How much should we pay for a DR program?
An estimation of network and generation system benefits

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Abstract: 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. However, allowing consumers to respond also entails significant investments. Therefore, estimating the potential benefits from DR programs is essential to assess their convenience. This paper presents an assessment of the benefits of a potential DR program in Spanish households, assuming that smart meters and control devices are installed to allow for automatic response and real-time pricing is implemented. The aim of the paper is twofold: [i] to illustrate the application of simulation models to quantify the benefits from DR measures for the generation system and the distribution network, and [ii] to contribute to the understanding of the cost-benefit implications of DR programs, providing some guidance for regulation.

Key words: demand response, cost-benefit, electricity.

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 environment and security of supply (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 moment. To do so, consumers should know the consequences (economic or other) of consuming at different times. However, in the vast majority of electricity markets nowadays, 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. Demand Response (DR) programs aim to overcome this market failure.

There are many types of DR programs[1], 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 cause, in most cases, a leveling of the demand curve, that can in turn lead to savings in the power system, both in terms of investment by reducing the need for peak capacity in generation and 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.

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

[1] Comprehensive introductions to DR can be found in (RMI, 2006), (IEA, 2011), (Batlle and

communication and automation technologies become more sophisticated and less expensive. This current interest in DR is materialized in numerous research projects[2], trials and other initiatives[3]. Some countries and regions have carried out studies to assess the cost-effectiveness or potential for advanced metering and DR[4], and many countries have started deploying smart meters or have set roll-out targets[5], which will facilitate the implementation of DR programs and broaden their possibilities.

However, before jumping into promoting DR programs, regulators should ensure that the savings and efficiency gains to be obtained exceed the costs to be incurred (associated mainly with the deployment of enabling technologies). Estimating the benefits a priori is not trivial: it is difficult to estimate how demand patterns would change, and understanding the effects of such changes on intrinsically complex power systems requires a thorough analysis. Moreover, these effects are very program- and context-specific[6]. Determining the costs is not easy either (EPRI, 2011), as some of the enabling technologies are still being developed or have only been implemented in pilot projects.

[2] Some research projects related to DR: GAD (www.proyectogad.es) in Spain, Smart-A (www.smart-a.org) and ADDRESS (www.addressfp7.org) in Europe, Demand Response Research Center (http://drrc.lbl.gov) in the USA and IEA Demand Side Management Programme (www.ieadsm.org) internationally.

[3] Examples of DR initiatives can be found in (RRI, 2008) –status of DR in the USA-, (Goldfine *et al*., 2008) -major developments in DR programs-, (Faruqui and Sergici, 2010) -survey of 15 experiments with dynamic pricing at the household level- , (Faruqui et al., 2013) –list of 31 experiments in seven countries, or (Stromback et al., 2011) – a comparative analysis of about 100 smart meter pilots.

[4] 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.

[5] E.g. In Europe, 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 (Faruqui *et al*., 2009).

[6] 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).

In order to remove some of the uncertainties in the cost-benefit analysis, we have chosen here to look just at the benefit side of a specific DR program. Therefore, the question we address here is: Based on the potential benefits, how much should we pay for DR programs?, that is, what is the maximum cost that would make profitable the investment?, or alternatively, how much should costs be lowered in order to make these programs interesting?

Past research has looked only partially at this problem: either it has assessed the consequences of DR for networks, or for generation systems, but has not done so in an integrated, consistent way, as we propose in the paper. Moreover, there are some original contributions in the way we assess the benefits both for the generation system and for the network system (see Section 2 for the literature review). However, it should be noted from the beginning that there is still little research about these issues. Our study presents limitations that will be highlighted, as well as the . possible paths for future research aiming to overcome these limitations.

The paper is structured as follows: Section 2 summarizes the state of the art on the assessment of DR benefits; Section 3 describes the case study to be analyzed; Section 4 presents our assessment of benefits for the generation system and for the distribution system, including methodology and results; and Section 5 concludes by analyzing the cost-benefit implications, recapping the limitations of the study and deriving some guidance for regulation.

2. Literature review

In broad terms, the valuation of DR benefits has been tackled in the literature in two ways: [i] deriving benefits analytically from some estimates, necessarily making simplifications about consumer and market behavior to express all relationships in algebraic terms[7], and [ii] using models to simulate the behavior of power systems. Studies based on estimates are simpler and

[7] E.g. (Baer *et al*, 2004) for the GridWise initiative in the USA, (CapGemini, 2007) for France, (Faruqui *et al*., 2009) for the EU, (Ofgem, 2006) for the UK, (Siderius and Dikstra, 2006) for the Netherlands, (Faruqui and George, 2002) for the USA, (Navigant, 2005) for Ontario, and (ESC, 2004) for Australia.

more transparent as results can be easily tracked back to the original assumptions, whereas studies with simulation techniques allow for more accuracy at the expense of higher complexity. An advantage of simulation models is that they allow for considering endogenously the dynamic processes involved in DR, particularly the interaction between changes in demand and electricity prices.

Regarding the estimation of benefits of DR on generation systems, there are a wide variety of studies in the literature that have applied simulation models[8]. Some models have been developed from the viewpoint of a utility in a regulated environment (Berg *et al*., 1983) and some others from a market perspective in a liberalized system, either assuming perfect competition (Borenstein, 2005) or imperfect competition (Allcott, 2012). DR is sometimes included endogenously into the simulation models, either by considering price-elastic demand-side bids in market equilibrium models (Su and Kirschen, 2009; Jonghe et al., 2011) or introduced as a resource of the system (Violette *et al*., 2006). Some other studies determine the demand exogenously, either assuming certain load reductions (Brattle, 2007) or evaluating *ex-ante* the changes in demand (Linares and Conchado, 2009). Some authors have even analyzed DR benefits considering the stochasticity of future outcomes for key variables (Andersen *et al*., 2006).

Our study contributes to the existing literature in four ways: (1) we use a generation expansion model to assess the impact of DR on future investments, thus accounting for long-term effects, which can 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 decision variables of the model-, instead of using the more common approach of applying elasticities; and (4) we

[8] See (Conchado and Linares, 2012) for the complete literature review summarized below.

consider actual wind production profiles in order to better represent wind variability and its possible interaction with demand response.

For the network systems, the assessment of benefits from DR using simulation models has been barely explored. Some studies have investigated operational benefits such as the reduction in distribution losses (Shaw *et al*., 2009) or in network congestion (Stanojević and Silva, 2009). We have found only one paper that, similarly to our study, focuses on the evaluation of the potential savings in network expansion allowed by the reduction of peak demand. However, we analyze a different type of DR program: while Veldman et al. (2013) assume that loads are managed in order to minimize peak demands at residential areas (so that the distribution network expansion needs can be minimized), we remain consistent with the DR program considered in which loads are shifted in response to real-time wholesale electricity prices.

3. Case study

The case study analyzed in this paper arises from the GAD Project developed in Spain by a consortium of companies and research centers to explore the possibilities of DR at the household-level in the country[9]. The DR program considered will be a highly-automated program for residential consumers in Spain, assuming the installation of smart meters and automatic control devices able to reduce or shift consumption of certain appliances in response to hourly electricity price signals[10]. Table 1 summarizes the main characteristics of the case study to be analyzed.

[9] See www.proyectogad.es or Section 7 (Acknowledgements) for more information about the GAD Project.

[10] 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, previous surveys within the GAD Project point to rather the opposite effect for the Spanish case.

Table 1: Summary of the case study

Context:	Spain (liberalized market, undergoing roll-out of smart meters)
Participants:	Residential consumers
Type of incentive:	Real-time pricing (hourly prices resulting from the wholesale electricity market)
Enabling technology:	Smart metering, automatic control, smart appliances and plugs
DR actions:	Demand conservation, demand shifting

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).

Based on internal reports of the GAD Project, we conclude that the appliances with significant potential to be managed in the context of the DR program analyzed are: washing machine, dryer and dishwasher (which can be grouped as washing appliances), and electrical heating, air conditioning (AC) and water heating (which can be grouped as thermostatically controlled appliances, following Lu *et al*. (2004)). Moreover, we assume that washing appliances can contribute to DR both in the form of demand conservation (using cold or Eco programs) or demand shifting (rescheduling the starting time), whereas thermostatically controlled appliances can only contribute in the form of demand conservation (moderating the temperature set point)[11]. We represent the potential for response of each appliance with two figures, which denote the fraction of the appliance consumption that can be conserved and shifted, respectively. Table 2 presents these figures.

[11] Actually, there is some potential for demand shifting of thermostatically controlled appliances. However, given the low penetration of air conditioning, electrical heating and water heating in Spanish households (ITE, 2008), the complexity involved in modeling shifts of their consumption (associated mainly to thermal inertia considerations), and the fact that these type of action would occur mostly in critical situations that are not considered in this study, the contribution of thermostatically controlled appliances to demand shifting will be neglected.

Table 2: Potential for demand conservation and demand shifting of considered electric appliances

Potential for…	Washing appliances: Washing machine	Dryer	Dish washer	Thermostatically controlled appl.: Water heating	Heating	AC
… demand conservation	40%	20%	40%	30%	50%	50%
… demand shifting	100%	100%	100%	0%	0%	0%

In order to provide an overview of the Spanish power system, Table 3 shows some key figures of total and residential demand in Spain in 2010. It is also useful to consider the generation mix: in 2010, 33% of the electricity was generated from renewable sources, of which wind power accounted for most of it (16% of the total); among the main conventional sources, combined cycle units accounted for 23% of electricity generation, nuclear for 22%, coal for 7% and hydro for 14% (REE, 2011).

Table 3: Total and residential demand in Spain in 2010 (CNE, 2012)

	Total demand	Residential customers (P<10 kW)		Average per residential customer
Number of customers	27,736,566	25,986,373	94%	
Energy demand[a]	244 TWh	75 TWh	31%	2.9 MWh
Turnover from access tariffs[b]	12,124 M€	5,854 M€	48%	225 €
Estimated turnover[c]	29,387 M€	10,628 M€	36%	408 €

[a] Demand of the consumers in the peninsula (islands, Ceuta and Melilla not included)

[b] Turnover from energy sales not included

[c] Assuming electricity prices (including both access tariffs and energy sales) 14.17 c€/kWh for households, 11.10 c€/kWh for others (Eurostat)

4. Assessment of benefits

This section presents the assessment of benefits in both the generation system and the distribution network, including an account of the methods used, and the results obtained.

The benefits will be computed as the difference in results between pairs of simulations, one for a baseline scenario (BS) without DR (named DR-0%) and one for a scenario with DR. Three scenarios with DR will be considered: DR-25%, DR-50% and DR-100%, where the percentage represents the fraction of households that participate effectively on the DR program out of the total of households considered. Thus, DR-25% corresponds to a scenario where only 25% of households participate in the DR program, whereas DR-100% corresponds to a scenario where all households participate in the program.

4.1. Benefits for the generation system

The benefits that we estimate for the generation system correspond to savings in investments (due to the reduction in the need for new generation capacity), in fuel costs (due to reduced operation of the costliest peaking units), and in CO_2 allowances (associated to variations in CO_2 emissions). Other potential benefits not accounted for here will be addressed at the end of this chapter.

4.1.1. Methodology

To estimate the benefits of DR for the generation system, we introduce DR endogenously into an advanced generation operation and expansion model. This model is a partial-equilibrium optimization model that represents thoroughly the Spanish generation system, and solves its operation and expansion minimizing the total cost of the system in a given number of years. This model is based in a previous model by Linares *et al*. (2008), in which the functioning of the market has been simplified from oligopoly to perfect competition (due both to computational limitations[12] and to the convenience of modeling DR as a resource of the system –as explained below).

Incorporating DR as a resource of the system can be modeled in an equivalent way to introducing a virtual power plant with special conditions for operation. Since demand and generation must be equal in every moment, reducing demand in a certain amount is equivalent in the model to generating the same amount with a virtual power plant. From this perspective,

[12] The need to represent the demand in detail to be able to evaluate the effects of DR requires a large number of variables, which -due to computational constraints- meant the model could only be solved using linear programming as allowed by the assumption of perfect competition.

demand conservation capacity can be modeled like conventional generation units, whereas demand shifting capacity can be modeled like pumping units: the demand reduction in the original moment of consumption would be equivalent to generating electricity with the stored water, and the demand increase in the moment to which the load is shifted would be equivalent to consuming electricity to pump water into the reservoir.

The capacity to conserve or shift demand is estimated in this model by breaking down the total residential demand into the loads corresponding to manageable appliances[13] and applying the percentages of potential for load conservation and load shifting for each appliance (shown in Table 2). Load management is only affected by these technical considerations regarding the potential of appliances, and not by economic considerations of consumers, which is equivalent to assuming an infinite price elasticity of consumers. For this reason, the results presented in this study can only represent an upper threshold of what can be expected in reality as consumers may have significantly lower elasticities for their demand[14].

A further improvement in the original model has been to consider wind production as input data for the model, in order to account for its non-dispatchability[15]. The hourly wind production is subtracted from the hourly total demand of the system to obtain the net demand, which allows for considering the interaction of DR with wind generation, as load conservation and load shifting will be optimized to cover the net demand. A further refinement, currently under way, is to consider this wind production as stochastic rather than fixed.

[13] Based on data of Spanish residential consumption by REE (1998).

[14] However, it should be remarked that typical assessments of elasticities account for the aggregate behavior of all electricity loads, and do not consider a fully-automated system for demand response. Since here we are only accounting for dispatchable loads, and assuming a fully-automated DR program, we believe that the infinite elasticity assumption is not that strong.

[15] The contribution of wind generation has become very significant in the Spanish system: in 2010, wind power accounted for 20% of the installed capacity, and covered 16% of the annual electricity demand (REE, 2011). Thus, adequately considering its non-dispatchable nature became important.

4.1.2. Results: changes in demand

From our results, a first aspect worth analyzing is how demand varies when residential consumers respond to real-time prices. Table 4 summarizes the variations in peak and energy demand at the end of a ten-year period[16] for both system and residential demand.

Table 4: Variations in demand at the end of the ten-year period

		BS	Reduction compared to BS					
		DR-0%	DR-25%		DR-50%		DR-100%	
Peak demand (MW)	System	45,334	212	0.5%	424	0.9%	847	1.9%
	Residential	15,933	0	0%	0	0%	0	0%
Energy demand (TWh)	System	283.27	0.93	0.3%	1.85	0.7%	3.70	1.3%
	Residential	68.70	0.93	1.3%	1.85	2.7%	3.70	5.4%

We can see how full deployment of DR could reduce the energy demand of the system by 1.3% (thanks to energy conservation) and its peak demand by 1.9% (thanks to both energy conservation and load shifting). However, for residential demand on its own we observe no peak clipping. The reason for this is that residential peak and system peak occur at different times, and since DR is optimized to minimize the generation cost of the system and not to reduce residential peaks, the optimal DR strategy does not necessarily imply reducing the residential peak load. However, for some months within the observed year (and also for other years), the optimal DR strategy does result in some peak clipping: the residential peak reduction reaches 3% in some months, and the median of all the monthly reductions in the observed year is 1.6%. We will come back to these results to build our assumptions about residential peak clipping for the distribution network analysis.

16 Ten years is considered an adequate time scope for a program of this type: a significantly shorter period would probably not justify the investment in DR infrastructure, and a significantly longer period would mean dismissing future risks of this program becoming obsolete (by the introduction of new technologies for instance).

4.1.3. Results: savings in the generation system

The savings estimated in investment, fuel and CO_2 allowances are presented in Table 5, expressed as the net present value in a period of ten years and assuming a discount rate of 9%. Total savings add up to between 270 and 1,080 million euros (in DR-25% and DR-100% respectively), which represent between 0.4% and 1.7% of the total system costs. In this particular case, the highest contribution to these savings is the reduction in fuel costs, and no savings are realized in investment. However, it should be remarked that this result is very specific for our study, as will be explained below.

Table 5: Benefits in the generation system

NPV (9%, 10years) **[million €]**	Costs in BS DR-0%	Savings compared to BS DR-25%		DR-50%		DR-100%	
Investment cost	12,327	0	0.0%	0	0.0%	0	0.0%
Fuel cost	41,330	232	0.6%	464	1.1%	926	2.2%
CO_2 allowances	8,939	39	0.4%	77	0.9%	155	1.7%
TOTAL	62,596	270	0.4%	541	0.9%	1,081	1.7%

The fact that no savings are realized in investment can be explained by the combination of two factors: the ample generation capacity installed currently in Spain, and the moderate growth in electricity demand that we assume – set to 0.5% to be consistent with current trends (REE, 2011). Both factors together mean that no new power plants are needed to cope with increasing demand –only power plants required to meet emission constraints or renewable objectives get built-, so there is no potential for reducing investment with DR. However, if the growth rate is set to 4% -which would represent an average level in Spain for the decade previous to 2008 (REE, 2011)-, savings in investment due to DR are indeed realized: up to 0.6% (106 M€) when objectives for renewable capacity are considered[17], and up to 2% (134 M€) when neglected – both results corresponding to full penetration of DR (DR-100%).

[17] We use renewable objectives set by the Spanish government (MITYC, 2010).

Another point worth making is that the reduction in CO_2 emissions and their associated cost results from the interaction of two opposing effects of DR: on the one hand, demand conservation means less electricity production and thus less CO_2 emissions; on the other hand, demand shifting leads in this particular case for Spain to more CO_2 emissions, as part of the production from gas units (at the margin in peak hours) is being moved to more CO_2-emitting coal power plants (at the margin in off-peak hours). Once again, this effect is specific to the Spanish power system, and the result may vary in other countries depending on their electricity generation mix.

4.1.4. Results: benefits for the generation companies

The results just presented constitute real savings in resources and therefore can be considered social benefits (i.e. benefits for the society as a whole). However, these results do not correspond to benefits for the generation companies, whose benefits will not only depend on the savings they can realize but also on their performance in the market. The operation profit for generation companies as a whole has been estimated as the difference between the market income (calculated as production multiplied by price on an hourly basis) and the operation costs (calculated as the sum of the costs of fuel and CO_2 permits).

Table 6 summarizes these results. It can be observed how both the operation costs and the market income of the companies decrease with the introduction of DR. However, as the savings in operation costs slightly exceed the reduction of market income, there is an overall positive effect on operation profit, which increases slightly as DR increases[18] (in the order of 0.1%). This increase in profits comes at the expense of consumers, who therefore see their surplus reduced[19].

[18] This is the average effect: of course, producers with baseload portfolios will benefit more than owners of peaker plants, which might lose out with the policy.

[19] This is not the usual effect of other energy efficiency policies, which typically result in benefits for the consumers at the expense of producers.

Table 6: Benefits for the generation companies

NPV (9%, 10years) [million €]	Results in BS DR-0%	Increase compared to BS DR-25%		DR-50%		DR-100%	
Operation costs	50,269	-270	-0.5%	-541	-1.1%	-1,081	-2.1%
Market income	89,130	-248	-0.3%	-511	-0.6%	-1,015	-1.1%
Operation profit	56,859	22	0.0%	30	0.1%	66	0.1%

4.1.5. Sensitivity analysis

A sensitivity analysis has been performed to understand the impact of relevant parameters on the results. The rate of demand growth has already been mentioned as a key parameter affecting the results: the greater the demand growth, the more potential for savings associated to DR –and vice versa, to the extent that no savings in investment are realized in the initial period if the demand grows slightly. The impact of the potential for demand conservation and shifting of the electric appliances has also been found to have a significant impact on the results: an increase of 25% on the baseline values of these parameters (which were presented in Table 2) induces an increase in the total savings in the order of 57%. Finally, the sensitivity of the results to the profile of wind production has been found to be very low: for a set of ten scenarios, the maximum variation in total savings obtained was in the order of 0.2% compared to the baseline savings.

4.2. Benefits for the distribution network

This section presents the assessment of benefits in the distribution network. We estimate only savings in network investment, which do not constitute the whole of potential savings enabled by DR for the distribution system, but a significant part of them. Again, other potential benefits will be discussed at the end of the chapter.

4.2.1. Methodology

We have used an existing reference network model used for distribution planning (Mateo *et al*., 2011), which simulates the expansion of distribution networks for given increments of demand. The model receives as input data the geographical coordinates and the electrical features of the main elements of the grid (substations, transformer stations, lines, consumers, generators, and protection equipment) and estimates the new investment needed in that grid to meet certain increments of demand. Investment decisions are made to minimize the overall cost of investment, maintenance and energy losses, while meeting technical constraints and quality of supply standards.

The effect of DR on the expansion of distribution networks can be measured with this model by comparing the results arising from different scenarios of peak demand increase as affected by DR. The scenarios considered are again DR-0% (baseline), DR-25%, DR-50% and DR-100%[20]. We build these scenarios considering that those residential consumers who do not participate in the DR program will experiment a fixed increase in their peak demand ("baseline increase"), whereas those who do participate in the DR program will be able to offset part of this increase by shifting or conserving some of their consumption ("DR reduction"). Thus, in the DR-25% scenario for instance, 25% of consumers chosen randomly among the cohort of consumers in the network are assumed to participate in the DR program and thus experiment a lower increase in their peak demand compared to the remaining 75% (those who do not participate in the program).

We assume a "baseline increase" in peak demand (for consumers not involved in DR) of 3%21,22, and a "DR reduction" consistent with the results we obtained from the electricity

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20 See the opening (2nd paragraph) of Section 4 for further explanation.

21 3% is the median of the annual increase in residential electricity demand over the period 2001-2011 in Spain (data from Eurostat: "Electricity consumption of households (tsdpc310)"). If we assume no significant changes in the pattern of consumption (which seems reasonable given that there has not been any DR program for Spanish residential consumers), we can assume that this increase in energy demand is reflected in an equivalent increase in peak demand.

market simulation for the generation system: 0% (base case), 1.6% and 3%[23]. Thus, consumers not involved in DR will have a 3% increase in their peak demand, whereas consumers involved in DR can potentially have a 3% increase (3%-0%), 1.4% increase (3%-1.6%), or zero increase (3%-3%), depending on how effective DR is assumed to be in achieving residential peak clipping. The resulting increases in the overall peak demand of the networks (at the low voltage level) in all the scenarios considered are summarized in Table 7.

Table 7: Increase in overall peak demand in all the scenarios considered

Assumed peak clipping thanks to DR program	Increase in overall peak demand			
	DR-0%	DR-25%	DR-50%	DR-100%
-0%	3%	3%	3%	3%
-1.6%	3%	2.6%	2.2%	1.4%
-3%	3%	2.25%	1.5%	0%

Finally, we should acknowledge that, due to computational limitations (common to these models), the model cannot be run for an electricity system the size of Spain, so the assessment of benefits for the distribution system has been carried out by looking at two real and specific (but representative) distribution networks and then extrapolating the results to the Spanish distribution system as a whole.

4.2.2. Data

Two existing distribution networks corresponding to a residential neighborhood in the city of Madrid, and a semi-rural area in the Madrid region have been selected as case study. In order to provide an idea of the scale of these networks, Table 8 shows the number of stations and customers connected to them, and their installed/contracted power. Real data for the location

[22] This increase in peak demand is assumed to be instantaneous and at the beginning of the period of analysis. This is only to suit the arrangement of the model.

[23] We obtained 0% reduction in the annual peak residential demand, median monthly reductions of 1.6% and monthly reductions of 3% for several months. See Section 4.1.2. for explanation.

and power of these elements were provided by Gas Natural Fenosa, the distribution company that operates the networks.

Table 8: Stations and customers in the analyzed networks

	Urban network		Semi-rural network	
	Amount	Installed/ contracted power	Amount	Installed/ contracted power
HV/MV[24] substations	5	780 MVA	8	2,314 MVA
MV/LV transf. centers	1,464	1,254 MVA	390	216 MVA
MV consumers	86	39 MW	367	106 MW
LV consumers	65,440	343 MW	27,564	288 MW
MV generators	1	6 MW	0	0 MW
LV generators	19	0.2 MW	0	0 MW

4.2.3. Results: savings in the case-study networks

When running the model for the different scenarios, we observe how the higher the assumed peak clipping and the higher the penetration of DR, the lower the need for expansion of the network: for instance, full penetration of DR could avoid the installation of about 35 km of lines and one hundred fuses in the analyzed networks. The reductions in the network expansion needs are translated into economic savings, as summarized in Table 9 for both networks analyzed and all scenarios considered. We include the investment costs in the baseline scenario and the savings realized in the three scenarios with DR compared to BS. These figures represent the net present value over a ten-year period, assuming a discount rate of 9%.

[24] HV, MV and LV refer to high voltage, medium voltage and low voltage respectively.

Table 9: Savings in investments for the case-study networks

NPV (9%, 10 years) [000 €]	Assumed peak clipping	Cost in BS DR-0%	Savings compared to BS					
			DR-25%		DR-50%		DR-100%	
Urban network	-0%	72,979	0	0%	0	0%	0	0%
	-1.6%	72,979	255	0.3%	417	0.6%	769	1.1%
	-3%	72,979	514	0.7%	849	1.2%	2455	3.4%
Semi-rural network	-0%	66,239	0	0%	0	0%	0	0%
	-1.6%	66,239	169	0.3%	249	0.4%	697	1.1%
	-3%	66,239	229	0.3%	529	0.8%	1357	2.0%

These results can be presented as savings per participant, which can be useful to understand their magnitude independently from the size of the case study networks and to extrapolate the results to other networks (taking into consideration, however, the limitations of the extrapolation approach). These savings per participating household are in the order of 10 to 50 euro (for a 10 year period). Table 10 presents the complete set of savings per participant in all the scenarios considered.

Table 10: Savings per participant household in the DR program

NPV (9%, 10 years) [€ per participant]	Assumed peak clipping	Savings compared to BS			Average
		DR-25%	DR-50%	DR-100%	
Urban network	-0%	0	0	0	0
	-1.6%	16	13	12	13
	-3%	31	26	38	32
Semi-rural network	-0%	0	0	0	0
	-1.6%	25	18	25	23
	-3%	33	38	49	40

4.2.4. Results: savings in the distribution system

In order to provide a rough estimation of the potential savings for the whole Spanish distribution system, we multiply these savings per participant household in the case-study networks by the number of households in Spain that could potentially participate in DR. Table 11 shows the results of this calculation, considering 26 million residential consumers in Spain (CNE, 2012), using average values of savings per participant (see Table 10), and assuming 49% of households are connected to urban networks and 51% of households are connected to semi-rural networks (Eurostat, 2012).

Table 11: Estimates of benefits for the Spanish distribution system

NPV (9%, 10 years) **[million €]**	Assumed peak clipping	Estimated benefits for the Spanish system		
		DR-25%	DR-50%	DR-100%
49% urban, 51% semi-rural	-0%	0	0	0
	-1.6%	118	235	470
	-3%	234	469	937

As can be seen in Table 11, benefits could range from zero to almost 1,000 million euros, depending on the assumed peak clipping and the degree of penetration of DR. As we take 0% peak clipping as the baseline scenario (to be consistent with the results for the generation system), our baseline result is that for the particular DR program analyzed, based on real-time pricing, we could expect no savings from investments in distribution networks. If peak clipping reached 1.6%, or 3% (levels that seem feasible in view of our results, if only peak residential demand in a year happens at a time of high system demand), and assuming all residential customers would enter in a DR program of this kind, savings in distribution network investments could represent almost 500 million euros, or 1,000 million euros, respectively.

4.2.5. Results: savings for distribution companies

These savings, which constitute social benefits, would also constitute short-term savings for the distribution companies under the current incentive-based regulation in Spain, but would probably be transferred to consumers in the medium term.

4.3. Summary of benefits

Table 12 summarizes all the long-term country-level benefits that we have estimated. When summing them up, we see that the total magnitude is not large, given that these are 10-year figures: it represents an annual reduction around 4-8 euros/year per residential customer[25], compared to their average expense on electricity supply of about 400 euro/year[26]. This raises the question of whether, if we assume a certain bounded rationality in consumers, they will really respond to price signals. Here is where the automated equipment certainly can play a significant role.

Table12: Aggregated benefits for Spain

NPV (9%, 10 years) [million €]		Estimated benefits for Spain		
		DR-25%	DR-50%	DR-100%
Generation	Investment[a]	0	0	0
	Fuel	232	464	926
	CO2 allowances	39	77	155
Distribution	Investment[b]	0 - 234	0 - 469	0 - 937
Sub-total		270 - 504	540 - 1,009	1,080 - 2,017

[a] Zero savings in generation investment are due to the particularities of the Spanish system (overcapacity and low demand growth). See Section 4.1.3 for explanation.

[b] The range provided corresponds to results for 0% and 3% assumed peak clipping respectively. See Section 4.2.1 for explanation.

4.4. Non-quantified benefits

As mentioned before, this assessment has not included all potential benefits from DR programs. Although previous partial assessments make us believe that they will not be as significant as those quantified here, the following benefits might also be considered:

[25] Note that these are not necessarily the savings that consumers would observe in their electricity bill (this is not an uncommon mistake in assessments of DR benefits). Real savings observed by the consumers will depend on the tariff design.

[26] Estimation based on average annual consumption of Spanish residential consumers of 2.9 MWh (CNE, 2012) multiplied by an average price of electricity for households –including both energy and access tariff- of 14.17 c€/kWh (Eurostat) (data for year 2010).

- Reduced cost of reserves[27]. Estimates in the ADDRESS Project point to potential savings of about 0.5 M€ for Spain (Lago et al., 2011).

- Reduced spillage of renewable electricity. Sioshansi and Short (2009) show how DR could increase the percentage of potential wind generation utilized up to about 7%, with a market value of up to $10 per MWh of incremental wind generation.

- Transmission network savings.

- Reduction of energy losses in T&D network. Previous studies have estimated reduction losses thanks to DR of about 2-5% for Spain (Lago et al., 2011), or about 1% for UK (Shaw et al., 2009). In the case of Spain, this reduction would mean savings of 2-6 M€ (Lago et al., 2011).

- Improved quality of supply. Affonso et al (2006) show how DR could help to improve system security and reliability, but do not assess the derived economic impact. Anyhow, quality of supply indices are quite satisfactory in Spain, which leaves little room for economic savings here.

- Mitigation of market power and price volatility.

On the other hand, we should remind that some of our assumptions will overestimate the benefits: we are assuming an infinite elasticity in the response of consumers (see however footnote 14); and we are also considering that none of the energy conservation and shifting actions take place currently, so their potential is intact. This will clearly not be the case, even without price signals.

[27] Greater DR could mean both a reduction in the need of reserves due to the increased flexibility of demand or, for a given level of reserves, an increase in the potential share of intermittent renewable energy.

5. Conclusions

This paper has illustrated the application of simulation models of the generation system and the network system to the valuation of DR benefits, and has presented the resulting estimates of benefits for a hypothetical DR program in Spain. The results obtained show that, in order to be cost-effective, the highly-automated infrastructure required for the DR program analyzed here should not exceed values in the range of 300-1,100 million euro for the system (for reaching 25% or 100% of residential consumers respectively), or of 42 € per participant household for a 10-year period (and about twice these values in case 3% peak clipping is achieved for residential demand). In relative terms, this amounts to annual savings between 0.1 and 0.4% compared to the total system turnover, and 1% for the customers compared to their average bill[28] (again about twice these values in case 3% peak clipping is achieved for residential demand).

These estimates can be compared with some projections of the costs of DR systems. For example, EPRI (2011) estimates that the cost per residential customer of a fully-functioning smart grid would be between 775 € and 1,090 € over a 10-year period. Although this includes more elements than just the DR system, it does not include essential elements such as consumer appliances and devices that may facilitate an automated operation of the system. Similar estimates carried out within the GAD project point to figures roughly eight times larger than the quantified benefits, just for setting up the infrastructure required for the DR program, this time including consumer appliances and devices.

The immediate conclusion would therefore be to question the social cost-effectiveness of such a DR program. However, three elements should be considered in this regard

First, we need to consider that the benefits estimated constitute only a portion of the potential benefits from DR -those associated to the leveling of the demand curve, and only for the

[28] See Table 3 for reference figures.

generation and distribution systems-, and that the estimation itself presents some limitations that have been mentioned throughout the paper. Future research could aim to overcome these limitations and assess other DR benefits: those related to the leveling of the demand that have not been covered in this study (particularly, in the transmission network) and those realized in low-probability, high-impact critical situations. Further exploring prospects for DR interaction with renewable intermittent generation, and even electric vehicles, would also be of interest.

Moreover, future conditions will probably be more favorable to DR than the present conditions assumed here at least for three reasons: first, the foreseeable increase in renewable energy would require higher flexibility of the demand; second, as the cost of electricity is likely to increase over time, the level of response from consumers –and therefore the benefits realized from it- could increase; and third, the cost of the enabling technology is expected to decrease with further development and mass production.

The second element has to do with the correct imputation of costs and benefits in this analysis. For example, the infrastructure required to allow implementing a DR program may also be used to introduce electric vehicles, to facilitate the operation of distributed generation, to increase the security of the network, to provide more feedback to consumers, or to reduce metering and billing costs. These actions will also produce benefits for the system, and is the sum of all of them which should be compared to the costs of the infrastructure. Alternatively, if we assume that part of the infrastructure is already in place (e.g. smart meters because of rollout mandates) then the cost-benefit analysis of DR will be much more favorable. Therefore, it may make more sense to require comprehensive cost-benefit analysis, instead of piece-meal, marginal ones. On the other hand, some of the costs, such as those of smarter appliances, are only attributable to DR programs, so separate accounts should also be considered within this comprehensive analysis.

The third element has to do with the level of sophistication of the infrastructure required for DR. Two main recommendations can be derived to guide the design of residential demand response programs: [i] it is important to find an appropriate level of sophistication of the infrastructure – less automated designs that avoid the high costs of making households “smart” seem more suitable at present, although this may change in the future; and [ii] it is advisable to implement DR gradually, targeting first the most responsive consumers and incorporating other consumers as benefits increase and costs decrease over time.

Finally, we would like to comment briefly on a rather relevant topic that has only been hinted by our results, the allocation of the benefits of a DR program: as we have seen, the different agents in the system (generators, system operators, consumers) will receive different benefits, and will also incur in different costs. Even if the overall cost-benefit analysis is positive, some agents may lose in the process, endangering the implementation of the program. A correct distribution of the costs and benefits is therefore critical for a successful DR program to take place. This includes not over-paying some of the agents, as is being currently considered in some systems, and which has already adequately been argued against by Hogan (2011) or Bushnell et al (2011).

To conclude: although the correction of the information market failure addressed by DR programs would clearly improve the efficiency of electricity markets, the high costs involved require a careful evaluation of the benefits expected from such programs, and also an appropriate distribution of the costs and benefits among agents, so that the right incentives are in place and the final result is a net positive social welfare gain. More research, some of it ongoing, is clearly needed to perform these tasks correctly, and regulators should clearly take this into account before jumping into promoting indiscriminately DR or broader smart grid programs.

6. References

ADDRESS, 2012. Evaluation of benefits of active demand. Address Project WP5-T5.1

Affonso, C.M., L.C.P. da Silva, W. Freitas (2006). *Demand-side management to improve power security*. Transmission and Distribution Conference and Exhibition, 2005/2006 IEEE PES, May.

Allcott, H. (2012). *The smart grid, entry, and imperfect competition in electricity markets*. NBER Working Paper No. 18071.

Andersen, F. M., S.G. Jensen, H.V. Larsen, P. Meibom, H. Ravn, K. Skytte, M. Togeby (2006). *Analyses of demand response in Denmark*. Risø-R-1565(EN). Roskilde (Denmark): Risø National Laboratory.

Baer, W., D. Fulton, S. Mahnowski (2004). *Estimating the benefits of the GridWise initiative*. Phase I report. Prepared for: Pacific Northwest National Laboratory. Santa Monica, California: Rand Corporation.

Batlle, C. , P. Rodilla (2009). Electricity demand response tools: current status and outstanding issues. *European Review of Energy Markets*, 3 (2). European Energy Institute.

Berg, S.V., B.L. Capehart, J. Feldman, S. LaTour, R.L. Sullivan (1983). An interdisciplinary approach to cost/benefit analysis of innovative electric rates. *Resources and Energy*, 5 (4), pp. 313-330.

Borenstein, S. (2005). The long-run efficiency of real-time electricity pricing. *The Energy Journal*, 26 (3), pp.93-116.

Bradley, P., M. Leach, J. Torriti (2013). A review of the costs and benefits of demand response for electricity in the UK. *Energy Policy*, 52, pp. 312-327.

Brattle (2007). *Quantifying demand response benefits in PJM*. Prepared for: PJM Interconnection, LLC and the Mid-Atlantic Distributed Resources Initiative (MADRI). Cambridge, Massachusetts: The Brattle Group.

Bushnell, J., S.M. Harvey, B.F. Hobbs, S. Stoft (2011). *Opinion on economic issues raised by FERC Order 745*, "Demand response compensation in organized wholesale Energy markets". Mimeo.

CapGemini (2007). *Comparatif international des systems de télé-relève ou de télégestion et etude technico-économique visant à évaluer les conditions d'une migration du parc actuel de compteurs.*

CNE (2012). *Información básica de los sectores de la energía: 2011. Anexo*. Madrid: Comisión Nacional de Energía.

Conchado, A., P. Linares (2012). The economic impact of demand-response programs on power systems. A survey of the state of the art. *In:* Sorokin, A., S. Rebennack, N. Iliadis, M. Pereira, P. Pardalos, eds. *Handbook of Networks in Power Systems*. Springer.

Darby, S. (2006). *The effectiveness of feedback on energy consumption: a review for DEFRA of the literature on metering, billing and direct displays*. Environmental Change Institute, University of Oxford.

EC (2005). *Green paper on energy efficiency or doing more with less*. COM (2005) 265 final. Brussels: European Communities.

EPRI (2011). *Estimating the cost and benefits of the Smart Grid: A preliminary estimate of the investment requirements and the resultant benefits of a fully functioning smart grid*. Technical report 1022519, March 2011.

ESC (2004). *Mandatory rollout of interval meters for electricity consumers*. Final decision. Melbourne: Essential Services Commission.

Eurostat (2012). *Around 40% or EU27 population live in urban areas*. Eurostat News Release 51/2012 - 30 March 2012.

Faruqui, A., S. S. George (2002). The value of dynamic pricing in mass markets. *The Electricity Journal*, 15 (6), pp. 45-55.

Faruqui, A., D. Harris, R. Hledik (2009). *Unlocking the €53 billion savings from smart meters in the EU*. Discussion paper. The Brattle Group.

Faruqui, A., S. Sergici (2010). Household response to dynamic pricing of electricity – A survey of the experimental evidence. *Journal of Regulatory Economics* 38 (2), pp. 193-225.

Faruqui, A., S. Sergici, E. Shultz (2013). *Consistency of results in dynamic pricing experiments – Toward a meta analysis*. Presented at the DistribuTECH Conference, San Diego, CA, January 29, 2013.

FERC (2006). *Assessment of demand response and advanced metering*. Staff report, AD-06-2-000. Washington: Federal Energy Regulatory Commission.

Gans, W., A. Alberini, A. Longo (2013). Smart meter devices and the effect of feedback on residential electricity consumption: Evidence from a natural experiment in Northern Ireland. *Energy Economics*, 36, pp. 729-743.

Goldfine, D., M. Haldenstein, A. Moniz, D. Traverso (2008). *Demand response review - A survey of major developments in demand response programs and initiatives*. Washington: Edison Electric Institute.

Haney, A.B., T. Jamasb, M. Pollit (2009). *Smart metering and electricity demand. Technology economics and international experience*. EPRG working paper 0903 - Cambridge working paper in economics 0905. Cambridge: University of Cambridge - Electricity Policy Research Group.

Herter, K. (2007). Residential implementation of critical-peak pricing of electricity. *Energy Polic,y* 35 (4), pp. 2121–2130.

Hogan, W.W. (2010). *Demand response pricing in organized wholesale markets*. Prepared for ISO/RTO Council. Comments on demand response compensation in organized wholesale energy markets. Notice of proposed rulemaking. Federal Energy Regulatory Commission Docket No. RM10-17-000.

Houde, S., A. Todd, A. Sudarshan, J.A. Flora, K.C. Armel (2013). Real-time feedback and electricity consumption: A field experiment assessing the potential for savings and persistence. *The Energy Journal*, 34 (1), pp. 87-102.

IEA (2011). *Empowering customer choice in electricity markets*. Paris: International Energy Agency.

IEA (2012). *World Energy Outlook*. Paris: International Energy Agency.

ITE (2008). *Análisis de clientes*. Proyecto CENIT GAD: Gestión Activa de la Demanda. Entregable PT 1.2. Instituto de Tecnología Eléctrica (ITE).

Jonghe, C.D., B.F. Hobbs, R. Belmans (2011). Integrating short-term demand response into long-term investment planning. Working paper CWPE 1132 & EPRG 1113.

King, C.S., S. Chatterjee (2003). Predicting California demand response. *Public Utilities Fortnightly*, 141 (13), pp. 27-32.

Kohler, D.F., B.M. Mitchell (1984). Response to residential time-of-use electricity rates. How transferable are the findings? *Journal of Econometrics*, 26 (1-2), pp. 141-177.

Lago, O., P. Linares, M. Baron, A. Delnooz, C. Linke, A. Cronenberg (2011). *Evaluation of benefits of active demand*. ADDRESS Project. WP5-T5.1-IR-Comillas-EvaluationOfBenefits

Linares, P., J. Santos, M. Ventosa, L. Lapiedra (2008). Incorporating oligopoly, CO2 emissions trading and green certificates into a power generation expansion model. *Automatica*, 44 (6), pp. 1608-1620.

Linares, P., A. Conchado (2009). Gestión activa de la demanda eléctrica: Evaluación de su impacto en el sistema de generación. IV Congress AEEE, 22-24 January 2009, Sevilla.

Lu, N., D.P. Chassin, S.E. Widergren (2004). *Simulating price responsive distributed resource*. Power Systems Conference and Exposition, IEE PES, 3, pp. 1538-1543.

Mateo, C., T. Gómez, Á. Sánchez-Miralles, J.P. Peco, A. Candela (2011). A reference network model for large-scale distribution planning with automatic street map generation. *IEEE Transactions on Power Systems*, 26 (1), pp. 190-197.

Ministerio de Industria, Turismo y Comercio (2010). Plan de Acción Nacional de Energías Renovables de España (PANER) 2011-2020.

Navigant (2005). *Benefits of smart metering for Ontario*. Discussion draft, April 5. Prepared for: Ontario Ministry of Energy. Toronto: Navigant Consulting.

NERA (2008). *Cost benefit analysis of smart metering and direct load control*. Overview report for consultation. Report for the Ministerial Council on Energy Smart Meter Working Group. Sydney: NERA Economic Consulting.

Ofgem (2006). *Domestic Metering Innovation*. Consultation document. London: Office of Gas and Electricity Markets.

REE (1998). *Atlas de la demanda eléctrica española*. Proyecto INDEL. Madrid: Red Eléctrica de España. Available at: http://www.ree.es/sistema_electrico/pdf/indel/Atlas_INDEL_REE.pdf [Accessed 6 March 2008].

REE (2011). *El sistema eléctrico español: 2010*. Madrid: Red Eléctrica de España.

RMI (2006). *Demand response: an introduction. Overview of programs, technologies, and lessons learned*. Boulder, Colorado: Rocky Mountain Institute.

RRI (2008). *The status of U.S. demand response*. Evergreen, Colorado: Research Reports International.

Shaw, R., M. Attree, T. Jackson, M. Kay (2009). The value of reducing distribution losses by domestic load-shifting: a network perspective. *Energy Policy*, 37 (8), pp. 3159-3167.

Siderius, H. P., A. Dijkstra (2006). *Smart metering for households: cost and benefits for the Netherlands*. SenterNovem.

Sioshansi, R., W. Short (2009). Evaluating the impacts of real-time pricing on the usage of wind generation. *IEEE Transactions on Power Systems*, 24 (2), pp.516-524.

Stanojević, V., V. Silva (2009). *Role of demand side management to reduce system constraints and investment*. Prepared for: "Smart domestic appliances in sustainable energy systems (SMART-A)" EIE project (WP 4). Imperial College London.

Strbac, G. (2008). Demand-side management: benefits and challenges. *Energy Policy*, 36 (12), pp. 4419–4426.

Stromback, J., C. Dromacque, M. H. Yassin (2011). *The potential of smart meter enabled programs to increase energy and systems efficiency: a mass pilot comparison* (Empower Demand). Helsinki: VaasaETT.

Su, C., D. Kirschen (2009). Quantify the effect of demand response on electricity markets. *IEEE Transactions on Power Systems*, 24 (3), pp. 1199-1207.

Summit Blue (2006). *Evaluation of the 2005 Energy-Smart Pricing Plan*. Final report. Prepared for: Community Energy Cooperative (Chicago). Boulder, Colorado: Summit Blue Consulting

US DOE (2006). *Benefits of demand response in electricity markets and recommendations for achieving them*. United States Department of Energy.

Vasconcelos, J. (2008). Survey of regulatory and technological developments concerning smart metering in the European Union electricity market. RSCAS Policy Papers 2008/01. Florence School of Regulation – Robert Schuman Centre for Advanced Studies. Italy: European University Institute.

Veldman, E., M. Gibescu, H.J.G. Slootweg, W.L. Kling (2013). Scenario-based modeling of future residential electricity demands and assessing their impact on distribution grids. Energy Policy, 56, pp. 233-247.

Violette, D., R. Freeman, C. Neil (2006). *Valuation and market analyses. Volume II: Assessing the DRR benefits and costs*. Prepared for: International Energy Agency, Demand Side Programme, Task XIII: Demand response resources. Boulder, Colorado: Summit Blue Consulting.

Weitzman, M.L. (1974). Prices versus Quantities. *Review of Economic Studies*, 61 (4), pp. 477-491.

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