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IChemE

Q1 # An estimation of the economic and environmental benefits of a demand-response electricity program for Spain

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A B S T R A C T

The evolution towards a more sustainable electricity system will definitely require a stronger role of demand. For example, Demand Response (DR) programs allow consumers to manage their loads in response to signals that reflect – at least to some extent – the time-varying nature of the cost of electricity, improving thereby the efficiency of electricity markets, and also allowing for larger shares of renewable energy. However, allowing consumers to respond also requires significant investments. Therefore, estimating the potential benefits from DR programs is essential to assess their convenience. This paper presents an integrated assessment of the benefits of a potential DR program in Spanish households, including both supply and demand considerations. For the first time in literature, we estimate together and compare the benefits for both the generation and the distribution network system. Our results show that, under the current conditions (the most important of which are rather low electricity prices, a well-developed network, and overcapacity in the generation system), the benefits are quite low compared to the costs, and most of them come from the generation system. This creates a challenge for policy makers if they desire to promote these programs within highly developed generation systems, as well as a complex situation about the distribution of the costs and benefits which needs to be addressed.

Keywords: Demand response; Cost–benefit; Electricity

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1. Introduction

Demand-side management (DSM), aiming to improve the efficiency of energy consumption, is regarded by many scholars and institutions as a critical tool to tackle concerns about the environmental impact and security of supply of our energy systems (IEA, 2012; EC, 2005). In the case of electricity, given that its cost and environmental impact are time-varying, consuming more efficiently implies not only consuming less, but also doing it in the most appropriate time. To do so, consumers should be aware of the consequences (economic or other) of consuming at different times. However, in the vast majority of electricity markets, even when the price of electricity is computed on an hourly or even sub-hourly basis, consumers only receive some kind of flat price signal. This information asymmetry constitutes a market failure that prevents demand to behave efficiently and sustainably. Demand Response (DR) programs aim to overcome this market failure (RMI, 2006; IEA, 2011; Batlle and Rodilla, 2009) or (Haney et al., 2009).

There are many types of DR programs, but in essence all of them involve sending some kind of time-varying price signals – or quantity signals, which can be equivalent depending on the circumstances (Weitzman, 1974) – to consumers, who can then react by managing their loads, both by reducing consumption (demand conservation) or by shifting demand to less costly periods (demand shifting).

This will result, in most cases, in a flatter demand curve, that can in turn lead to savings in the power system, both in terms of investment by reducing the need

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for peak capacity in generation and also in transmission and distribution networks, and in terms of operation by avoiding costly generation from peaking units and possible network overloads. DR may be particularly relevant in case of emergencies and critical events—such as risk of network default or extremely high electricity prices. Moreover, DR can contribute to reducing price volatility and to compensating the variability of intermittent generation by making demand more flexible, and therefore can facilitate higher shares of renewable sources. For a more extensive description of the benefits of DR, see e.g. US DOE (2006), FERC (2006), Strbac (2008), Conchado and Linares (2012) or Bradley et al. (2013).

In all cases, and in the long term, DR programs should facilitate the transition to a cleaner and more efficient electricity system, if the right signals are sent to consumers. This may explain why, although DR is not a new concept, it has been gaining interest recently, as power systems become more congested, smart grids develop, the share of renewable generation increases, and communication and automation technologies become more sophisticated and less expensive. This current interest in DR is materialized in numerous research projects, trials and other initiatives. Indeed, many countries have started deploying smart meters or have set roll-out targets, which will facilitate the implementation of DR programs and broaden their possibilities. In Europe, for example, the installation rate of smart meters exceeds 85% in Italy and 25% in France. UK, Spain, Ireland, the Netherlands, Norway and France have set deployment targets to achieve nearly 100% smart meter installation by 2020.

However, designing and implementing good DR programs requires not only deploying the required infrastructure, but also a thorough estimation of their costs—associated mainly with the deployment of enabling technologies, – see EPRI (2011) or Bradley et al. (2013) – and their benefits; and even more importantly, of the distribution of these costs and benefits among the different agents and subsectors (generation, transmission and distribution networks, or demand).

Some countries and regions have already carried out these assessments, e.g. FERC (2006) for the USA, NERA (2008) for Australia, Vasconcelos (2008) for the European Union, Navigant (2005) for Ontario (Canada), and Bradley et al. (2013) for the UK. They show that these effects are very program- and context-specific. Some of the factors that may affect the results of DR programs are: the rate type and feedback provided to consumers (Faruqui and Sergici, 2010; Darby, 2006), the enabling technologies installed (US DOE, 2006), the demographic and climatic conditions of the region (Kohler and Mitchell, 1984) and the segment of consumers involved (King and Chatterjee, 2003; Herter, 2007).

Most of these studies have focused on the response of consumers. For example, Conejo et al. (2010) estimate households' response from an approach based only on cost minimization. But that misses the behavioral elements which may influence to a large extent consumers' response, and which are not typically considered within a purely economic optimizing behavior, such as loss of comfort, bounded rationality, or also pro-environmental attitudes (e.g. Fenrick et al., 2014; Groothuis and McDaniel Mohr, 2014). This can only be accounted for by ex-post assessments, such as those provided by Faruqui and Sergici (2010), Stromback et al. (2011), Torriti (2012), Faruqui et al. (2013), or Prüggler (2013) for residential consumers, or Jessoe and Rapson (2015) for commercial and industrial ones.

However, these estimations do not include the feedback loops on power systems, and thus risk overestimating the changes induced: when there is a significant degree of demand response, the demand curve will flatten out and hourly prices will become less spiky, in turn reducing the response by consumers. Another shortcoming of these studies is that they only account for short-term effects.

In this paper we address these shortcomings by assessing in an integrated manner the benefits of DR programs on electricity systems, jointly for the generation, distribution network and demand side of the system. The integration of these three components is essential for a rightful estimation of the benefits, and is also able to produce long-term estimates. Our exercise contributes to the existing literature in five ways: (1) we use generation and network expansion models to assess the impact of DR on future investments, thus accounting for long-term effects, which may be more significant than the short-term ones usually identified in the literature; (2) we introduce DR endogenously into the model, avoiding the overestimation of impacts that results when DR is assessed as an external shock; (3) our approach to include DR endogenously is bottom-up—we disaggregate residential demand by appliances with different potential for dispatchability, and consider demand conservation and demand shifting as optimizing decision variables of the model; (4) we consider actual wind production profiles in order to better represent wind variability and its possible interaction with demand response; and (5) we address jointly, and consistently, the benefits for both the generation system and the distribution network, which has not been done before.

The paper is structured as follows: Section 2 describes the case study analyzed and Section 3 explains the methodology used. Section 4 presents our results for the generation system and for the distribution system; and Section 5 concludes by analyzing the cost–benefit implications, recapping the limitations of the study and deriving some guidance for regulation.

2. The demand-response program under study

In this paper we simulate the effects of a system-wide, highly-automated demand-response program for residential consumers in Spain. Consumers would receive hourly real-time prices based on the electricity wholesale market through smart meters, and with the aid of automatic control devices (such as energy boxes or smart plugs), would reduce or shift the consumption of certain appliances in order to minimize their electricity bills. We are not considering here an additional potential impact of smart meters, which is the reduction of consumption induced by the provision of information to consumers. Although some studies (Gans et al., 2013; Houde et al., 2013) show a significant effect of this feedback, others are not that optimistic (Timm and Deal, 2016).

This is an innovative scheme that has not been tried in full, although there are some experiences in other countries with some common characteristics. For instance, in the USA, the Energy Smart-Pricing Plan in Illinois evaluated the response of consumers to dynamic pricing, but did not install any automatic-control device (Summit Blue, 2006), whereas the Good Cents Select program in Florida did install automatic-control devices but experimented with time-of-use tariffs instead (Faruqui and George, 2002).

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