Electricity demand response tools: current status and outstanding issues[1]

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Key words: demand response, smart meters, electricity tariffs, unbundling.

[1] This paper has been submitted April 2009, so many of the discussions and specially the references are a little bit out-of-date.

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Abstract

The present social and economic scheme is characterized by a growing concern for the environment. Particularly, in the electricity context, the limits of electricity grids and the persistent growth of energy demand, which rises more intensely in peak periods, raise the need for innovative tools to allow a sustainable development of power systems. Among the ones that can be currently envisioned, electricity demand response is undoubtedly "the great white hope".

The present paper is the result of intense data collection, study and analysis of countless international experiences underway or planned in electricity systems around the world. The primary aim, in light of this analysis, is to review the most relevant developments while reflecting on the issues still outstanding that will necessarily have to be addressed if progress is to be made along these lines.

1. Introduction

Electricity demand response programmes have a dual aim. Firstly, they constitute a new tool for the electricity system, which in turn has a two-pronged objective: in the short and medium term it seeks to minimize technical constraints and possible system collapse by adjusting loads to distribution/transmission capacity, and in the long term, to lower investment needs and permanent congestion. The second aim of such programmes is to minimize the cost of consumers' power needs without modifying their degree of comfort by attempting to shift loads to lower price (i.e. cost) intervals.

This approach is a necessary initiative in the present social and economic context, characterized by a growing concern for the environment, the limits of electricity grids and the sustained and the asymmetric growth of energy demand, which rises more intensely in peak periods.

The main objective is not new. The first measures designed to reduce demand peaks were implemented in the United States as early as the nineteen seventies, when time-of-use tariffs were established for large accounts in California, for instance. But much ground has yet to be covered. Developments in information technologies and home automation are preparing the way for new services intended to make the most of the demand-side capacity to contribute to modulating the load curve.

The present paper is the result of intense data collection, study and analysis of countless international experiences underway or planned in electricity systems around the world. The primary aim, in light of what has been learnt in these international experiences, is to review the most relevant developments while reflecting on the issues still outstanding that will necessarily have to be addressed if progress is to be made along these lines.

1.1. Demand management: background

The paper begins by focusing on the problem with a review of the several dimensions of "demand management" service, distinguishing among the various ways the service is understood in different systems: i.e. the different definitions and classifications of the levels into which it can be broken down.

Firstly, mention is made of the two main areas into which demand management is divided: energy efficiency programmes and demand response programmes, such as in [1].

Energy efficiency generally refers to the suite of actions geared to optimizing the ratio between the amount of energy consumed and the end products and services obtained. It is usually attained through a series of measures, investments and subsidies whose targets are technology-related (such as the replacement of inefficient motors, installation of thermal insulation, use of low energy light bulbs…).

Demand response programmes aim to (directly or indirectly) manage consumption by shifting part of the demand to times of day when (system) costs are lower.

The present article addresses this second area, which may be broken down in accordance with different criteria:

– Incentive-based demand response vs. time-based rates [2], [3].

– Price-based programs vs. emergency-based programs [4], or market-led programs vs. system-led programs [5].

– Direct load control, implemented by the system operator with remote control equipment, for instance, and passive load control, left to user discretion, such as time-of-use tariffs [6].

1.2. Roadmap

This article reviews the main factors relating to demand response tools. Firstly, a distinction is drawn between technological and economic tools. Section 2 briefly reviews some of the technological tools, in particular smart meters, that play an essential role in demand response projects. Section 3 focuses on the economic tools on which such programmes are normally based.

Subsequently, section 4 introduces the main issues to be considered when evaluating the potential economic impact of these programmes, citing a series of interesting studies that address this type of analysis. And finally, in section 5 we discuss what in our opinion is one of the key factors affecting the matter in which there is still a lot of research needed: the regulatory design issues.

2. Technological tools

Demand response programmes build on new electronic hardware developments to enable end consumers to manage their demand both manually and automatically.

This article does not revise the many technological alternatives available in very great detail. Rather, the review focuses primarily on a discussion of the functionalities of smart meters as a central element of the service and their implications for regulatory design (direct implications for tariffs, designation of distributor/retailer competencies and so on). Other relevant alternatives are also listed, along with references to papers where they are described more fully.

2.1. Smart meters

Smart meters are the key component in any demand response management mechanism. More specifically, they are indispensable to implementing the time interval-based differential pricing tools described in the following section.

A number of countries have allowed large-scale consumers to install interval meters to manage their power consumption more efficiently, providing savings for both the consumer and the system as a whole. The next and much more ambitious step is to extend this feature to domestic consumers. Any progress in this regard obviously entails replacing old electro-mechanical meters.

Electro-mechanical metering equipment has barely evolved in the last 50 years. In principle it offers a substantial competitive advantage: low installation and maintenance costs. And yet it also has important drawbacks:

– High reading costs, for readings must be made *in situ* (and accessibility to such meters varies from one country to the next, for in some they are located in each home instead of in a single meter room for the entire building[1]). Where readings are missing, consumption must be estimated from historical records[2].

– Inability to send temporary price signals to the end consumer: since all that domestic electro-mechanical meters record is cumulative power consumption, power demand at different time intervals cannot be billed separately[3].

– Lack of information on each customer's consumption profile: this hampers retailer planning and their ability to individually counsel end consumers.

Electronic meters and more specifically smart meters provide solutions to the above shortcomings and open the door to new alternatives.

AMRs (automatic meter reading) devices can be read remotely and in addition provide time-of-day information. One of the first reasons for their development was to surmount the difficulties encountered by utility companies (water, gas, electricity and so on) to obtain domestic readings (in part due to limited meter accessibility as mentioned above). Moreover, AMR meters greatly simplify other tasks, such as fraud detection or change of supplier.

Remote control meters call for a communications channel between the meter and the data centre. A number of different technological alternatives are available in this regard, including SMS text messaging, internet, radio and PLC technology. While the specific details fall outside the scope of the present article, be it said that none is universally applicable. By way of example, SMS messaging can only be used for meters within reach of a mobile telephony network.

[1] This, which is a drawback in the case of electro-mechanical meters, is a huge advantage when replacing them with smart meters, for it facilitates meter-user communication (via a led screen, for instance).
[2] In the Austrian system, for instance, meters are read once a year, an arrangement that entails considerable shortcomings in connection with final settlement.
[3] Billing is possible, however, if a clock is installed along with several electro-mechanical meters, or with a single meter fitted with several integrators. This was the arrangement used for Spain's "night-time tariff", for instance. The problem is the high costs involved (not only of installing new technology, but of taking more complex *in situ* readings).

The most advanced (and costly) meters presently available are AMMs (automatic meter management), which accommodate two-way communications. This opens up a whole new world of possibilities, most prominently the ability to send consumers (hourly, half-hourly, by other intervals…) price signals and to institute remote management. AMM meters, which employ third generation technology, are sometimes what is meant by the term "smart meter".

In addition to the above, smart meters afford other advantages:

- Retailers would have the infrastructure required to broaden the variety of their offers and customer services, which would contribute on the one hand to increasing the efficiency of market signals and on the other to driving market competition.

- In some countries (England for instance) special conditions are established for the fuel poor, i.e. households devoting over 10% of their income to keep their homes reasonably warm [7]. Such terms consist in the existence of pre-pay tariffs that both simplify economic management in such cases and minimize the credit risk to which retailers would be exposed (such terms go hand-in-hand with certain financing facilities[4]). The problem is that these tariffs call for the installation of a special meter whose maintenance significantly increases costs (and therefore the power bill). New smart meters, more highly developed and initially less expensive, could palliate such problems [8].

- The use of smart meters may encourage the residential sector (solar panels, small wind generators…) to participate in distributed generation. Smart meters are a necessary component in such facilities, for the power generated and consumed must be measured by the minute [8].

- In addition to remote management (which may entail substantial savings), distribution companies would be able accurately measure the connection point quality of supply [9]. Calculations of other parameters such as loss coefficients or reactive power would also be more accurate.

- These new meters simplify the detection of grid faults and reconnection after power outages.

[4] See www.energywatch.org.uk/

- Smart metering systems can be integrated with new home automation technologies, providing for the efficient programming of certain types of demand. One obvious example would be the "energy manager", an option offered by EDF (see item 3.1) that enables consumers to plan their demand on the basis of the tariff applicable at any given time.

In light of this new world of functionalities and expectations, why are domestic customers still using electro-mechanical meters? Besides that there is still no clear evidence about the profitability of the change for small consumers, technological immaturity, uncertainty about actual demand elasticity, have up to very recently cast certain doubts on the suitability of the change.

Technical progress and the growing importance attached to energy efficiency are changing this scenario the world over, however. In the European Community in particular the need to replace the old electro-mechanical meters with new smart meters has now been established. Reference is made to advanced metering systems in Directives 2006/32/EC on energy end-user efficiency (Article 13) and 2005/89/EC on measures to safeguard security of electricity supply and infrastructure investment (Article 5). This subject is also dealt with in depth in the paper COM(2006)841, where the generalized use of smart systems is viewed as a tool for intensifying competition on the European energy market.

2.2. Smart thermostats

To date, the installation of smart thermostats is the sole method for limiting consumption at peak hours that has passed the experimental stage and is now in commercial use. Several experiences are underway in the USA [10], [11] and others have been initiated in Canada [12].

2.3. Lighting control systems

Lighting control systems respond automatically to demand management signals by modifying lighting consumption without necessarily cutting it off entirely. They are particularly useful from the energy efficiency standpoint when supplemented with occupancy and/or lighting sensors. A University of Berkeley[5] project implemented in campus offices showed that such systems can lower the lighting power demand by up to 40%. The project cost six million dollars, but yearly savings have been estimated at over one million dollars. Remote-controlled lighting systems are also in place for large-scale consumers, shopping malls, buildings and so on [13]; [14].

2.4. Undervoltage and under-frequency relays

Undervoltage and under-frequency relays are automatic load shedding devices that are tripped when the frequency or voltage signal crosses a (configurable) threshold. Such technology is usually mandatory in emergency services (direct load control). In Spain, for instance, an under-frequency relay must be installed to deliver interruptibility services.

2.5. Microturbines

The market offers a wide variety of products with capacities ranging from under 100 kW up to 500 kW. While microturbines have been used in some pilot demand management programmes, they are not presently an economically feasible option for reserve generation.

2.6. Others

Technological development has opened up a broad spectrum of additional options in this regard [15], [16]. Many of these options are still in an early research and development stage. A few are listed below:

– Flywheels store mechanical energy that can be converted into electric power, making them good candidates for use in demand management. With a response time of around 5 ms, flywheels can only be used for short time intervals (up to 15 minutes). The first flywheels designed to provide support for demand management services are expected to come to market in 2008.

– Ultracapacitators can transfer stored electric power almost immediately, but their use is limited to very short intervals (1 to 60 seconds). Such

[5] http://physicalplant.berkeley.edu/lightingretrofit.asp

power is normally used as a "bridge" during the start-up of some other emergency power source (such as a microturbine).

– Residential consumption record displays provide real-time (or near real-time) information on the cost incurred by a household's main electrical appliances [17].

– Thermal storage systems: The objective is to consume thermal energy at times when the price is lowest. Cold accumulators that use ice encapsulation and storage technology are also presently available.

3. Economic tools

The development of tools such as described in the preceding section, in particular electronic meters, has opened up a wide range of possibilities that enhance customer awareness of efficient market signals. In recent years, a wide variety of economic incentives have been implemented to heighten consumer, especially domestic consumer, involvement in demand management.

Such incentives can be classified under three main categories: tariffs, regulated incentives and market mechanisms.

3.1. Tariffs

Based on interval meters, a wide variety of tariffs have been designed to encourage demand to shift the load away from hours when system costs are highest.

The three most prominent of the various alternatives are:

3.1.1. Real-time pricing (RTP)

The aim of RTP tariffs is to give off short-term pricing signals. Such prices could even eventually include the costs associated with real-time generation/demand balancing. This approach is not normally taken to that extreme, however, and prices are calculated one day in advance for each of the 24 hours of the following day.

Such tariffs are scantly used, particularly among domestic consumers. The earliest programmes featuring this scheme appeared in the nineteen eighties in California as a mechanism designed to reach demand management objectives. This was followed by any number of pilot experiences in the USA. For evaluations of this approach, see [18] or [19]. In some states the default tariff for large-scale consumers includes RTP characteristics.

The FERC [2] describes a few typical RTP tariff formulas:

- Day-Ahead Real-Time Pricing: consumers are informed on a daily basis of the prices to be in effect the following day, to enable them to plan consumption in advance. The Niagara Mohawk experience constitutes one of the earliest examples of the application of this type of tariffs to large-scale consumers. In Chicago a residential project was implemented (ESPP); 1100 service connections had voluntarily requested this formula by 2006.

- Two-Part Real-Time Pricing: in this case part of customers' consumption is exempted from the risk involved in market prices. The practical implementation of this scheme generally entails calculating a baseline demand profile from historical records. Consumption above or below this profile is charged or credited at market prices.

3.1.2. Time-of-use (TOU) tariffs

This is the most common alternative, see [1]. Countless experiences have been carried out in the USA as well as in Canada (Ontario) and Australia (particularly Victoria). The paradigmatic example in Europe is ENEL's "offerta bioraria" [20], in which two time intervals are defined, with the higher price applied on weekdays from 8:00 a.m. to 7:00 p.m. Other examples of domestic TOUs with only two rates are the Economy 7 and Economy 10 tariffs (which require different meters) in the United Kingdom and Spain's 2.0N[6] tariff.

The hours included in the intervals of a TOU tariff may depend on factors such as season of the year or geographic location. Seasons are usually

[6] The 2.0N tariff, also known as the night-time tariff, will come to an end in July 2008. It will be replaced by an "interval tariff" characterized by more low-price hours (14, up from 8), although the discount will be smaller than in the present 2.0N scheme (47% compared to 55%). One of the major differences is in the new day-time surcharge (35% compared to 3% in the 2.0N tariff).

defined before the beginning of the new power year.

3.1.3. Critical peak pricing (CPP)

Critical peak pricing (CPP) is based on the existence of abnormally high prices characteristic of critical situations[7].

Under this tariff formula, a fairly high price is established for power consumed during what are defined to be critical peak periods (CPP). Although many different events can give rise to a CPP, most tend to be associated with the appearance of narrow reserve margins.

Unlike the TOU tariff intervals, critical peak days are not shown on the tariff, but are announced as they arise. Nonetheless, the tariff does usually specify the maximum number of times the device may be applied and the minimum advance notice[8].

The main variations include:

– Fixed period critical peak pricing, (CPP-F): in CPP-F tariffs, the time and duration of the critical interval are predefined, although not the calendar days when critical prices will be billed. The maximum number of days per year involved is usually pre-established.

– Variable period critical peak pricing, CPP (CPP-V): CPP-V tariffs do not specify the time, duration or the day when prices will rise. Calls are normally made on the preceding day. This formula usually goes hand-in-hand with the installation of home automation equipment that automatically regulates consumption when CPPs are called.

– Variable peak pricing (VPP): proposed in New England, it constitutes one of the most recent CPP formulas. As in all CPP tariffs, the valley and plateau prices are determined *ex ante* for each month or season. In the version proposed in Connecticut, the price for each critical peak period is established in terms of the locational marginal prices or LMPs for the load zone. This price is adjusted to include losses and other costs

[7] Critical prices should not be confounded with the characteristic prices for high demand hours (that give rise to the peak prices defined in the TOU).
[8] CPP tariffs may supplement other types of tariffs (TOUs for instance).

normally included in energy component of the tariff (the so-called volumetric charge). The advantage of VPP tariffs is that they send out price signals more closely related to the wholesale market than any of the preceding alternatives.

– Critical peak rebates (CPR): in this type of programmes, customers are charged fixed rates but are paid rebates for reducing consumption during critical periods [21]. These reductions are measured in terms of expected consumption [22].

CPP tariffs may supplement other types of tariffs (TOUs for instance).

Many experiences have been conducted both in the USA [4] and Canada. [23] describes the response level of participants in an Australian pilot programme that included CPP. In Europe, the most prominent example is EDF's "*option Tempo*" [24], which is dealt with in greater depth below because it combines several of the aims pursued by demand response programmes.

EDF's "Tempo" tariff

The "Tempo" tariff combines the principles of time-of-use and critical peak period pricing. EDF's earliest trials with a new time-of-use dynamic tariff date back to 1989. Different versions of the project were launched between 1993 and 1995, but it was not until 1995 when this tariff, christened "Tempo", was commercialized among domestic consumers. Today the tariff is in place for 350,000 residential customers[9] and over 100,000 small businesses.

The Tempo tariff establishes six price levels depending on the type of day (blue, white or red (*bleu, blanc et rouge, les trois coleurs*) in increasing order of price) and the time (with two intervals, the higher price being charged between 6:00 a.m. and 10:00 p.m.).

EDF announces the colour assigned to each day on the evening before at around 5:00. This information is recorded in customer meters, whose leds show the colours for the present and the following day. Information on the next day's colour can also be found on the Internet or requested by e-mail or SMS message.

[9] Customers must apply for at least 9 kVA to qualify for this tariff.

The colours are assigned in accordance with the following structure:

– 22 red days from 1 November to 31 March, from Monday through Friday, no more than five consecutive days at a time;
– 43 white days, from Monday through Saturday;
– 300 blue days.

The present rates for each of the six tariffs are shown below (note that the difference in peak prices between blue and red days is upward of 800%).

Table 1. Tempo tariff rates (www.edf.fr)

Blue days		White days		Red days	
Off-peak	Peak	Off-peak	Peak	Off-peak	Peak
0,0456	0,0566	0,0931	0,1104	0,1728	0,4833

The Tempo tariff has led to substantial reduction in demand on both white (15%) and red (45%) days. Customers have benefited from a mean tariff reduction of 10% with a generally high level of satisfaction. The provision that has prompted greatest discontent is the existence of consecutive red days. That such consecutive application is typical can be clearly seen in Figure 2.

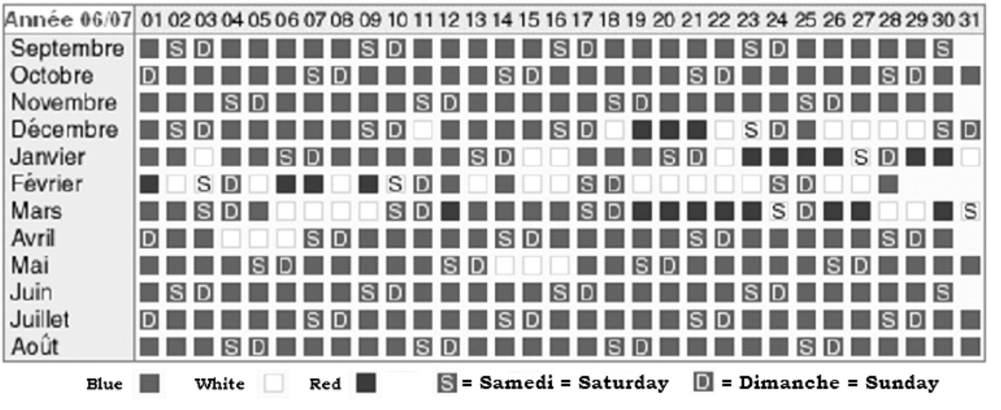

Fig. 2. Types of days: year 2006/2007 (www.edf.fr)

An additional home automated system may be installed to supplement EDF's Tempo tariff. This system not only manages consumption by defining comfortable temperatures (for specific rooms and times), but is inter-connected to the smart meter to program consumption depending on each day's colour.

EJP[10] is another EDF tariff based on TOU and CPP principles. The main feature of this tariff (since January 2007) is that it divides France into four geographic areas, making it possible to define high price days in keeping with regional needs.

The effectiveness of the various alternatives (RTP, TOU or CPP) depends critically on the nature of the system where they are implemented. See [25] for an analysis and comparison of the efficiency of the various alternatives.

3.2. Regulated incentives

Regulators often establish incentives as additional encouragement for consumers to participate in demand management programmes. This type of incentives ranges from the traditional "integrated resource planning" that imposed certain obligations on incumbents, to more or less strict industry objectives. Examples of the latter are the 5% decline in peak demand by 2007 sought (but not met) in California's demand management programme, Energy Action Plan II [26], [4], and Italy's energy efficiency objectives, associated with a white certificate mechanism [27].

Some US states have required non-domestic consumers to either accept a real-time tariff or convert to a time-of-use system. In others, regulators have established incentives to encourage consumers to switch from traditional tariffs to time-of-use arrangements [28].

3.3. Other market mechanisms

Demand side bidding is a mechanism whereby consumers participate in an electricity market or system operation, directly or through a retailer, by submitting bids that prompt changes in their normal consumption pattern.

Certain systems have programmes along these lines in place at this time [29], [30].

[10] Not presently open to new takers.

4. Economic analysis

As a result of the countless pilot programmes implemented since the beginning of the present decade (especially in the USA), the literature contains ample information from which to draw conclusions on the impact of this type of programmes on the cost of service. This is less true in Europe, where experiences have been more sparing and recent; some systems (e.g., Italy, France, Sweden, Spain and The Netherlands) have installed to a certain extent hourly meters at the domestic level, but for the time being, in most cases the primary objective was not demand response management, but improvements in metering procedures, fraud reduction and so forth.

As a rule, demand management is associated with a series of beneficial effects for the overall system costs as well as the environment. The visibility of such effects varies with the country, depending on a series of factors, including most notably:

- Demand growth pattern: demand management can contribute significantly to environmental conservation in systems where the growth in electric power consumption, particularly during peaks, soars year after year. Consequently, the impact is not the same in England, where demand growth is moderate, as in Italy where the mass installation of air conditioning has led to a sharp rise in domestic consumption.

- Generation park characteristics: marginal peak and off-peak generation is of particular relevance, for the chief aim in demand management, as noted above, is to shift peak consumption to lower price times. The effect of demand management on total emissions depends on the emission rate of each of the above technologies (see [31] and [32]).

- Medium- and long-term effects of demand management programmes: demand management programmes can not only shift demand from peaks to valleys, but as a rule they can also reduce total consumption. Nonetheless, lowering the average amount of the electricity bill may prompt a backlash (the so-called rebound effect), encouraging further consumption and concomitant increases in total demand. In such cases, the environment would benefit less from the new consumption patterns.

- Enhanced grid use efficiency: the mitigation of demand peaking translates into a direct savings in transmission and distribution system design costs.

- Emergency network management: AMM, besides constituting a tool to implement interruptibility at all network levels, may allow the low-voltage network operator to improve its service restoration procedures in case of black-outs, by discriminating among different customers according to their needs.

The following is a selection of studies regarded to be particularly valuable, from both the methodological and technological standpoints, for estimating the results of the different alternatives.

- For the USA, interesting analyses are contained in [3], [19], [33], [34]. Southern California Edison has published detailed analyses of the results of thermostat and intelligent lighting pilot programmes [35]. Likewise in the American context, Faruqui [4], [36] has analyzed demand-side ability to respond to dynamic price signals, while [22] has evaluated the results obtained with CPP tariffs.

- In Canada, the Ontario Energy Board Smart Price Pilot reduced peak demand by from 5.7% (TOU) to 25% (CPP) on critical days [21], [37].

- In Australia, NERA [38] has conducted a detailed cost/benefit analysis of the first phase of electronic meter installation.

- In Europe, analyses have been published on case studies of Denmark [39] and the UK [40] on the evaluation of the various options afforded by electronic meters. A pilot project implemented in Sweden to measure demand-side response capacity is also relevant in this context.

- Peak load reductions may allow distributors avoiding the cost of having to reinforce medium- and low-voltage networks. We could not find any relevant study of the potential savings that demand response might imply for transmission network investment. There have been analyses that could be taken as a good reference point linked to the study of the beneficial impact of distributed generators. Precisely, one of them, [41], is currently been extended in the context of the GAD project[11] to

[11] www.proyectogad.es (in Spanish only).

valuate the potential savings for the Spanish networks due to the implementation of advanced demand response programs [42].

None of the experiences in place can be exported *in toto* to other systems, in view of the particularities that characterize each. The potential of any given electricity demand response mechanism depends largely on:

– the specific physical properties of the electricity system in question: potential savings that can be obtained depending on generation technology (where the peak and off-peak generation price spreads play a key role) or grid characteristics[12];

– the capacity of electricity system agents (primarily system operators and retailers) and the regulator to furnish consumers with tools (equipment and incentives) that eliminate structural and economic barriers, furthering demand-side action;

– and lastly, demand-side ability or willingness to implement such tools.

The scope of economic analyses may be either global, seeking to quantify net social benefit, or individualized, seeking to evaluate the benefit for each of the actors involved (the main stakeholders being the end consumer, the retailer and the grid owner). The second approach is fundamental to detect whether split incentives are in place.

The cost-benefit analyses conducted from the standpoint of net social benefit tend to attach importance to investment[13]. However, the individualized study reveals the presence of the aforementioned split incentives. Moreover, in case just one agent invests in the new technology, there would be a potential situation of free-riding. Where none of the stakeholders (grid managers, retailers, consumers or all of them together) takes the initiative, the regulator is obliged to consider the convenience of intervening either by imposing investment measures or introducing further economic incentives.

[12] For instance, in a hydroelectric system with no capacity constraints such as Brazil's, shifting loads from one period to another would not, at first glance, appear to entail any advantage whatsoever.
[13] Analyses leading to the opposite conclusion can also be found in the literature (see [43]).

5. Regulatory design

Along with the economic analysis of demand response management, the final issue addressed in this review is the regulatory design required to implement a model of this nature. This matter turns to be a key issue not only for the success of these demand response tools to achieve relevant efficiency gains, but also in those electricity systems that have opted for liberalising the supply activity, for the adequate development of the retail market.

We could not find many good references facing this issue. [5] and [44] have reflected briefly on some of the challenges that regulation should address. [2] and [4] have discussed the relevant regulatory barriers, the latter focusing on the situation in California. [45], in turn, has discussed certain relevant regulatory considerations, albeit collaterally.

The factor largely conditioning regulatory policies on the introduction of new meters is the degree to which the metering service is to be unbundled. In a context in which the regulator's decision is not to clearly unbound the distribution and retailing activities (as it is the case of almost all the Latin American systems or many North American ones) the discussion is circumscribed to the field of the traditional cost-of-service regulation, i. e. which the meters standards should be, how to defray them the and which incentives for distribution or regulated retailers could be implemented to enhance demand response.

However, smart meters happen to be unavoidably one of the key vehicles to drive retail market development. In this new framework, an adequate regulatory design of the metering service (involving meter purchase, installation and maintenance, data storage, and data management and provision to different agents) is crucial. If this task is not properly faced, the meters can conversely be the "perfect" tool for incumbents to set additional entry barriers for new suppliers.

There is a long list of open issues still pending that should necessarily be faced. The main ones are briefly outlined next.

5.1. Compulsory roll-out versus liberalised updating

Generally speaking, two models for the introduction of smart metering are in place in European Union Member States:

– the deregulated model in which the installation is left to the free initiative of market agents;

– the regulated model in which the regulator sets the precise rules in which smart meters can or have to be installed, together with the way to remunerate the corresponding costs.

5.1.1. The liberalised approach

The main advantages of this alternative are:

– the choice of technology is left, as a rule, to those best positioned to make the decision (retailers and the consumers themselves). The introduction of competition constitutes an incentive for agents to seek new value added technological and logistic solutions;
– the risk of choosing a technology that is not equally satisfactory for all is avoided;
– it does not disturb companies' plans, contacts or investment.

This is the alternative adopted in the United Kingdom and it appears to be also the alternative to be implemented in Germany.

In the United Kingdom, after doubts were raised about the procedure implemented, a public inquiry was conducted to evaluate the suitability of the alternative. Besides the obvious standardization matters, which we review in the next section, this process identified certain barriers that in practice were hindering the introduction of new metering systems [8]:

- Risk of abandonment: the ease with which customers can change retailer, along with the new retailer's freedom to choose to use the customer's existing meter or otherwise, meant that retailers' risk of not recovering their investment was inordinately high. Such risk could lead either to a lack of investment or to attempts at accelerated recuperation.

A possible solution to this problem would include meter standardization, along with retailer commitments to use previously installed meters (if standard-compliant). Investment risk could also be reduced by seeking some manner of financing to support the change process.

- Visual inspection: this is a problem specific to regulation in the United Kingdom, where the mandatory bi-annual visual inspection of meters partially might cancel the possible savings afforded by remote readings.

Additionally, as it is the case when it comes to remove regulated energy tariffs, the regulator should in some way design a kind-of "last-resort metering supplier", in order to guarantee minimum and universal metering quality standards.

5.1.2. The regulated roll-out

A way to guarantee the installation of smart meters is to pass legislation requiring the metering responsible party (the network operator, the retailer or even an alternative agent exclusively devoted to this task) to measure consumption by means of metering systems that comply with certain standards (this is for instance the case of the Ontarian, the Italian or the Spanish systems). Such standards need not be particularly restrictive (they might refer to the communications interface only, for instance).

The chief advantage of this option is that it simplifies the mass introduction of new systems, such as in Italy. It also provides for economies of scale in meter purchase and installation.

This alternative entails making a key decision: the choice of the technology to be installed. Note that the consequences of a mistaken decision would be ultimately borne by consumers. Moreover, it is difficult to reflect the diversity of different types of customers' needs in the decision adopted.

This formula is not incompatible with a certain degree of metering service unbundling, for instance, the facility installation and ownership could be integrated within the grid service, maintenance, reading and data management could be made subject to competition.

In the case retailers are the metering responsible parties, this approach may generate some risk for retailers who would have no guarantee of recovering their investment if the regulations allow customers to switch companies shortly after meter installation (as in the United Kingdom).

The way to properly design the authorization and financing procedures is not an easy task. A scheme could be established in which metering responsible parties would be allowed to seek their own solutions, subject to some mechanism which would in practice limit costs. Unfortunately, there is not a lot of useful literature on this issue. The regulator of the state of Victoria has reflected on the subject [43]. Legislation enacted in Ontario contains provisions for financing electronic meters [44].

If the introduction of a metering system is to be regulated, the order in which installation is to take place will have to be established. The co-existence of different hourly rates for some time (for customers with and without new meters) would entail the temporary discrimination of certain customers.

5.2. Standardization

In any case, no matter if the decision to install new meters is left to the market or determined by the regulator, this latter has to define which the minimum standards of the new meters should be.

A number of initiatives are in place for establishing the minimum requirements that such metering equipment should meet: [38], [47], [48], [49] and [50]. As it has been pointed out, in the liberalised model, the definition of minimum standards may be essential to preventing the appearance of retail market entry barriers, or even to avoid incurring in unnecessary costs[14].

Unfortunately, in many cases regulation is already late: the minimum standards of the new meters are still being discussed (or what it is worse, the

[14] For example, in the Spanish case, the size of the meters can turn to be a problem, since in most of the city households in the big cities buildings the traditional electricity meters are often "tightly" placed in a room in the basement. If the new meters would be of a larger size, there might not be room enough to place them, implying that costly works should be required (one of the solutions actually conceived is to install some of them in the ceiling of the room). This fact has also implications regarding certain types of smart meters already developed (the ENEL ones, for instance), since it would be of no use to place a led screen in the meter itself, since the client cannot interact with it on a regular basis.

discussion has not even begun) and at the same time many network operators are already installing new meters without taking into consideration any standard and therefore conditioning any future decision of the regulator[15].

5.3. Roles of the distributors and retailers

One of the key points to be addressed from the regulatory standpoint is the role played by the distributor and the retailer in these new services. Unfortunately, as far as we know, no prior experiences have seriously taken this factor into account, since to date most have implemented what might be termed the "regulated retailer" model, which does not clearly distinguish between the two roles. The delimitation of each actor's functions and services is particularly relevant when defining the possible service interruptibility model for residential demand, as well as the inclusion (if reasonable and possible) of the tariff of last resort in such service.

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