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Review and classification of barriers and enablers of demand response in the smart grid

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ABSTRACT

Demand for flexibility in electricity systems and the transition to the Smart Grid is increasing opportunities for demand response (DR). However, there are many barriers which prevent the full potential of DR being realised. Unlocking of this potential, through identification of DR enablers, can be aided through systematic classification and analysis of DR barriers. To this end, while previous works mostly focused on individual aspects, this paper develops a comprehensive 'socio-techno-economic' review, classification and analysis of DR barriers and enablers in a Smart Grid context. This provides an intellectual framework which may be used to underpin further work on the study and integration of DR. DR barriers are classified as either fundamental (i.e., relating to intrinsic human nature/essential enabling technology) or secondary (i.e., relating to anthropogenic institutions/or system feedbacks). Fundamental barriers are defined as economic, social or technological, whilst secondary barriers relate to political regulatory aspects, design of markets, physical (electrical network) issues, or to general understanding of DR. Subsequently, associated enablers for the defined barriers are suggested. Consideration of technical and commercial/social aspects for both power system and information and communication technology (the "internet of things") domains provides a foundational contribution to improve understanding of DR within the Smart Grid paradigm. Finally, the complexity resulting from connections between various barriers, enablers and the energy system generally, and the existence of the signature characteristics of complex systems is acknowledged and implications discussed.

1. Introduction

The need for increased flexibility in modern, low carbon electricity systems to maintain economic and secure operation has been well-documented [1,2]. In this respect, demand response (DR) is often considered a particularly suitable source of such flexibility, and one of the main components of the Smart Grid [3]. DR may be described as change in electrical energy usage by end-use customers from their normal consumption patterns, in response to some signal [4], typically an economic one, but not necessarily (e.g., it might be an environmental signal [5]). It may be based on direct/explicit control, or on indirect control via a price signal [6]. Directly controlled DR is typically used for system/network issues as reliability and speed of response is paramount in these situations. Price-activated DR is typically used in energy markets [4]. In the existing literature, the benefits of DR have been recognised in relation to the increased efficiency in grid and generation investment and in operation efficiency, particularly in systems with high renewable/distributed energy integration [7,8]. At the same time, DR has been appreciated as attractive, due to prevalence of DR potential, in domestic, commercial and industrial premises [9–11], and the lack of necessary substantial additional investment. However, due to the highly distributed nature of DR, which is a structural characteristic of the developing Smart Grid, the intrinsic and complex relationship with (heterogeneous, unpredictable, complex) people, and the requirement for enabling technologies, there are significant barriers to the adoption of DR schemes. Identification of these barriers and associated enablers is key to identifying how to overcome them, and increase the prevalence of DR.

In the remainder of the paper the existing literature on the barriers to DR and related literature on the barriers to energy efficiency (EE) is reviewed and the contribution of this paper is outlined in Section 2. Then, the fundamental and secondary DR barriers are classified and analysed in Section 3, before possible DR enablers are detailed in Section 4. Subsequently, in Section 5, the described barriers and enablers are summarised and the relationship between described barriers and enablers is discussed. Finally, in Section 6, conclusions from the work and resulting policy recommendations are detailed.

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2. Existing literature

2.1. Barriers to demand response

There are several works in the literature addressing the issues/ challenges/barriers related to DR. An early work covering challenges/ barriers to DR is [7]. This work noted several key challenges to DR adoption. One was the lack of information and communication technology (ICT) infrastructure. Whilst this may be considered decreasingly relevant as developments in computing and Smart Grid ICT technologies enable DR [12], deficiencies in sensing, computing and communication/actuation for DR can be expected to hamper deployment for some time. Other barriers relate to the inter-related challenges of lack of understanding of DR and its system value, general complexity and the lack of appropriate market structures for realising the value of DR. The lack of appropriate market structures was also highlighted as a barrier in [13], in which barriers were regarded mostly as products of the required but unrealised changes to relevant institutions (such as markets). Such institutions are usually slow to adapt to advancements in areas such as aggregator functions [14] and communication infrastructure [15], which render restrictive rules on minimum unit size and telemetry less relevant. Kim and Shcherbakova offered some fresh perspective through the recognition of behavioural and informational consumer-related barriers, highlighting the often under-appreciated importance of the energy consumer, as a central actor in DR provision [16]. Most recently O'Connell et al. and Nolan and O'Malley offered comprehensive reviews of the issues around DR including analysis of challenges/barriers [8,17]. Key contributions here, with respect to previous work, are the foci on challenges related to DR markets, behaviour and business cases. Reinforcing the importance of appropriate market structures O'Connell et al. also highlighted the lack of market mechanisms, and regulation which prevented cost reflective market prices being passed through to the consumer [8]. A particular issue is agreement on how DR can be measured, and hence remunerated, i.e., what should be the baseline for any DR action [17]. Lack of market mechanisms, together with understanding of the potential value of DR, is further highlighted as a barrier to DR [17]. This can be understood as a lack of a business case, highlighted as a substantial barrier in its own right [18]. In addition to market/value barriers O'Connell et al. offers fresh and necessary perspective on previously underappreciated social elements, which is particularly relevant to DR from residential and small commercial consumers [8]. Specifically, O'Connell et al. highlights that consumers are economically rational to only a limited extent, and that various other priorities, such as comfort and convenience, can dictate behaviour [8]. This vein is furthered by Bradley et al. who define a framework of 'consumer' barriers based on findings from a UK pilot study [19]. Considering more physical aspects, the possibility of barriers related to network capacity have been highlighted, if DR synchronises demand (e.g., in response to a price signal) and results in loss of load diversity and violation of network capacity limits [20].

As demonstrated, the literature on DR, and the barriers (and, implicitly, enablers) for DR, is growing. In this literature technological aspects are appreciated but not systematically explored and market elements are central. However, a coherent and comprehensive classification of DR barriers, in particular one including analysis of social/ behavioural aspects is missing. Such a classification may be informed, to some extent, by reference to the more developed literature on another important demand side measure, i.e., EE.

2.2. Barriers to energy efficiency

Given the variable nature of demand for, and the potentially multiple purchasers of, DR it is characterised by a dynamic and "smart" interaction with markets and by a greater role of Smart Grid technology. Although EE is not dynamic or "smart", the literature on EE may be useful to inform analysis of the more fundamental economic and social elements. An early work in the EE area [21] studied the 'paradox' of gradual diffusion of apparently cost-effective EE technologies. This work made the important observation, derived from the field classical economics, that 'barriers' could be categorised as market failures or non-market failures (alternatively, market barriers). In the first case the barrier is due to a failure of a market to operate properly. Thus the barrier can be removed by improving the functioning of the market. In the second, the barrier is due to non-(classical) economic reasons. Sorrell builds on this separation of barriers into market and non-market failures, by defining barriers as: (i) economic; (ii) behavioural; and (iii) organisational; although the typology is not exclusive, and barriers may have multiple and overlapping aspects [22]. Moving into literature on electricity demand reductions more generally, behavioural aspects are attracting further interest more recently. Chiming with the realisation of the importance of social aspects to DR, especially for residential and small commercial consumers [8], the uncertainty on consumer preferences (which are often time-variant and inconsistent; i.e., economically irrational) has been highlighted as a particularly intractable barrier to exploitation of DR [23–25]. Emerging from this literature, and also useful for DR, is therefore a broad classification of the fundamental barriers to EE as either economic (market failures and market barriers) or social (behavioural and organisational barriers). Though it should be highlighted that the complexity of the relevant systems means that such classes are interrelated [25].

2.3. Contribution

The contribution of this work is to address the lack of a systematic analysis of the 'fundamental', and derivative secondary, barriers to DR in the current literature on DR challenges/issues/barriers, which is crucial if the penetration of DR, which may be the most cost effective source of flexibility, is to be increased. As reasoned in Section 3.1, fundamental barriers can be understood as barriers which relate to intrinsic human nature (social/economic barriers), and to essential enabling technology (technological barriers) in a Smart Grid context. Such barriers are relevant to DR from all sectors of electricity consumers (industrial, commercial and residential). These fundamental barriers (and associated enablers) cover power system and ICT technical and commercial/social aspects, ensuring full coverage of relevant perspectives of the Smart Grid vision. This comprehensive 'socio-techno-economic' classification and analysis provides an intellectual framework which covers the fundamental aspects of DR, on which analysis of specific DR schemes can be based. Recognising the importance of more practical DR barriers, secondary barriers are also examined. The broad classifications and hierarchy of DR barriers (and, hence, enablers) is demonstrated in Fig. 1. This comprehensive classification may be used to underpin further work on the study and integration of DR, and thus be a useful contribution to the field.

3. Barriers to DR

As noted in Section 2.2, literature on EE defined barriers as economic, behavioural or organisational [26]. The common factor in

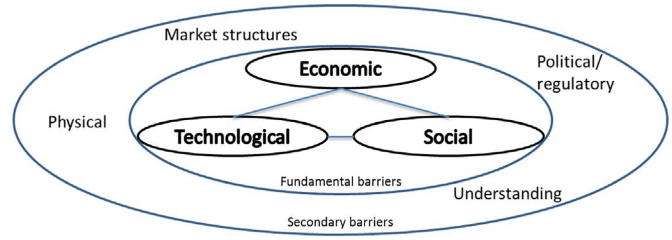

Fig. 1. Classification and hierarchy of DR barriers.