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# Further exploring the potential of residential demand response programs in electricity distribution

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## HIGHLIGHTS

- Households respond to demand based time-of-use electricity distribution tariffs.
- They respond by cutting demand in peak hours and shifting demand from peak hours.
- Decreases in electricity consumption are a by-product of demand response programs.
- Demand response is less marked in rental and particularly condominium apartments.
- Demand response in single-family homes does not decrease in the long term.

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## ABSTRACT

Smart grids play a key role in realizing climate ambitions. Boosting consumption flexibility is an essential measure in bringing the potential gains of smart grids to fruition. The collective scientific understanding of demand response programs argues that time-of-use tariffs have proven its merits. The findings upon which this conclusion rests are, however, primarily derived from studies covering energy-based time-of-use rates over fairly short periods of time. Hence, this empirical study set out with the intention of estimating the extent of response to a demand-based time-of-use electricity distribution tariff among Swedish single-family homes in the long term. The results show that six years after the implementation households still respond to the price signals of the tariff by cutting demand in peak hours and shifting electricity consumption from peak to off-peak hours. Studies conducted in the Nordic countries commonly include only homeowners and so another aim of the study was to explore the potential of demand response programs among households living in apartment buildings. The demand-based tariff proved to bring about similar, but not as marked, effects in rental apartments, whereas there are virtually no corresponding evidences of demand response in condominium apartments.



## 1. Introduction

Smart grids are considered part of the solution in realizing political ambitions to reduce emissions, expand the use of renewables and increase energy efficiency in deregulated power markets. In anticipation of smart grids contributing to these ends, researchers have engaged in highly interdisciplinary research on this phenomenon [1]. Besides adapting public policies and providing an appropriate infrastructure, stimulating consumption flexibility is a key component in actualizing the vision and bringing the potential gains from smart grids to fruition [2,3]. Increased demand response is expected to boost market efficiency and enhance security of supply, which will ultimately benefit customers by way of options for managing their electricity costs and lead to reduced environmental impact [4–6]. Distribution system operators play a crucial part in effecting demand response as they provide the necessary technical infrastructure to that end. At present, Swedish regulations require no more than monthly meter readings, but at least 91% of existing meters are designed to register and store electricity use by the hour [7]. The incentives for distribution system operators to encourage consumption flexibility are manifold. A decline in demand would involve cutting costs associated with power losses, wheeling charges, maintenance and postponing or calling off investments in the grid [8]. Demand response programs are,

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however, still exceptional in residential electricity distribution [9]. This state of affairs is not only prevalent in Sweden, but all across Europe. One of the reasons for demand response policies being slow to emerge, as identified by Torriti et al. [10], is limited knowledge on the scope of potential gains.

The literature offers a wide variety of definitions of the concept of demand response [11], one of which reads: "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" [12, p. 6].

There is a wide range of different demand response programs, which are generally categorized into incentive- and price-based programs [13]. Incentive-based demand response programs provide economic incentives for customers to reduce demand at times of capacity shortage or exceptionally high electricity prices, whereas price-based demand response programs involve dynamic tariff rates that promote general changes in patterns of electricity use. Time-of-use tariffs, which are one the major price-based demand response programs in use and which are the subject of this article, involve different unit prices within different blocks of time and reflect the average cost of utilities during these periods [14].

Several studies have found conclusive evidence that households respond to price signals by reducing peak demand. A statewide pilot experiment in California generated residential response to time-of-use tariffs and critical peak pricing in the order of 5% and 13% respectively [15,16]. Two subsequent reviews, covering the fourteen [17] and fifteen [18–20] most recent pricing experiments in the U.S. at the time, suggest that time-of-use tariffs induce a drop in residential peak demand of 5% and 3–6% respectively and that critical peak pricing produce corresponding cuts ranging from 15% to 20% and 13% to 20% respectively. Another U.S. meta-study by Newsham and Bowker [21], which supplements the findings of Faruqui and Sergici [18] by adding more recent studies, reanalyzing the primary sources and including further performance metrics, concludes that critical peak pricing, under certain circumstances, may bring about reductions in peak load by as much as 30%, whereas the corresponding response to time-of-use programs adds up to no more than 5%. An even more recent study into Canadian households' response to a time-of-use tariff showed that a 2:1 and 12:1 peak to off-peak price ratio bring about a 2.6% and 9.2% reduction in peak demand [22].

An extensive review by Chardon et al. [23] of research on experiences with demand response programs, covering most of the EU-15 countries, Slovenia, the U.S., Canada and Australia, showed that the average effect of such measures in terms of demand response ranges from 20% to 50%, the latter of which represents studies involving enabling technology and thus automated reductions in peak demand. Studies that are conducted in North America and Australia are in general more large-scale and commonly involve more automation technologies than those that are carried out in Northern Europe, which are typically small-scale and tend to focus on active, i.e. including no enabling technology, demand response programs. Seeing that demand response programs have proven their potential, the authors conclude that future research endeavors in the field should focus on understanding domestic markets and refining demand response programs [23].

The Nordic countries have similar deregulated market designs, which entail that distribution system operators and retailers are legally separate entities and, in turn, that customers are charged separately for electricity distribution and consumption [24]. A large-scale Norwegian pilot study suggests that residential demand response to real-time rates in retail, a time-of-use distribution tariff and a combination of the two is some 0.5 kW h/h, 0.18 kW h/h at a price difference of approximately 0.15 €/kW h and 0.7 kW h/h respectively [25]. A subsequent survey showed that many customers adapt their electricity consumption to the price signals of the tariff by taking manual action and investing in energy control systems [26]. One of the overall implications of the pilot project is that a full-scale implementation of a time-of-use distribution tariff is economically justifiable, seeing as it better reflects the higher costs involved in using the power grid in peak load periods [25]. Another Norwegian study on the residential response to a distribution tariff combining a variable energy rate (NOK/kW h) and a variable demand charge (NOK/kW/year) resulted in an average demand reduction of 0.37 kW h/h, which correspond to a 5% drop, in peak hours. The maximum reduction was 12%, but the authors anticipate that the response would have been even greater if customers had access to real-time feedback [27].

As for the Swedish power market, there are only two instances of distribution system operators having introduced tariffs that involve a time-dimension in the residential sector, one of which was launched in the suburban city Sollentuna and the other in the country town Sala. These time-of-use tariffs are, unlike customary ones, based altogether on peak demand [7] and entail a unit price on the average of the three and five highest instances of demand in peak hours respectively. A small-scale study into the effects of the former produced no evidence to suggest that customers had reduced their peak-demand [28], but a subsequent internal evaluation undertaken by the distribution system operator in question suggests that the tariff has brought about a cut in peak demand by 5% [29].[2] As for the latter, an empirical study by Bartusch et al. [33] established that households living in single-family homes, in the short-term[3], adjust their electricity consumption to the price signals of the demand-based tariff by reducing demand in peak hours and shifting electricity use from peak to off-peak hours. However, the question remains as to whether the demand-based tariff also brings about energy efficiency measures in the long-term, i.e. whether or not households tend to relapse into old habits after some time. Moreover, the fact that the analysis involved only households living in single-family homes suggests that the potential of demand response programs in apartment buildings is yet to be estimated. Thus, the overall aim of the present study is to confirm previous results as regards the short-term response to a demand-based tariff in single-family homes, to estimate the scope of the corresponding long-term[4] effects as well as to assess the demand response potential of introducing a demand-based tariff in condominium and rental apartments.

The remainder of the article is organized as follows. The next chapter provides an account of the methodological approach and empirical basis of the study. The subsections of chapter 3 present the findings in the respective housing categories, which are subsequently discussed in chapter 4. The overall conclusions are recapped in chapter 5 and an outline of planned for future research in the field is given in chapter 6.

## 2. Methodological outline

The study was conducted in close cooperation with Sala Heby Energi Elnät AB, the electricity distribution area of which covers the provincial country town Sala and its environs. As part of the distribution system operator's efforts to reduce overall diversified

[2] The studies of Pyrko [28,29] were conducted as early as 2003 and 2006. None of three more recent reviews of studies into residential demand response – one by Renner et al. [30], one by Stromback et al. [31] and one by Darby and McKenna [32] – do however provide more recent results relating to demand-based time-of-use electricity distribution tariffs.

[3] "Short-term" does in this particular case refer to two years.

[4] "Long-term" does in this particular case refer to six years.