



Measuring the financial impact of demand response for electricity retailers



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HIGHLIGHTS

- Ex post simulation to quantify financial impacts of demand response.
- Effects of Demand Response are simulated based on real-world data.
- Procurement costs of an average electricity retailer decrease by 3.4%.
- Retailers can cut hourly peak expenditures by 12.1%.
- Cost volatility is reduced by 12.2%.

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ABSTRACT

Due to the integration of intermittent resources of power generation such as wind and solar, the amount of supplied electricity will exhibit unprecedented fluctuations. Electricity retailers can partially meet the challenge of matching demand and volatile supply by shifting power demand according to the fluctuating supply side. The necessary technology infrastructure such as Advanced Metering Infrastructures for this so-called Demand Response (DR) has advanced. However, little is known about the economic dimension and further effort is strongly needed to realistically quantify the financial impact. To succeed in this goal, we derive an optimization problem that minimizes procurement costs of an electricity retailer in order to control Demand Response usage. The evaluation with historic data shows that cost volatility can be reduced by 7.74%; peak costs drop by 14.35%; and expenditures of retailers can be significantly decreased by 3.52%.

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1. Introduction

The integration of intermittent sources of electricity generation, such as wind and solar power, comes at the cost of unprecedented fluctuations in electricity supply. Although their intermittent nature poses a challenge from the grid operation perspective, many states aim at increasing the share of renewable energies extensively. For example, the European Union strives to have renewable sources make up 20% of the energy consumption by the year 2020. Germany, the largest member state, even passed a law in 2011 mandating 35% of renewables by 2020 and 80% by 2050. Since renewable electricity sources are volatile in nature – in contrast to the so-called baseload power sources such as coal or nuclear, which are independent of weather conditions – the integration of 20% and more of renewables into the electricity

markets will lead to considerable discrepancies between power supply and demand.

One possible path to match power supply and demand is given by the concept of Demand Response. Demand Response (DR) is defined by the [U.S. Department of energy \(2006\)](#) and the [FERC \(2009\)](#) as: “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.” Even though Demand Response implies shifting load to when supply exceeds demand, the general idea of managing the demand-side of electricity markets is referred to as Demand Side Management. This umbrella term thus refers not only to Demand Response, but also to similar approaches such as the general increase of energy efficiency and time-based electricity pricing for end-consumers ([Sui et al., 2011](#)).

In many studies related to Demand Response (cf. [EU-DEEP, 2009](#); [SEDC, 2011](#); [Faruqui et al., 2010a](#), and EU funded project ADDRESS), it is frequently assumed that Demand Response will be driven by electricity retailers. Consequently, we focus on a setup

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where Demand Response activities are being integrated on the distribution network level. In this way (cp. [Mohagheghi et al., 2010](#)), we implicitly incorporate requirements imposed by the power grid structure (e.g. congestion and node voltage limitations) into the proposed model.

Hence, this paper focuses on a retailer level to derive optimal Demand Response decisions. Based on these decisions, we can estimate and quantify the economic effects of Demand Response.

The remainder of this paper is organized as follows. [Section 2](#) gives a literature overview how consumers react to price changes. In [Section 3](#), publications related to the financial benefits from Demand Response are reviewed. Afterwards, [Section 4](#) identifies parameters that govern decisions in Demand Response programs to pioneer a mathematical problem such that Demand Response decisions of retailers are optimized. Finally, [Section 5](#) evaluates the decisions derived by the model in a simulation based on historic data and analyzes their financial benefits.

2. Pricing effects

The integration of Demand Response is closely linked with the reaction of consumers to price changes. In this section, we review related work on price elasticities ([Section 2.1](#)) as this gives evidence how price changes control demand. Understanding price elasticities is the key to designing suitable pricing strategies ([Section 2.2](#)).

2.1. Price elasticities

Several studies estimate price elasticities in the residential sector ([Faruqui and Sergici, 2010](#); [Filippini, 1995](#); [Hirst, 1994](#); [Hunt et al., 2003](#); [Torriti, 2012](#)). For example, [Filippini \(1995\)](#) calculates and compares the short-run as well as long-run own-price elasticities in the Swiss residential electricity market. The author finds long-run values to be higher and his results also show a high responsiveness of electricity consumption to changes in price. Furthermore, positive values of cross-price elasticities indicate that peak and off-peak electricity demand are substitutes. Altogether, these affirmative results suggest that pricing policies can be an effective instrument for achieving electricity conservation. [Gyamfi et al. \(2013\)](#) provide a detailed survey on references estimating the elasticity of demand as a result of time-of-use (TOU) pricing. According to the authors, own-price elasticities range from -0.29 to -0.79 (-0.049 to -0.79 with dynamic pricing), while elasticities of substitution range from 0.04 to 0.21 with significant differences across seasons. Finally, [Espey and Espey \(2004\)](#) perform a meta-analysis to determine factors that affect estimated elasticities systematically.

[Masiello et al. \(2013\)](#) argue that it might not be sufficient in the future for balancing authorities to simply calculate the volume of load shifting. Effectively, it may become important to also estimate the reaction to prices.

2.2. Time-based pricing

Price-based programs that control the demand side are alternatives to flat tariffs. Examples include critical peak pricing, extreme day pricing, real-time pricing and time-of-use (TOU) tariffs ([Albadi and El-Saadany, 2008](#)). Understanding how consumers react to various pricing strategies is crucial to control electricity demand effectively. Several studies investigate the relationship between time-of-use tariffs and energy consumption ([Bernard et al., 2011](#); [Garcia-Cerrutti, 2000](#); [Kamerschen and Porter, 2004](#); [Olmos et al., 2011](#); [Walawalkar et al., 2010](#)). Pilot studies have reported significant

demand reductions in the industrial and commercial sectors for some time-based pricing experiments ([Barbose et al., 2004](#)).

Furthermore, other publications deal with the effects of time-based pricing. Time-based pricing is an instrument enabling Demand Response that has recently drawn significant attention. For example, [Cappers et al. \(2010\)](#) provide empirical evidence on price-based Demand Response in the U.S. electricity markets. A positive price responsiveness has been reported for some programs that have been implemented recently, while the majority of them remained in pilot phase ([Faruqui and Sergici, 2010](#)). [Torriti \(2012\)](#) assesses the impacts of time-of-use tariffs from residential users in Northern Italy. Apparently, a significant level of load shifting occurs during morning peaks, while there is only a marginal effect during evening peaks.

Finally, [Gyamfi et al. \(2013\)](#) present an economic model in the Demand Response context that links price elasticities and pricing strategies with human behavior. The authors recommend incorporating social psychology in order to realize changes in electricity consumption.

3. Financial benefits from demand response

To understand the financial dimension of Demand Response, we look at previous publications that estimate financial savings at household level ([Section 3.1](#)) and at an aggregate level ([Section 3.2](#)).

3.1. Household level

To simulate and evaluate the economic effects of Demand Response at household level, related research studies how Demand Response can be controlled by real-time pricing. More precisely, [Gottwalt et al. \(2011\)](#) propose an optimization procedure for load shifting based on real-time pricing. They also analyze the effect at household level, but neglect the financial benefits. Similarly, [Lujano-Rojas et al. \(2012\)](#) present an optimal load management strategy that considers predicted electricity prices, electricity demand and renewable power production. In their fictitious scenario, users can reduce electricity bills by 8–22% during a typical summer day.

Other authors pursue approaches that optimize the deployment of each household appliance individually. As a result, a household may save up to €18 per months in winter and up to €26 per month in summer ([Vasirani and Ossowski, 2012, 2013](#)). [Gudi et al. \(2012\)](#) show that their heuristic optimization leads to cost savings of up to 21%. However, both findings rely upon a fictitious setting without being calibrated by real data.

[Prügler \(2013\)](#) analyzes the economic potential of Demand Response using different standardized load profiles. Additionally, the author compares break-even investment costs across various lifetimes of infrastructure. According to the study, annual cost savings reach around €6.5. However, this result relies on the assumption that load shifting accounts for 15% during 12 h per day.

While the literature gives insights into Demand Response programs, none of them are based on real data and, to sum up, the conclusions drawn are just estimates.

3.2. Aggregate level

Various references ([Ridder et al., 2009, e.g.](#)) suggest that, due to the usage of Demand Response, profits of electricity retailers will increase. Demand Response activities do not actually decrease the amount of electricity consumed, but merely shift it to when it is more convenient from the grid operation perspective ([Shaw et al., 2009](#);

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