electricity consumption

Statistics for the hourly electricity consumption of costumer categories, based on meter-data from about 4500 representative customers (covering all categories of customers in Denmark), are available from the Danish Energy Association Paneldata [22].

Fig. 1 provides an example of how different categories contribute to the aggregated Danish load in a sample week (50) in December 2012.

[1] Light living room, light secondary room, refrigerator, freezer, combined refrigerator/freezer, HI-FI radio, DVD player/recorder, TV CRT, TV plasma, TV LCD, TV Set-top box, cooking hobs and oven, microwave, kettle, dishwasher, washing machine, dryer, mobile phone charger, printer, wireless LAN, router, laptop, desktop PC with monitor, vacuum cleaner.