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DEMAND RESPONSE IN BLOCKS OF BUILDINGS: OPPORTUNITIES AND REQUIREMENTS¹

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Abstract. Increased Demand Response (DR) is essential to fully exploit European power systems, which in turn is an absolute prerequisite for meeting European targets related to energy efficiency and climate change. Essentially DR involves consumers reducing or shifting their electricity usage during periods of peak electricity demand in response to time-based tariffs or other forms of financial incentives. The opportunities for realising demand response vary across Europe as they are dependent on the particular regulatory, market and technical contexts in different European countries. Nevertheless successful DR programs are becoming increasingly common for large industrial customers. However DR programs aimed at small and medium scale customers have mostly failed to meet their expected potential. Blocks of buildings offer more flexibility in the timing of energy use, local energy generation and energy storage than single buildings and as such researchers and the energy industry are beginning to consider how blocks of buildings can operate collectively within energy networks to enhance the effectiveness of DR programs. This paper identifies the opportunities and technical, market and regulatory requirements for

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realising DR services in blocks of buildings in the European context. The work presented is part of an ongoing European Horizon 2020 project entitled Demand Response in Blocks of Buildings.

Keywords: Demand Response (DR), block of buildings, electricity systems, Electric Utilities, Energy networks

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1. Introduction

The European 2030 climate and energy framework adopted in 2014 sets three key binding targets for the year 2030: At least 40% cuts in greenhouse gas emissions (from 1990 levels); at least a 27% share for renewable energy; and at least a 27% improvement in energy efficiency (European Commission 2016a). Increased Demand Response (DR) is an absolute prerequisite for meeting these European energy efficiency and climate change targets. Essentially DR involves consumers reducing or shifting their electricity usage during periods of peak electricity demand in response to time-based tariffs or other forms of financial incentives. The opportunities for realising demand response vary across Europe as they are dependent on the particular regulatory, market and technical contexts in different European countries. Nevertheless successful DR programs are becoming increasingly common for large industrial customers. However DR programs aimed at small and medium scale customers have mostly failed to meet their expected potential. Blocks of buildings offer more flexibility in the timing of energy use, local energy generation and energy storage than single buildings and as such researchers and the energy industry are beginning to consider how blocks of buildings can operate collectively within energy networks to enhance the effectiveness of DR programs (Ala-Juusela et al 2016). This is because blocks of buildings offer more flexibility in the timing of energy use, local energy generation and energy storage than single buildings (Crosbie et al 2016).

The potential value of DR in blocks of buildings depends on the telemetry and control technologies embedded in the building management systems currently deployed at any given site and the potential revenue sources: both of which vary according to specific local and national conditions (Thomas et al 2009, Crosbie et al 2006). In this context, to encourage the growth of DR services' and reap the potential benefits of DR, it is necessary for current research to demonstrate the economic and environmental benefits of DR for the different key actors required to bring DR services in blocks of buildings to market. This is the aim of a current EU funded project called "Demand Response in Blocks of Buildings" (DR BOB) which is co-funded by the EU's Horizon 2020 framework programme for research and innovation. The research presented in this paper is based on the work conducted in the initial stages of the DR BOB project to identify the opportunities and technical, market and regulatory requirements for realising DR services in blocks of buildings in the European context.

Following this introduction, to set the context, section two of this paper outlines the drivers of demand response in blocks of buildings in Europe. In section three of the paper different types of DR programs are defined. Finally section four analyses the potential of each of the DR programs to be deployed in blocks of buildings pointing to the regulatory and market conditions required.

2. The Drivers of Demand Response in the EU

The three key binding targets for the year 2030 adopted by the EU in 2014 build on the 2020 climate and energy package which set targets of a 20% reduction of greenhouse gas emissions, raising the share of EU energy

consumption produced from renewable resources to 20% and a 20% improvement in energy efficiency compared to 1990 levels (European Commission, 2015). As illustrated in Figure 1 energy consumption in the built environment (households and services sector) forms a major portion (40.3 %) of the total energy consumption in EU member states (European Commission, 2014). Thus, energy use in non-industrial buildings offers the potential to make a significant contribution to achieving Europe’s targets for climate change and has a very significant impact of peak energy demand. As such it provides a huge largely untapped potential for demand response, offering an avenue for energy aggregators DSOs and TSOs to further manage energy demand.

In efficient energy markets during the hours of peak energy demand energy prices are at their maximum. In relation to electricity, this is because when national electricity demand is low, supply comes from relatively inexpensive base load generation and when demand is high and base load generation is exhausted, supply comes from relatively expensive peaking generators (Crosbie et al 2015). This creates rapidly fluctuating energy costs throughout the day in wholesale electricity markets that peak at times of peak load/ demand (see figure 2). This impacts on the ability of European Industries to compete globally (Capgemini, 2008). Large peaks in energy demand also creates problems with grid reliability, stability and efficiency (Crosbie et al 2015).

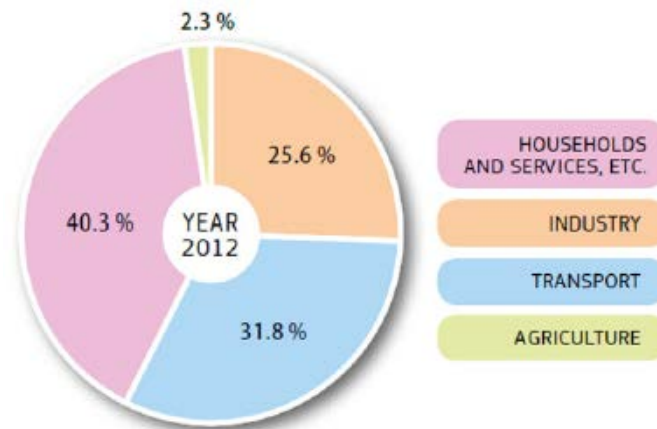


Fig. 1: Breakdown of energy consumption by sector in EU-28 in 2014 (Source European Commission, 2014)

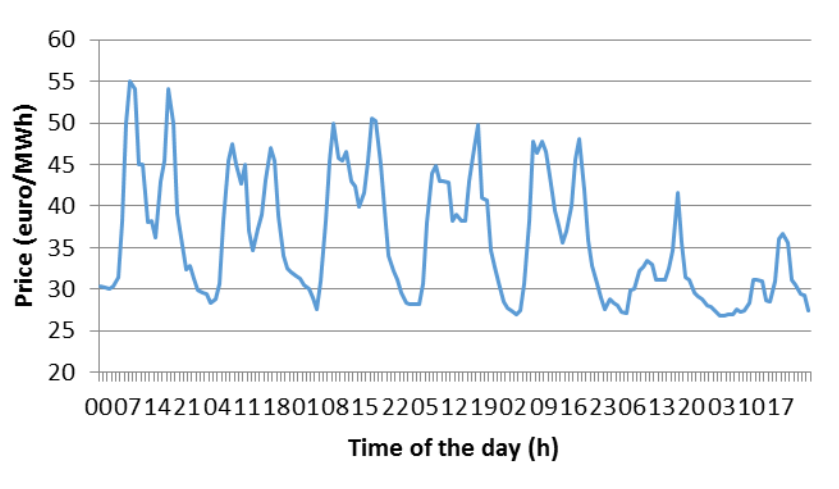


Fig 2.Example of the fluctuation in EU energy markets: Nord Pool Spot prices during an average week (Monday to Sunday) in Finland in February (Source Crosbie et al 2015)

The growing share of intermittent distributed renewable energy generation in Europe (see Fig 3) is exacerbating the problems created by peak demand in terms of grid security and stability and energy costs. The strong EU policies backing the introduction of renewable energy generation has encouraged this growth in distributed renewable energy which stood at 16 % in 2015. In 2015 25 EU countries were meeting their 2013/2014 interim renewable energy targets arising out of the 2020 climate and energy package. This means that the EU has three times more renewable power per capita in Europe than anywhere in the rest of the world. Renewable energy sources are also likely to continue to grow significantly in the near future with the 2030 climate and energy framework set to encourage an increase in the share of renewable to at least 27% by 2030.

To invest in more capacity is becoming an increasingly expensive option to the challenges created by growing peak energy demand and renewable energy sources, both for utilities and consumers, requiring heavy expenditure on power generation, transmission and distribution capabilities (Capgemini, 2008, Crosbie et al 2015). For example, it is estimated that European electricity networks (EDNs) will require six hundred billion Euros of investments by 2020, with two thirds of these investments required in Distribution networks (Eurelectric 2013). By 2035 the distribution share of the overall network investment is estimated to grow to almost 75 percent and to 80 percent by 2050 (Eurelectric 2013). When thinking about these figures it becomes clear that the prospect that DR solutions to reduce peaks in energy demand is significant. Thus, in recent times, the emphasis is on developing novel solutions which can align the energy demand to the energy supply in real-time (Patteeuwa et al, 2015; Bergaentzlé, 2014). With distributed renewable energy generation and real-time pricing and demand response, the end user can actively participate in energy markets.

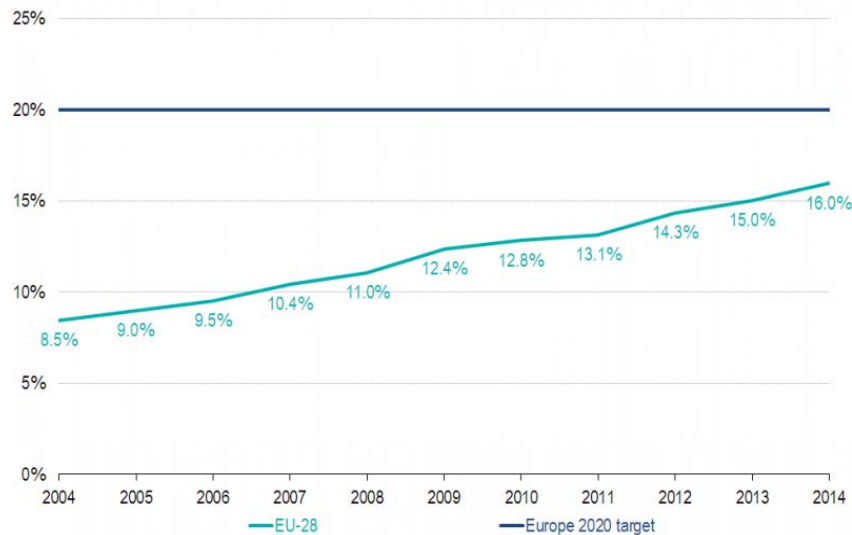


Fig. 3: Share of energy from renewable sources in gross final consumption of energy, EU-28, 2004-2014 (source Eurostat).

Given that more than 40% of the energy demand from buildings is in the service and domestic sector it would seem that the potential of DR in blocks of buildings is significant and the increasing penetration of DER and climate change targets are significant drivers of demand response. However to fully realise the potential for DR in blocks of buildings, it will be necessary to identify which types of DR response programs are applicable to blocks of buildings in different technical market and regulatory contexts as discussed in the following sections.

3. Demand Response program archetypes

Although DR programmes are to a certain extent unique - having to fit specific geographic and regulatory requirements - common elements and characteristics can be identified. Earlier research identified seven main DR program types (OpenADR Alliance 2016) and this work forms the basis of the types of DR programs discussed here. However those DR programs involving cost and pricing signals for typical DR programs involving variable tariffs - such as traditional Critical Peak Pricing (CPP), Real-Time Pricing (RTP), Time of Use Pricing (TOUP), Two-Tier Pricing (2TP) and various combinations thereof, can be combined. Therefore to simplify the analysis that follows, DR programs involving these pricing signals have been merged into a single 'Generic Variable Tariff' DR program.

Generic Variable Tariff (GVT) DR program: GVT DR programs provide variable pricing structures for electricity which are designed to reduce consumption during periods of high wholesale market price or during known periods of system contingency, and encourage consumption in times of low wholesale market price. In a GVT program, hourly or sub-hourly prices for electricity consumption (possibly having several tiered levels) will be advertised to DR participants by the program sponsor at least one hour in advance, typically one day in advance - and in some cases even months in advance. Although prices are variable and reflect market conditions, maximum prices may be negotiated in advance. Typically they are linked to day-ahead market conditions and seasonal market changes. Such DR programs are especially useful for planning and scheduling controllable resources such as smart appliances and the charging times of electric vehicles. There are no minimum load restrictions and the targeted participants may be residential, commercial or industrial.

Capacity Bidding DR Program (CPB): A DR program which allows a load resource and its owner to identify how much load it is willing to curtail for a specific price to the DR program sponsor requiring the demand reduction. Although CPB contracts may be negotiated by the resource owner and the sponsor well in advance, real-time negotiation may also be performed e.g. based upon balancing (real-time) market conditions to help cover unplanned contingencies such as loss of expected renewable availability due to inaccurate weather forecasts. Notice periods for activating negotiated CBP contracts are typically one hour minimum and are mostly one day-ahead. Such DR programs are especially useful for deferring planned operation of large/medium sized industrial loads, where enforced loss or change of production is recouped through pre-commitment contracts and subsequent activation payments. There are minimum load restrictions (typically 100 kW) and the targeted participants may be load aggregators, commercial or industrial.

Direct Load Control (DLC) DR Program: A DR activity in which the program sponsor remotely controls a participant's electrical equipment on short notice (normally several hours). Typically this would involve temporarily reducing temperature, humidity or air pressure set points in home and building HVAC equipment to achieve a short-term reduction in electricity demand. Once the DR event has passed, conditions are automatically returned to nominal levels. Financial incentives are paid for enrolling in the DR program and may also include bonuses when DR events occur. It is possible for a participant to opt-out of a given DR event for a financial penalty. There are no minimum load restrictions and the targeted participants may be residential or (small) commercial.

Fast Dispatch / Ancillary Services (FD/AS) DR Program: A DR program which provides incentive payments to participants for fast load reductions (or increases in some cases) during emergency conditions on the grid that require immediate action to prevent loss of transmission lines, distribution equipment and/or generator tripping which can negatively impact the reliability of the wider system. Contracts are negotiated in advance and often activated without prior warning, as load needs to be shed (or increased) at very short notice (≈ 2 seconds for frequency regulation). Such DR programs are especially useful for large/medium sized industrial loads where enforced loss or change of production is recouped through pre-commitment contracts and subsequent activation payments. There are minimum load restrictions (typically 100 kW) and the targeted participants may be load aggregators, commercial or industry. This DR program is very similar to the CBP DR program, but timescales for

real-time response and reliability of load change are much more stringent (and participation incentives much larger).

Distributed Energy Resources (DER) DR Program: These are DR activities which are utilised to smooth integration issues for Distributed Energy Resources (DER) into the wider electricity grid, e.g. to help curtail over or undersupply issues. For most implementations of this DR program, some form of storage and/or a dispatchable² DER are required. The DR participant responds to day-ahead pricing signal incentives from the sponsor to either increase or decrease its nominal load at requested times during the day, using batteries, flywheels or other forms of energy storage or by dispatching a DER for a particular time period when it would not normally do so. This allows the DR participant to modify its nominal load profile in accordance with the sponsors' incentives (which are often linked to intermittent availability of renewable energy elsewhere in the grid). There are no minimum load restrictions and the targeted participants may be residential, commercial or industrial.

4. Potential of DR Programs for Blocks of Buildings

The different types of DR programmes outlined in the previous section all have potential for DR in blocks of buildings. However some may be expected to be deployed more easily in a wider variety of situations than others due to significant variations in their technical, market and regulatory requirements.

Table 1 below presents an assessment of the different types of DR programmes for deployment in blocks of buildings based upon an estimation of the level of effort required and technical and regulatory considerations related to the implementation of each DR program. Note that since all DR programs require an existing Advanced Metering Infrastructure (AMI) and DR ICT infrastructure, this is not stated as an explicit technical requirement.

Table 1. Technical, Market and Regulatory Requirements for DR Programs block of buildings potential

DR Program	DR Incentive and Impacts	Technical Requirements	Regulatory and market requirements	Block of Buildings Potential
General Variable Tariff (GVT)	Low to medium economic benefit to participant, continual peak-to-peak reduction	Schedulable / controllable devices or Electric vehicle (EV) charge points, Optimizer, Human-machine interface (HMI), Building management system (BMS) or Home area network (HAN).	Relevant variable tariffs	Very High
Capacity Bidding DR Program (CBP)	High economic benefit to participant, sporadic peak reduction	Sheddable load of 100 kW or more, HMI	Relevant CBP DR product and load aggregators	Low
Direct Load Control (DLC)	Medium economic benefit to participant, sporadic peak and energy usage reduction	HVAC with appropriate control system or other suitable load, HMI, BMS or HAN	Relevant DLC product and load aggregators	High
Fast Dispatch / Ancillary Services (FD/AS)	Potentially very high economic benefit to participant, sporadic peak reduction	Fast sheddable load of 100 kW or more, Plus high-speed and reliable telecontrol & telemetry interfaces OR frequency sensitive / frequency aware loads	Relevant FD/AS products and load aggregators	Very Low
Distributed Energy Resources	Medium to high economic benefit to participant, continual	Dispatchable DER, Storage, Optimizer, HMI, BMS or HAN	Relevant variable tariffs allowing renewable energy self-consumption and	Medium

² Dispatchable renewable energy refers to sources of renewable electricity that can be dispatched at the request of power grid operators or of the plant owner; that is, renewable generating plants that can be turned on or off, or can adjust their power output accordingly to an order.

(DER)	peak-to-peak reduction		decentralised storage.	
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The most favourable DR programs according to this initial evaluation are GVT, DLC and DER. This is principally because in most (not all) blocks of buildings have some controllable appliances (e.g. washing machines and EV chargers etc.) and HVAC systems for climate control (temperature and humidity). Since market conditions in most EU countries already support simple on-peak and off-peak tariff structures – and many are moving towards RTP pricing structures - the basics for implementing GVT and DLC DR Programs are present, even if manual implementations are required. In addition, in many modern buildings, distributed energy generation is also present (typically in the form of PV panels and/or a CHP plant). Therefore a DER DR program also seems favourable, albeit slightly less so due to the additional need for storage and day-ahead signal from the DR sponsor.

The main reason for less favourable conditions for the CPB and FD/AS DR programs is the need for a controllable resource which is large enough to be activated (at very short notice in the FD/AS case). This is less likely to be available in a block of buildings. However, in many cases it is most likely that hybrid combinations of the DR programs outlined in section 3 can be considered for a particular area. For example, recent works by Zhou et al. (2015) and Patteeuwa et al. (2015) have shown that by aggregation of multiple HVAC systems and the application of co-ordinated controls, it is possible to provide FD/AS-type DR programs to provide demand-side frequency regulation services to support intermittency of renewable generation, e.g. in the presence of fluctuating wind power. The work by Patteeuwa et al. (2015) also considers the use and role of thermal storage units in such applications. These DR approaches are, in essence, hybrid combinations of DLC, FD/AS and DER DR programs which are enabled and supported by appropriate ICT infrastructures and control/optimization systems.

Another possible approach to providing fast ancillary and dispatch services for leveraging demand-side contributions to frequency regulation could also be emerging (Molina-García et al. 2011; Villena et al. 2015). In this decentralised approach, instead of having demands under tele-control by a DR sponsor, loads are equipped with (low-cost) instrumentation which is able to measure frequency directly at the point of supply. They are also equipped with controls which can quickly react to frequency deviations by modulating demand accordingly, without the need for any external signals. If properly implemented, a form of fast-acting demand-side primary droop control can be achieved by participating loads. Follow-up secondary frequency stabilisation using tele-control signals from the DR sponsor can also be used within such a framework ('traditional' DR). With respect to blocks of buildings, then HVAC systems seem to be the most appropriate for this kind of droop control by manipulating temperature and air-flow set-points to obtain fast, short-term reductions in demand (which are not likely to impact occupant comfort if only present for short time periods). This approach avoids the need for fast and reliable tele-control and telemetry interfaces and infrastructures, but requires the development of an appropriate set of technical standards and legislation. However currently seems to be a minimal market with few financial incentives offered for providing such services within the EU. This is currently a barrier to an approach which appears to be emerging as one of the most technically feasible and potentially effective approaches for DR. Current exceptions are the Frequency Control by Demand Management (FCDM) and Enhanced Frequency Response (EFR) services introduced in 2016 as part of a range of demand-side management initiatives for the UK market (Proffitt 2016). FCDM is a tendered balancing service which requires that a load of 3 MW minimum is shed by participants within 2 seconds of the system frequency falling below a preset threshold, for minimum duration 30 minutes. EFR extends traditional primary frequency controls to the demand side in the manner described above, but the product is still in development and the technical and contractual requirements not yet fixed.

An example of how DR involving the control of local energy production are inhibited in some EU countries is the way in which the price paid to individuals and organisations that generate renewable energy is subsidised. Many EU countries have introduced Feed-in-Tariffs (FITs) that guarantee a price for the renewable electricity produced

by distributed energy resources. Two types of tariff schemes are commonly applied: fixed-price FITs (FFITs) which guarantee a fixed price for every unit of produced electricity and premium based FITs (PFITs) which pay a premium on top of the variable market price (Crosbie 2016). *“FFITs do not provide any incentive to produce electricity when marginal production costs are high. Also, costs for balancing intermittent electricity production may be significantly lower with PFITs. Therefore, PFITs provide an incentive to match renewable power output better with marginal production costs in the system”* (Schmidt, 2013). So, for example, in France while recent changes to regulations make self-consumption possible the currently very generous FFITs make this financially unrewarding.

It would seem that within a block of buildings scenario featuring large enough quantities of schedulable devices and controllable loads - along with DER/storage units (e.g. CHP with batteries / hot water tank) - modern optimization and control techniques such as those described by Ogwumike et al. (2016), Short et al. (2016), Patteuwa et al. (2015) and Zhou et al. (2015) – including others - allow for potentially large opportunities for DR in blocks of buildings. A key enabling factor, however, will be the selection and deployment of an appropriate AMI/DR ICT framework to assist with coordinated actions between buildings and blocks of buildings, and the selection and deployment of appropriate local controls and optimisers.

In the case of DER DR it must be highlighted that there are three key barriers to consider when thinking about the potential for the deployment of DER DR in blocks of buildings in some EU countries. Firstly renewable energy self-consumption and decentralised storage are not allowed in all EU countries (European Commission 2016b). Secondly complex and burdensome administrative and authorisation procedures still represent an important barrier for the competitiveness of small-scale self-consumption projects in blocks of buildings where renewable energy self-consumption and decentralized storage are allowed (European Commission 2016b). Thirdly on-line information platforms and applications are so far used in only a few Member States (e.g. Portugal, Hungary, Italy and Sweden) (European Commission 2016b). Thus while several EU countries have introduced facilitated notification procedures for small renewable energy installations such as roof-top PV installations, additional national action is required (European Commission 2016a).

When considering the potential for DR in blocks of buildings the rise of the independent aggregator within European electricity markets is also crucial. As demand response in blocks of buildings will be difficult to capitalise on in those EU countries whose regulatory frameworks discourage or ban their growth. This is especially in the case of Explicit DR programs in which consumers receive direct payments to change their consumption (or generation) patterns upon request, such as what we have called CPD, DLC and FD/AS. This is because most blocks of buildings do not have the level of generation / demand reduction/ storage capacity to engage in many of the current DR products. Consumers, if they are to be engaged in DR need a clearly defined offer, which is clearly beneficial and simple to use. As such they *“require a party with expertise in selling and providing this offer through aggregation. Aggregation service providers (who may or may not be electricity suppliers) are therefore central players in creating vibrant demand-side participation and Explicit Demand Response”* (SEDEC 2015).

In 2015 an analysis³ of sixteen of the EU's member states found six EU member states have commercially active explicit demand response markets; while a further four states had partial opening of demand response markets and two were found to have no current opening of the market for explicit demand response (SEDEC 2015). However, there are considerable barriers in many countries to be overcome before there is an EU market for a solution to enable explicit demand response in blocks of buildings. One of the key barriers being that in most EU countries consumers cannot choose a separate service provider for providing demand response. *“They are*

³ This analysis graded markets according to the four main criteria: 1) Enabling consumer participation and aggregation 2) Appropriate programme requirements 3) Fair and standardised measurement and verification requirements and 4) Equitable payment and risk structures.

restricted to their supplier, or at least need their supplier's permission before working with a third party aggregator. Often the supplier is in direct competition with the aggregator, or may have other reasons to hamper the uptake of Demand Response, and thus has an incentive to block the aggregator from doing business with the consumer" (SEDEC 2015).

The pilot sites in the DRBOB project are situated in France, Italy, the UK and Romania. Of these the markets in France and the UK have commercially active explicit demand response markets, while in the pilot site countries all except Romania have current variable energy tariffs. The findings presented suggest that in the first instance the demonstrations in the DRBOB project should seek to illustrate the potential of existing capacity bidding (across all sites), variable tariffs (UK, France, Italy) and direct load control programs (UK, France) to underpin demand response in blocks of buildings. However, it is also noted that energy tariffs which offer real incentives for demand response and DLC products are not available in all EU countries and these markets will need further development. For demonstration of decentralised fast ancillary and dispatch services, the UK market seems to be most appropriate with some early DR products currently available and others in latter planning stages.

In summary the UK market, at present, offers the largest scope for DR demonstrations at the block of buildings level due to its recent initiatives on the demand side in general. The outputs of the DR-BOB project will therefore include an assessment of potential socio-technical (Grünewald, et al. 2012) and techno-economic (Crosbie et al 2016) barriers to DR deployment in blocks of buildings, to guide less mature market development using the UK market (and its emerging operational and contractual specifications) as a reference point. Following energy studies informed by the social sciences (Crosbie 2006, Crosbie and Baker 2009, Stephenson et al 2010, Grünewald, et al. 2012) the approach adopted will involve in-depth interviews with stakeholders (including facilities managers, building owners and building occupants) to explore the various perspectives, motivations and vested interests which are at play when seeking to implement demand response in blocks of buildings.

Conclusion

The different types of DR programmes discussed all have potential for DR in blocks of buildings. However given the different technical market and regulatory contexts in different EU countries some will be deployed with greater ease in some countries than others. To address the uneven development of the technical, market and regulatory requirements for realising DR services in blocks of buildings the DR-BOB project will seek to identify how mechanisms for DR response from more mature markets could be implemented in EU countries with less mature markets for DR (Crosbie et al. 2016). The results will provide feedback to the market participants with recommendations on how that country could adopt new mechanisms and what value there is in doing so for the different actors involved in the value chain required to bring DR in blocks of buildings to market (Crosbie et al 2016).

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