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Electricity load profiles in Europe: The importance of household segmentation

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ABSTRACT

In the current market design, the increasing use of renewable energy sources for electricity generation leads to new challenges in balancing supply and demand. While households are responsible for 29% of total electricity demand in Europe, a good understanding of their consumption and load profiles is missing. Similar to existing clustering methodologies from marketing science, this paper proposes an approach for the segmentation of households. The approach particularly focusses on the impact of socio-demographic factors and the equipment with electric appliances as well as new technologies for electricity and heat supply on residential load profiles. In addition to these three factors themselves, the dependencies between them are identified as crucial. Therefore, in order to adequately assess the future development of residential load profiles, on the one hand, a qualitative analysis of socio-demographic factors is carried out and, on the other hand, the influence of selected technologies is quantitatively modeled. Beyond the mere impact on households' annual energy demand, in focus of most existing research in the field, particular emphasis will be given to the peak load development, which is considered increasingly relevant for balancing supply and demand and maintaining security of supply.

1. Introduction

Many European energy systems are undergoing significant changes. The increasing share of renewable energy sources (RES) leads to more distributed and fluctuating power generation. From systems with a limited number of large players with conventional power plants being responsible for power generation, they move to systems where many small players participate in the market. Even households, formerly classic electricity consumers, nowadays take part in power generation through photovoltaic (PV) and micro-CHP (combined heat and power). Responsible for 29% of total electricity demand in Europe (cf. Fig. 1 [1]), households play an important role in future electricity systems as they provide an increasing share of power generation capacity and are at the same time an important electricity consumer. Nowadays, neither their generation nor their consumption are well controllable for external parties but they strongly influence the electricity system, especially in low voltage grids, to which they are attached. To enable electricity markets to cope with these upcoming challenges on a macro-, e.g., security of supply, and micro-economic level, e.g., capacity pricing, households' load profiles need to be better understood. Especially in Germany these effects can be observed due to the so called "Energiewende" (energy transition mainly based on RES). Additionally, the German government decided the nuclear phase-out until 2022 resulting in even less predictable power generation capacity [2]. Hence, potential solutions developed for Germany might become a role model for other countries and are in special interest of research.

Overall, electricity markets strive to a cost structure similar to today's ICT (information and communication technology) markets. In ICT markets, the single bite or phone call create only negligible variable costs while the investment in the required infrastructure, e.g., fiber optic cables and mobile transmission towers, are the key cost drivers. Consequently, most existing internet tariffs consist of a fix price component based on the chosen transmission capacity whereas the data volume is often for free, i.e., so called flat-rate tariffs. Obviously, in electricity markets flat-rate tariffs are undesirable due to environmental reasons. Moreover, the variable costs constitute a significant cost component in markets dominated by fossil power generation. Nevertheless, the variable costs of electricity generation constantly decrease in electricity markets driven by RES. Contrariwise, the investments in market

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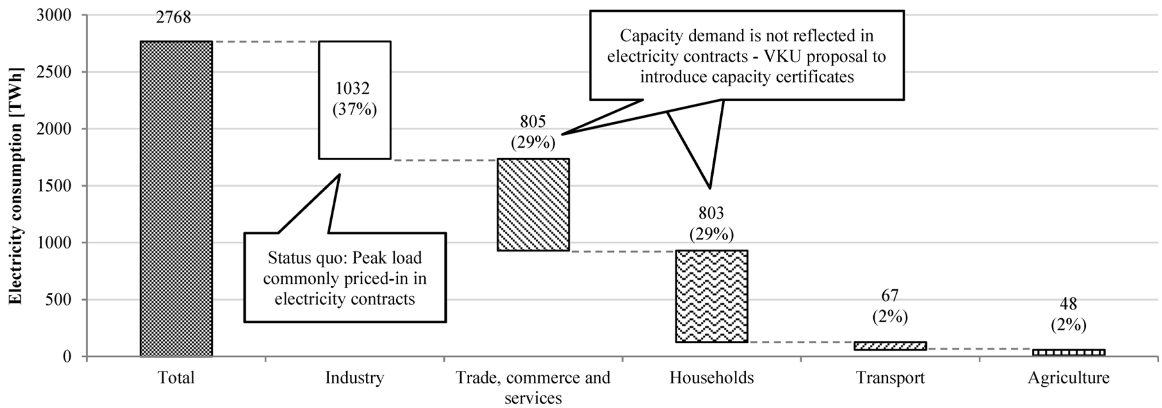

Fig. 1. European electricity consumption by sector, 2011 [1].

infrastructure, e.g., grid technologies, increase in order to ensure the required transport capacity from the many distributed generation sites to the consumers. In the existing "energy-only" market design in Germany's electricity market the pure availability of generation capacity is not rewarded, except from the share of flexible capacity traded at the balancing markets. With decreasing wholesale electricity prices and less operating hours of conventional power plants due to RES feed-in, covering the fix costs of conventional plants becomes more challenging. The profitability of those plants is at risk leading to the ongoing discussion on capacity mechanisms in Germany [3]. Besides capacity mechanisms, also means to increase demand flexibility are in focus of research, especially demand response[1] (DR), in order to decrease the peak load of the entire system aiming at a reduced need in conventional generation capacity [5]. For households, responsible for around 29% of Europe's electricity demand (cf. Fig. 1), currently discussed DR measures are, for instance, based on electricity tariffs with dynamic electricity prices (per kWh) with the purpose to shift or reduce load in times of high prices and increase demand in times of low prices. The technical load reduction potential of these measures in Germany's residential sector is estimated at around 6.7 GW on average [5]. If this technically available load reduction potential coincides with the peak load of a country, less installed conventional power plant capacity would be required to fulfill demand. Even if only one-tenth of the technical potential could be realized during peak load times, it may still substitute some smaller gas power plants. The use of new technologies for electricity and heat supply in households in the course of technological change and innovation may further alter the DR potential. Additionally, other forms of residential electricity tariffs, for instance, tariffs with variable capacity prices[2] (in kW) similar to industrial tariffs, can reveal further opportunities for load reduction. These tariffs can also help to increase overall system stability if households' demand can be reduced in critical peak times. To analyze the effect of those DR measures a better understanding of households' electricity consumption over time, i.e., their load profiles[3], especially in conjunction with the increasing penetration of new technologies, such as PV, micro-CHP and heat pumps, is required.

A recently published study of the German VKU (Verband kommunaler Unternehmen e.V.) proposes a new market design introducing a decentralized capacity market with capacity certificates. In this model, electricity contract providers are requested to purchase enough certificates to ensure the security of supply for their customers [6]. In industry tariffs, it is already common to include a price component for capacity. The VKU now suggests to extend this model to trade, commerce and services as well as to the residential sector in order to better predict the required market capacity (cf. Fig. 1). Therefore, electricity tariffs with variable capacity prices can be an adequate means to capture the individual level of desired supply security. A similar concept is discussed by Oren [7] who suggests electricity tariffs with different prices depending on the level of contracted service reliability. Based on such tariffs load reduction potentials can be realized in case of generation shortages as every customer can be restricted to its contracted level of supply security. This would increase the market's ability to balance electricity demand and supply. To enable households or intermediaries offering such kind of contracts to define the appropriate height of required capacity ensuring the desired level of supply security, households' load profiles need to be better understood. Besides the analysis of new tariffs as described above, a better understanding of household's electricity consumption is also required to evaluate the impact of changing consumer behavior or technological trends on low voltage grids or residential load management potentials [8].

In energy systems modeling, households are often represented with a standard load profile (SLP), e.g., the H0 profile of the BDEW (German Association of Energy and Water Industries), or based on guideline VDI 4655. As these profiles are based on historical data and do not reflect the ongoing changes they are only of limited usability for modeling and predicting load profiles of small samples or technological trends. However, the ongoing changes in electricity systems require to analyze more distributed and consequently smaller systems. Also new technologies like PV, e-cars or heat pumps will alter the electricity consumption of households (cf. Section 5). Hence, even in large samples the existing standard load profiles might not be appropriate anymore. A more detailed segmentation of residential electricity consumption enables a better reflection of future energy systems and allows for a wide range of related analyses, e.g., the need for grid expansion or load prediction for electricity markets, and might even be used for new load profiles [9]. Creating household segments based on replicable characteristics with comparable load profiles would help to better model households' electricity consumption. The development of these segments through the analysis of the influence of different

[1] Definition according to the U.S. Department of Energy [4]: "Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized."

[2] The term "variable capacity prices" is used in this paper to describe the occurrence of different prices for different levels of secured capacity in households' electricity tariffs.

[3] A load profile represents the electricity use of a unit in watt, e.g., a household, a device or a plant, over time, e.g., in minutes, hours or days.