



Future potential for DSR in GB

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Future potential for DSR in GB

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Executive Summary

DECC has commissioned Frontier Economics, with support from Sustainability First, to review the potential for demand side response (DSR) in the electricity sector to 2035.

DSR in the electricity sector is growing in importance but there are large uncertainties

The move to a low-carbon economy is likely to increase the demand for DSR, as generation from intermittent sources increases, and the electrification of heat and transport increases overall and, potentially, peak demand. At the same time, this growth of potentially flexible load and the roll out of smart meters may increase the supply of DSR, particularly in the household sector.

While there is significant potential for DSR, there are also considerable uncertainties around its current potential, and how it will develop over time.

Integrating DSR into DECC's modelling will help DECC explore these uncertainties and understand the consequences.

As well as providing relevant information that could inform future policy development, this report will be used to help develop DECC's Dynamic Dispatch Model (DDM) and inform DECC's modelling of the levelised costs of DSR. In parallel with this report, Lane Clark and Peacock (LCP) have undertaken work to extend the functionality of the DDM to cover DSR.

Modelling should consider the interactions between DSR uses across the whole electricity system.

There are a wide variety of potential uses for DSR. For example, the system operator can use DSR to balance electricity supply and demand, both on very short timescales (such as for frequency response) or longer periods (such as the use of the Capacity Market to ensure periods of high demand can be met). At the same time, by reducing peaks on the transmission and distribution networks, DSR can reduce reinforcement costs for the TNO and DNOs. In addition, suppliers may use DSR to reduce the wholesale costs faced by their customers, or reduce their exposure to imbalance charges. These different uses for DSR have different requirements for load-shifting (in terms of the **location** of assets, **notice period** required to initiate DSR, **duration** of load-shifting, and **frequency** of events required).

As a result, some sources of DSR may be particularly well suited to certain uses, and less suited to others. Where the same source of DSR could supply multiple uses there may be conflicts (increasing the cost of DSR for a given use due to competition to sign up sources of DSR) or synergies (where the cost is reduced due to cost-sharing across different uses). DSR called for one use (for example, wholesale cost avoidance) may additionally increase or decrease the requirement

for DSR in other uses (for example, network reinforcement cost avoidance). These interactions mean that it is important to model DSR holistically, rather than considering one use in insolation.

It is also important to represent the impact of market arrangements in the inputs to the modelling (although this is an area under active discussion, with considerable uncertainties for the future). For example, if market rules were to give local networks priority access to DSR, this could reduce the supply of DSR for other uses. Inputs to the DDM (such as whether a particular form of DSR is available for a particular use) can be flexed to consider the consequences of such rules.

Under the broad definition provided for this research, "DSR" can be supplied by load shifting as well as distributed and back-up generation.

For the purpose of this report, the term "DSR" is assumed to refer to all actions that reduce demand from the transmission system at a particular moment in time.[1]

This definition includes "DSR" provided by distributed generation (such as back-up generators, or even dedicated units such as OCGTs). It also includes forms of load-shifting that occur predictably and cannot be called on demand (including the load shifting associated with static time-of-use tariffs like Economy 7).

Most "DSR" capacity is currently provided by distributed generation, and depending on future design of market rules, this may persist.

The flexibility provided by distributed generation is likely to be of a greater scale than any individual form of load shifting. The inclusion or absence of such generators in markets for DSR services may therefore have a significant impact on the outcomes in those markets.

It is clear that diesel back-up generators are also currently an important source of DSR – but with significant uncertainties regarding capacity.

DSR provided by back-up generators is another significant DSR resource which is already available. However, there is poor evidence regarding the scale of the available capacity. DECC may wish to consider engaging further with generator owners and aggregators to understand more about the installed base of back-up generators, and the costs of enabling them for DSR (which will affect the size of generator it is economic to contract with).

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1 This report makes no assessment regarding what the "best" definition of DSR should be. The appropriate definition will depend on the circumstances, and for the purpose of a broad survey such as this report, it is important to avoid drawing the line too narrowly. However, there are still two main exclusions from this definition. First, we do not explicitly consider the use of DSR to *increase* demand (although many of the technologies considered here would be capable of doing so, and the load-shifting amendments to the DDM can model this). Second, we do not consider permanent reductions in demand (such as caused by increased appliance efficiency).

Industrial load shifting could play an important role in the near-term, although it is difficult to categorise many of the heterogeneous end-uses of electricity.

We have found significant potential for I&C DSR across a number of end-uses. For example, I&C heating and lighting[2] could potentially offer several GW of DSR. However, there is an extremely large amount of industrial demand (perhaps around 10GW) which, for the purpose of this analysis, has been grouped as "other industrial processes". It is difficult to make generalisations about these heterogeneous sources of load: although some research has been carried out on the types of process that may be amenable to DSR, statistics on energy usage are not generally available at this level of disaggregation. There is a role for parties such as aggregators to identify and access this capacity.

The role for additional domestic DSR may remain more limited in the near-term, although new technologies hold promise for the future.

Most current domestic DSR comes from storage heaters on time-of-use tariffs. Following the smart meter rollout, these appliances may be suitable to provide more dynamic (called at short notice) forms of DSR. All of the other forms of domestic demand-led DSR that we have considered have the potential to be significant sources of DSR capacity (for example in excess of 1GW), given sufficient consumer acceptance. However, the extent to which sources such as wet and cold appliances[3] can be exploited will depend crucially on consumer acceptance and the costs of setting up DSR arrangements. For example, while some consumers may be willing to adjust their usage of appliances such as washing machines in line with time-of-use tariffs, dynamic DSR from this source is unlikely to be cost-effective compared to some other sources of DSR considered in this report. The greatest opportunities for domestic DSR will occur in the future, if and when technologies such as heat pumps, electric vehicles, and electrical energy storage systems reach mainstream acceptance. However, projections for the take-up of these devices vary significantly.

Smart grid technologies should also be considered alongside these forms of DSR.

Both grid-level storage and enhanced automated voltage control might offer significant potential for load shifting and reduction respectively. The latter technology in particular is not frequently considered existing literature (perhaps because it does not fit neatly into the categories of "generation", "DSR", and

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2 It should be noted that many in the UK believe that widespread temporary reduction of lighting load through dimming is not feasible in this country. For example, see Element Energy for Ofgem (2012), *Demand side response in the non-domestic sector* and IHS (2009), *Demand Side Market Participation Report for DECC*

3 Although the duration of event that cold appliances can provide may limit their potential for some forms of DSR.

"storage"). It may be worthwhile further investigating the costs and capabilities of these systems (for example, incorporating the results of trials into DECC's modelling as they become available).

Table 1 below summarises, for each broad type of DSR covered in this report, some of the evidence that exists around overall potential, as well as the associated uncertainties.

Table 1. Summary of DSR sources considered in this report

Source of DSR			Description of potential	Main uncertainties
Distributed generation	Conventional generation Renewable generation CHP generation	Near-term	National Grid's "Gone Green" scenario suggests that there is currently well in excess of 5GW of dispatchable distributed generation (including thermal, renewable and CHP generation) that might be able to provide DSR services.	Of the types of DSR covered in this report, this has the least uncertainty. However, the capacity of smaller "behind-the-meter" generation can be difficult to quantify accurately. Although the technical capabilities of most types of distributed generation are broadly well-known, there is considerable heterogeneity in the DSR capabilities that CHP may provide.
		Future	This is indicated by National Grid as rising to approximately 9GW by 2035, divided roughly equally between conventional, renewable and CHP generation technologies.	Forecasts of future generation capacity are subject to much greater uncertainties, given questions regarding future technological development, government policies etc.

Table 1. Summary of DSR sources considered in this report

Source of DSR			Description of potential	Main uncertainties
I&C back-up generation	I&C back-up generation	Near-term	It has been suggested that there may be up to 20GW of I&C back-up generation currently installed within the UK. However, not all of this is currently available to aggregators. Smaller generators (for example those below 500kW) are currently uneconomic for many aggregators, due to the largely fixed costs of acquiring a site for DSR. Moreover, aggregators may only be able to engage with a small proportion (perhaps 20% according to one study) of the sites they contact.	The 20GW capacity figure is subject to an extremely large uncertainty. The extent to which it is economic to acquire smaller back-up generators for DSR will depend heavily on the fixed costs of engaging with generator owners.
		Future	The available DSR from back-up generation will increase if I&C users install more such assets, or if changes in technology or business models mean it is economic for a greater proportion of the installed generators to be utilised for DSR. It is however possible that future air pollution regulation could curtail some uses of back-up diesel generators.	All these factors are subject to extremely large uncertainties.

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Table 1. Summary of DSR sources considered in this report

Source of DSR			Description of potential	Main uncertainties
I&C demand-led DSR	Heating, ventilation and air conditioning Hot water Refrigeration Lighting Water pumping Other industrial processes	Near-term	Significant DSR capacity exists from I&C heating, ventilation and air conditioning – although the capacity that can respond for long periods may be limited. Water pumping, industrial (the data used does not cover commercial) refrigeration and to a lesser extent hot water could perhaps supply hundreds of MW of DSR each (they use roughly 400MW, 600MW and 300MW at peak respectively). A large proportion of I&C load (perhaps accounting for around 10GW of peak demand) relates to an extremely heterogeneous collection of other industrial processes, some of which may be suitable for DSR.	Estimates exist for current I&C electricity consumption by end-use, but these are too broad to capture the many heterogeneous industrial processes that could offer DSR. There is very little robust data available on the half-hourly load profiles of I&C consumption by end-use, on how acceptable different forms of DSR may be to firms, or on the costs to firms and/or aggregators of enabling DSR.
		Future	Load reduction through the dimming of lighting has been demonstrated in the US, even in the absence of natural daylight. If feasible in the UK (many have doubts about this), this would be a highly significant source of DSR.	The uncertainties described above are compounded when attempting to produce scenarios for future DSR use.

Table 1. Summary of DSR sources considered in this report

Source of DSR			Description of potential	Main uncertainties
Domestic demand-led DSR	Electric resistive storage heating Heat pumps (with storage or gas hybrid systems) Electric vehicles Wet appliances Cold appliances Domestic electrical energy storage	Near-term	Electric resistive storage heating is already subject to static time-of-use-tariffs and could be controlled dynamically using systems such as smart meter auxiliary load control switches in the next few years. Night-time demand might be approximately 3GW. Existing wet and cold appliances offer significant, currently unused, flexible capacity at peak (perhaps around 4GW), although cold appliances are limited in the duration of load-shifting they can provide, and (as indicated on the left) consumers may not accept DSR.	Consumer acceptance of contracts is a key uncertainty, although there is a growing body of trial and survey evidence. There are a wide range of technical and contractual means of carrying out domestic DSR (with different costs and capabilities), and it is uncertain which types of arrangement might become commonplace.
		Future	Heat pumps, electric vehicles and domestic electrical energy storage have the potential to provide significant amounts of DSR in the future. Some scenarios we have considered imply peak demand of 7GW from air-source heat pumps and 1.2GW from electric vehicles by 2035. However, heat pumps may displace DSR from storage heaters.	Scenarios for the future uptake of technologies such as electric vehicles, heat pumps, and electrical energy storage are subject to considerable variations. Future acceptability of DSR contracts is largely unknown.

Executive Summary

Table 1. Summary of DSR sources considered in this report

Source of DSR			Description of potential	Main uncertainties
DNO smart grid technologies	Grid-level electrical energy storage Enhanced automated voltage control	Near-term	Installation of these technologies for DSR is limited to a small number of trial sites at present.	Some I&C sites already have voltage control devices installed within their premises. Within the scope of this project, it has not been possible to quantify the extent to which this could be used to provide a source of DSR.
		Future	Both of these technologies, if widely deployed, could be capable of facilitating significant quantities of DSR. For example, it is feasible that 7GW of distributed storage could be built by 2035. Enhanced automated voltage control technologies could perhaps reduce demand by around 5%, which would lead to significant capacity for reductions if deployed widely.	The potential for grid-level electrical energy storage will depend to a large extent on the rate at which the costs of storage technologies can continue to decrease and, the extent to which the costs of these systems can be spread across multiple uses for DSR. Relatively little work has been done to understand the costs and capabilities of voltage control for DSR, however further information will be published later this year from Electricity North West's CLASS project.

LCP have added additional functionality to DECC's Dynamic Dispatch Model (DDM) to incorporate DSR.

As a result of these modifications, the DDM is now capable of modelling the following key characteristics of different categories of DSR.[4]

- The interaction with the **wholesale market** – this may be through direct participation or indirectly through reducing or shifting load;
- the contribution to the **Capacity Market** – either through direct participation for contracts or indirectly in the form of a reduced requirement for conventional generation capacity;
- the investment **decisions / uptake of DSR** – the model now has the additional capability to capture the drivers that will determine the level of potential DSR that is realised; and
- **wider system impacts** – to maintain consistency with ongoing work to model "whole system impacts", the contribution of DSR to ancillary service markets (such as STOR, frequency response and the balancing market) has been allowed for.

Scenario analysis and sensitivity tests will be especially important

The DDM is now capable of modelling all the forms of DSR discussed in this report, subject to available input data, and consistency with DECC's current demand scenarios.[5] However, as discussed above, there is great uncertainty in many of the inputs. By using the DDM to run sensitivity tests, DECC will be able to start assessing which of these uncertainties may have the greatest impact on the future energy system, and would therefore benefit most from additional quantification.

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4 The modifications to the DDM mean that it can now select investment in DSR technologies in a way similar to that described in the 2014 report for DECC by the Centre for Sustainable Energy, *An analysis of D3 in DECC's energy system models*. It should be noted that while our report (and the associated modelling) consider demand response and distributed energy, demand reduction (the other "D" of "D3") is outside the scope of this work.

5 At present, the overall demand scenarios used within the DDM do not break domestic and I&C demand down into further sub-categories, and assume a daily load shape which varies with different day types and seasons, but not through time. This report has drawn together illustrative future load profiles for different forms of demand that could be amenable to DSR, however these are unlikely to be consistent with the assumptions underlying the overall demand scenario in the DDM. Using these assumptions alongside the DDM is therefore likely to lead to inconsistencies (for example, demand being shifted that did not exist in the first place).

1 Introduction

DECC has commissioned Frontier Economics, with support from Sustainability First, to review the potential for demand side response (DSR) in the electricity sector to 2035. In particular, this work will be used to develop DECC's Dynamic Dispatch Model (DDM) and inform DECC's modelling of the levelised costs of DSR. In parallel with this report, Lane Clark and Peacock (LCP) have undertaken work to extend the functionality of the DDM to cover DSR.

The aims of this report are to:

- create an initial framework to capture which drivers affect the capacity and costs of all types of DSR in the long-run;
- populate this (where possible) using evidence from literature, studies and interviews, which can be used for DDM scenarios; and
- highlight the uncertainties that exist in the evidence base.

This introductory section sets out some general background on the importance of DSR, the scope of the forms of "DSR" covered in report, and some important caveats regarding the empirical evidence that currently exists on this topic.

1.1 The increasing importance of DSR

DSR has the potential to help reduce costs and emissions across the energy sector. By changing the profile of demand, and increasing the flexibility of the demand side, DSR can reduce the need for investment in generation and network capacity, and increase the utilisation of more efficient generating plant.

The move to a low-carbon economy is likely to increase the demand for DSR, as generation from intermittent sources increases, and the electrification of heat and transport increases overall and, potentially, peak demand. At the same time, this growth of potentially flexible load and the roll out of smart meters may increase the supply of DSR, particularly in the household sector. DSR is therefore likely to have an increasingly significant part to play across the electricity system – and an increasingly significant role within DECC's models of that system.

1.2 Which kinds of DSR are covered in this report?

This report is intended to give a broad survey of the different types of DSR that exist and how they compare. We have therefore adopted a wide definition of "DSR", which includes all actions that reduce demand from the transmission

system at a particular moment[6] in time. **Table 2** below summarises the main elements of this definition, and how they differ from alternative approaches.

This report makes no assessment regarding what the "best" definition of DSR should be, and the appropriate definition will depend on the circumstances. For example, the National Grid's *Future Energy Scenarios* does not include standalone embedded generation within the definition of DSR, while such generation may be eligible for the Capacity Market's Transitional Arrangements for DSR.[7] For the purpose of a broad survey such as this report, it is important to avoid drawing the line too narrowly.

6 Significant potential also exists for *permanent* reductions in demand, for example through increased efficiency of appliances. Such developments are outside the scope of this report, which is focussed on flexible demand.

7 The Capacity Market defines DSR as "…*the activity of reducing the metered volume of imported electricity of one or more customers below a baseline, by a means other than a permanent reduction in electricity use.*" The Transitional Arrangements also include non-Central Meter Registration System generators with a capacity not exceeding 50MW.

Table 2. Definition of DSR used within this report

Aspect of DSR	Definition used in this report	Alternative approaches
What types of load-shifting asset should be included?	**Wider:** Include anything that can decrease demand on the distribution network	**Narrower:** Some definitions[8] exclude stand-alone distributed generators like OCGTs, and may also exclude back-up generators
Should forms of "DSR" that are pre-determined far in advance be included?	**Wider:** Include DSR that is specified in advance ("static" DSR) as well as that which can be called at short notice ("dynamic" DSR)	**Narrower:** Some definitions have only included dynamic DSR
Should measures be included that lead to a permanent (not temporary) decrease in demand?	**Narrower:** Include only actions that lead to a targeted reduction in demand at a specific period in time	**Wider:** Include actions such as efficiency measures that reduce demand across the year
Should targeted load *increases* also be included?[9]	**Narrower:** Include only actions that lead to a decrease in demand	**Wider:** Also include actions that lead to an increase in demand

Source: Frontier Economics

Based on this definition, **Table 3** sets out the broad categorisation of DSR types which we have used in this report.

8 For example,.

9 DSR to increase demand could be used to balance excess generation, whether nationally or locally.

Table 3. Types of DSR considered in this report

Distributed generation	This category includes generation technologies connected to the distribution network (for example, thermal power stations, or CHP plants), with the exception of back-up generators.
I&C back-up generation	This refers to use of pre-existing emergency back-up generators to carry out DSR.
I&C demand-led DSR	Industrial and commercial customers may provide DSR by reducing or shifting their demand (for example power consumed for electric heat, ventilation and air conditioning). As noted in **Table 2**, we have not included efficiency measures that would produce a *permanent* drop in demand.
Domestic demand-led DSR	Domestic customers may be able to provide DSR by shifting or reducing their demand (for example, altering the time at which storage heaters are charged, or postponing the charging of electric vehicles). Again, we have not included efficiency measures that would produce a *permanent* drop in demand.
DNO smart grid technologies	Electrical energy storage and voltage control systems are being investigated by DNOs for network management purposes, and can also have wider DSR applications.

Source: Frontier Economics

1.3 Uncertainties regarding quantitative evidence

There are extremely large uncertainties across many of the figures that this report draws together. Some examples are listed below.

- The overall capacity of potentially flexible load that is *currently* available is, in some cases, subject to great uncertainties. For example, data is scarce regarding the current capacity of I&C back-up generation, or the demand profile for various I&C end-uses of electricity.

- The extent to which this load will change in the future is even less certain. For example, there are a wide range of plausible scenarios for heat pump take-up, based on differing assumptions regarding technological progress, costs and policies. These scenarios would give rise to highly different capacities for DSR from heat pumps – and from technologies that they may replace (e.g. electric resistive heating). Developments which could increase electricity usage (for example general economic growth) or decrease it (for example increased efficiency) will have a substantial effect on both the

availability and requirement for DSR, and are cannot be accurately forecasted.

- The proportion of customers that could take up contracts that facilitate DSR is, at this stage, broadly unknown. This is particularly the case for forms of DSR (such as contracts with domestic customers) that have yet to be rolled out beyond trials, but even for existing I&C DSR there are no sector-by-sector figures for customer engagement.

- Data on the costs involved with different forms of DSR is also frequently difficult to come by. For example, we have only approximate figures on the costs incurred by aggregators in signing up new customers – and even less certainty on how these could change over time as new business approaches may be adopted.

This report will be used to feed into modelling work for DECC. We have therefore endeavoured to provide quantitative evidence around capacity and cost that has been used as a starting point to populate the new functionality in the DDM. We have drawn upon a diverse range of sources, including past literature, trials, public data, as well as less formal interviews with market participants. However, these sources are not all equally robust (for example, empirical trials, if representative, *might* offer a more robust estimate of future customer behaviour than surveys or informed assumptions), and in some cases there is virtually no evidence base on which to draw.

It is important that DECC are aware of the uncertainties surrounding specific figures. This is partially so that figures with a high degree of uncertainty can be subject to sensitivity tests in modelling, to confirm whether the overall model results depend significantly upon the assumptions made. Additionally, this may suggest areas to prioritise for future data gathering. Throughout this report, we have therefore highlighted the quality of the evidence base we have drawn upon, within "Summary of the evidence base" boxes.

1.4 Structure of this report

The remainder of this report is set out as follows.

- Section 2 provides information on some of the different possible uses for DSR and how they may interact. This is significant for DECC's modelling since the availability of DSR for one use (for example, the Capacity Market) may depend on whether other DSR uses are in conflict or synergy.

- Section 3 sets out the frameworks we have used to assess the capacity, capabilities, and cost of each form of DSR.

- The subsequent sections use this framework to go through each of the broad types of DSR identified in **Table 3**.

- Finally, section 9 notes some implications for DECC's modelling of the wholesale, capacity and ancillary services markets within the DDM.

The majority of this report is primarily structured as a reference to guide future developments in DECC's modelling of DSR. However, the Executive Summary also contains some general conclusions regarding some of the possible areas for greatest DSR potential, alongside the main associated uncertainties.

2 Uses for DSR and the interaction between them

This section summarises the range of uses for DSR, how these interact, and what this might imply for different players in the electricity market. Much of DECC's use of the DDM (dynamic dispatch model) modelling currently focusses on two uses for DSR:

- within the Capacity Market (to assist security of supply); and
- within the wholesale market (to reduce the costs of electricity generation).

All possible uses of DSR – whether currently modelled or otherwise – are relevant to the modelling carried out by DECC since they may affect the amount of DSR that is able to come forward under the wholesale and Capacity Markets, and the cost at which it does so.

This section covers the following areas.

- We first summarise the range of uses for DSR, and consider the different technical requirements for each one. The framework developed here is used in the rest of this report to indicate which uses each particular type of DSR may be suited to, which in turn will influence whether their capacity or cost may need to be adjusted in modelling.

- We then set out the types of interactions that could occur when a DSR resource has the technical capability to serve multiple uses. This provides a framework that can be used alongside modelling, to determine whether the presence of multiple DSR uses might increase or decrease the supply of DSR. However, we note that there are considerable uncertainties, due to the range of possible future administrative and market approaches to coordinating DSR among different market actors.

Summary of the evidence base

The table below summarises the main types of sources that have been used in this section, and indicates where some of the greatest uncertainties lie.

Area	Main sources of evidence and robustness
Technical requirements for different DSR uses	The requirements (for example in terms of notice period and duration) for existing services such as STOR are generally well-known, and have been taken from publicly available documents. However, it is possible that these requirements could change in the future. For example, Triad charges are currently used to encourage demand to move away from the national system peak, and some firms respond to Triad warnings from suppliers (or others) that may be issued a day in advance. However, there is nothing intrinsic preventing Triad warnings within different timescales. More materially, the structure of transmission charging itself could potentially change over the next 20 years. As a result, these technical requirements may shift in the future.
Revenue available from different DSR uses	Average revenue for many current schemes (e.g. STOR) is publicly available. However the revenue available in the future will depend on the future supply and demand of flexibility, which is unknown. Revenues obtained from DSR could therefore change substantially in the future (for example, increasing due to competition between users of demand side services).
Extent to which different demands may have conflicts or synergies	This will depend on future administrative approaches to co-ordination between parties in the market, which are currently under active discussion – see section 2.2.2.

2.1 The uses for DSR

There are a wide variety of ways in which DSR can provide value to the electricity sector (both now and in the future). When modelling DSR, it is important to understand which sources of DSR may be appropriate for different uses.

Uses for DSR and the interaction between them

Table 5 sets out a variety of different uses that could be made of DSR by the system operator, the transmission and distribution network operators, and suppliers.[10] This is primarily based on the types of DSR that are currently being used commercially or in trials. As described in the box above, it is entirely possible that over the coming 20 years, different arrangements in areas such as network charges could lead to different requirements for DSR.

For each use, we have set out the main driver of DSR value. This relates to the best alternative options each party has for delivering the required flexibility. It will typically be whichever is lower of:

- the cost of producing an alternative means of flexibility; or
- the consequences of going without flexibility.

The price paid for DSR services will depend both on this underlying value (the demand for flexibility) but also the availability and cost (i.e. the supply) of flexibility. This can be seen in the STOR market, where an increased supply of flexible generation and demand has pushed prices down substantially in recent years. We have therefore not provided extensive data on existing payments for these services, as these are likely to change substantially over the period considered by this report. However, for context, the box below provides some information on the typical payments and volumes for some of these services.

10 This draws on the analysis within ENA (2014) *Demand Side Response Shared Services Framework Concept Paper* and Sustainability First (2012), *What Demand-Side Services Can Provide Value to the Electricity Sector*

Table 4. Examples of prices and volumes for existing DSR uses

Existing DSR use	Price paid	Capacity procured
STOR	As of January 2015, the average STOR utilisation price was £131.94/MWh and a typical availability payment was £2.60/MWh.[11] Given a utilisation of approximately 40 hours per year, and 3,860 hours of availability windows per year,[12] this would imply annual payments of roughly £15/kW.	For winter 2014/2015, National Grid procured 3,444MW of STOR.[13] Of this, 237MW was "load reduction". We understand that STOR providers provide this categorisation, and so some of this may include back-up generators.
Fast Reserve	In January 2015, total expenditure on availability and utilisation excluding bids and offers was £0.99m.[14] This implies an annual price of roughly £44/kW.	270MW in January 2015, 400MW in April 2014[15] (volume is typically within these bounds). Normally this capacity is from pumped-storage hydro and not DSR.
FFR	Annual payments of approximately £50/kW - £60/kW,[16] mainly through availability and nomination (holding) fees.	For static services: up to around 1,400MW of secondary response, 600MW of primary response, and 200MW of high response.[17] Just over 400MW of dynamic response (both for low and high frequency events).

11 National Grid (2015) *Monthly Balancing Services Summary January 2015*, p7 provides a figure of £4.38/MWh, however this includes more expensive long-term STOR contracts which will be rarely called. National Grid have informed us that £2.60/MWh is more representative.

12 From the STOR Annual Report for 2013/14.

13 National Grid (2015), *STOR Fuel Type Analysis – Season 8.5*, p1

14 National Grid (2015) *Monthly Balancing Services Summary 2014/15*

15 National Grid (2015) *Monthly Balancing Services Summary*

16 Sustainability First (2012) *What Demand-Side Services Can Provide Value to the Electricity Sector?*

17 National Grid (2015), *Firm Frequency Response Frequently Asked Questions* p7. Primary and secondary low frequency response services fully increase output within 10s and 30s respectively, high frequency response services fully decrease output within 10s.

Uses for DSR and the interaction between them

Capacity market	The 2014 T-4 auction cleared at a price of £19.40/kW/year.	Approximately 49.3GW of capacity was procured in the first T-4 auction, of which 8MW came from proven DSR CMUs (both diesel generators), and 166MW from unproven DSR CMUs. A further 4,056MW came from distributed generation[18] (including around 785MW of gas reciprocating engines, and 198MW of diesel reciprocating engines).[19]
Triad avoidance	Annual TNUoS charges are split into 14 locational zones. The demand tariffs for 2015/16 range from £23.469/kW in Northern Scotland to £46.237/kW in London.[20]	National Grid estimates[21] that typical Customer Demand Management (CDM) levels of 1.2GW were experienced throughout the Triad period.
DUoS charge avoidance	Depends on region, time and type of consumer. As an example, in SSEPD's Eastern region, a LV half-hourly metered customer might earn £26/kW per year if they shifted load every weekday from the red to the amber zone.[22]	Some empirical evidence suggests that the introduction of banded DUoS charges may not have led to significant load-shifting for HV and LV customers.[23]

18 Including existing, refurbishing and new-build generation. Note that some of this capacity will be CMRS registered or above 50MW in size and therefore would not have been eligible for the DSR Transitional Arrangements within the Capacity Market.

19 Reciprocating engine figures based on analysis carried out by DECC (we have excluded the 8MW of diesel generators entered as proven DSR).

20 National Grid (2015), *Final TNUoS tariffs for 2015/16*

21 National Grid (2015), *Winter Review and Consultation July 2015*

22 Based on 10.268p/kWh for red and 0.161p/kWh for amber, from SSE (2015), *Southern Electric Power Distribution plc Use of System Charging Statement Effective from 1st April 2015*

23 Customer-Led Network Revolution (2015), *April 2010 Tariff Reform Analysis – Introduction of the Common Distribution Charging Methodology (CDCM)* p4

DSR by DNOs	The CLNR project reported an indicative ceiling price (i.e. the highest price that should be paid to DSR to avert network reinforcement) of around £17/kW/yr.[24]	These applications of DSR are currently at trial stage, or only just being introduced to DNO business-as-usual.

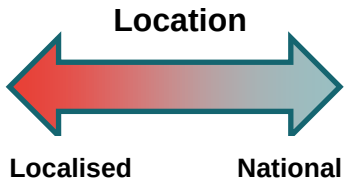
Source: See above

Alongside each usage, we provide an example of how this demand for flexibility is currently met, and any specific requirements that the DSR must meet. A further explanation of each of the specific requirements is provided in **Figure 1** below.

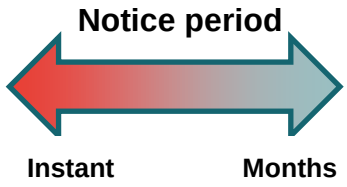
24 CLNR (2015), *Project Closedown Report* p15

Uses for DSR and the interaction between them

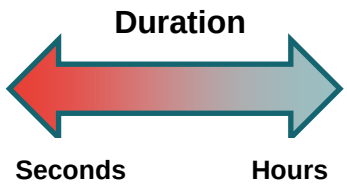
Figure 1. Ways in which requirements for DSR may vary by use



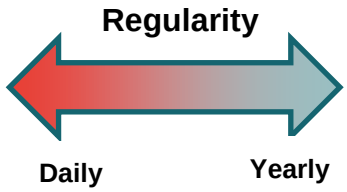
Some uses for DSR will be highly localised, requiring that a response takes place within a specific region or section of local network. Other uses may be indifferent as to where a response takes place.



This refers to the length of time between a requirement for DSR becoming apparent, and the DSR action being taken. At the extreme, second-by-second balancing requires an instant response to a call for DSR. Other needs for DSR can be predicted months in advance.



Some uses for DSR may require a reduction in load lasting several hours (for example, if a DNO needs to reduce demand while a fault is fixed). Others, such as frequency response services, many only require a response lasting minutes. It may be possible for an aggregator to call short-duration DSR resources one after another to meet a need to a long-duration event – although this could significantly increase the costs of providing a given DSR capacity.



Some uses for DSR (for example, wholesale market savings) may require a more frequent response to obtain significant value. Other uses (for example post-fault DSR called by a DNO) may be more infrequent.

Source: Frontier Economics

Table 5. Summary of different uses for DSR and their requirements

DSR use	Examples of existing scheme(s)	Driver of value	Requirements			
			Location	Notice period	Duration	Regularity
System operator: Balancing the system to ensure that demand is equal to generation on a second-by-second basis	Firm Frequency Response (FFR)	Cost of procuring next-cheapest service to provide security of supply, or value of lost load	Any	30 seconds (secondary FFR); instant (dynamic FFR)[25]	Typically up to 5 minutes for dynamic FFR – however most providers need to be contractually capable of 30 minutes.	May be tripped 10-30 times pa for a low frequency event (depending on frequency relay threshold setting)[26]
System operator: Balancing the system to ensure	STOR[27]	Cost of procuring next-cheapest service to provide security of supply	Any	Up to 4 hours[28] (STOR)	2 hours or more (STOR)	Approximately 40 hours per year[29]

25 Dynamic FFR is delivered for a set period and volume if the system frequency reaches a predefined trigger level.

26 Sustainability First (2012) paper 4 p97

27 For simplicity we do not show Fast Reserve, which falls between FFR and STOR: Participants must be able to deliver power for at least 15 minutes with 2 minutes warning.

28 More typically within 20 minutes

29 National Grid also specifies that STOR parties must be able to provide power for at least three times a week.

Uses for DSR and the interaction between them

Table 5. Summary of different uses for DSR and their requirements

DSR use	Examples of existing scheme(s)	Driver of value	Requirements			
			Location	Notice period	Duration	Regularity
that demand is equal to generation over longer periods		(flexible generation), or value of lost load				
System operator: Ensure that there is sufficient generation to meet demand at times of system stress	Capacity Market, including DSR Transitional Arrangements	Cost of procuring next-cheapest service to provide security of supply (flexible generation), or value of lost load	Any	4 hours	As long as a stress event lasts – multiple hours	Infrequently – only during system stress events
System operator: Constraint management	Redispatch of plant via the balancing mechanism	Value of lost load (or, in the long run, cost of reinforcing system to avert constraints)	Regional – depends on where congestion occurs	Within an hour (after gate closure)	Variable – as long as congestion occurs	Location dependent – any time congestion occurs

Uses for DSR and the interaction between them

Table 5. Summary of different uses for DSR and their requirements

DSR use	Examples of existing scheme(s)	Driver of value	Requirements			
			Location	Notice period	Duration	Regularity
TNO: General reduction in required transmission capacity	TNUoS charges (Triad avoidance)	Cost of reinforcing the transmission network, or redispatching generators (see above)	Regional	Day ahead[30]	Around one hour	Around 20 triad warnings per year
DNO: General reduction in required distribution network capacity during system normal conditions	DUoS charges (both for demand and generation)	Cost of reinforcing the distribution network	Regional	Months ahead	Several hours	Every day
DNO: Constraint management during system		In the short run, the value of lost load	Local	Months ahead	2 – 4 hours	Every day

30 Triads are only known after they occur and are not "called" as such. However, firms carrying out triad avoidance will typically rely on a service (provided by their supplier or a third-party) which gives triad warnings a day in advance. These warnings are intended to cover the three actual Triads that occur.

Uses for DSR and the interaction between them

Table 5. Summary of different uses for DSR and their requirements

DSR use	Examples of existing scheme(s)	Driver of value	Requirements			
			Location	Notice period	Duration	Regularity
normal conditions on the distribution network (static)		In the longer run, the cost of network reinforcement				
DNO: Constraint management during system normal conditions on the distribution network (dynamic)		In the short run, the value of lost load In the longer run, the cost of network reinforcement	Local	¼ - 4 hours	2 – 4 hours	Will depend upon local network conditions[31]
DNO: Constraint management during fault conditions on the distribution network (instant)		In the short run, the value of lost load In the longer run, the cost of network	Local	Instant	Up to 8 hours	Rarely, during a fault

31 The ENA Shared Services Framework paper does not indicate how often these services may be called.

Table 5. Summary of different uses for DSR and their requirements

DSR use	Examples of existing scheme(s)	Driver of value	Requirements			
			Location	Notice period	Duration	Regularity
		reinforcement				
DNO: Constraint management during fault conditions on the distribution network (planned)		In the short run, the value of lost load In the longer run, the cost of network reinforcement	Local	½ - 4 hours	Up to 8 hours	Rarely, during a fault
Suppliers: Reduction in wholesale costs[32]	Time-of-use tariffs, including those faced by larger I&C customers on half hourly metering	Differentials in the wholesale cost of electricity	Any	Months ahead (but greater gains from dynamic dispatch, especially if prices become	Half an hour or more	Will need to be frequent to obtain meaningful savings[33]

32 Suppliers may also seek to avoid payments for the Capacity Market levy in a similar way, by lowering demand on winter evenings.

33 Unlike many of the other uses for DSR, which obtain value by driving down peak *power* consumption, gains from DSR in the wholesale market are driven primarily by the amount of *energy* that can be shifted from high-price to low-price periods.

Uses for DSR and the interaction between them

Table 5. Summary of different uses for DSR and their requirements

DSR use	Examples of existing scheme(s)	Driver of value	Requirements			
			Location	Notice period	Duration	Regularity
				more volatile)		
Suppliers: Reduction in exposure to imbalance charges post gate-closure		If DSR being used to avoid imbalance: Cash-out charges for being out of balance[34]	Any	Within an hour (after gate closure)	Half an hour or more	Will need to be frequent to obtain meaningful savings

Source: Frontier Economics

34 At present, if a supplier is short then they pay the System Buy Price if the market as a whole is short, and the (lower) Market Index Price if the system is long. As an example, on Monday 2nd February 2015, the System Buy Price peaked at £162/MWh (at 19:30, data from www.bmreports.com). Note that the system for setting imbalance prices is changing as a result of Ofgem's Electricity Balancing Significant Code Review, which will introduce a single marginal cash-out price.

Uses for DSR and the interaction between them

2.2 Interactions between uses of DSR

The different uses for DSR listed above may interact with one another, affecting either the demand or supply for other uses. Such interactions are relevant for modelling, where it will be necessary to specify which uses each source of DSR is suitable for. Even if some uses for DSR are not included within the model, it may still be necessary to adjust the supply of DSR to account for the way these uses could act in competition or synergy with the uses of DSR that are modelled.

2.2.1 Effect of different DSR uses on the demand for DSR

One use of DSR may affect the **demand** for DSR for another use.[35] Below, we set out how the demand for DSR across a number of uses may be affected by events called by a different party.

- **Effect on system operator (for balancing):** Large-scale DSR actions called by other parties might require the system operator to carry out DSR to maintain the balance of generation and demand.

- **Effect on system operator (for Capacity Market):** The presence of DSR called by other parties may affect the target capacity. For example, Triad avoidance, by flattening load profiles, will reduce peak demand, ultimately lowering the target capacity (which sets the demand for DSR within the Capacity Market). More directly, the Capacity Market target is lowered to account for sources of capacity outside the Capacity Market, including long-term STOR contracts.

- **Effect on TNO and DNOs:** DSR actions called by other parties may affect peak power flows on the networks. If peaks are reduced then this may reduce the need for network operators to carry out their own DSR actions. However, if peaks are increased (for example, if a sudden increase in wind output causes wholesale prices to fall during a time of high demand) then peaks may increase and the networks operators may wish to carry out counteracting DSR actions.

- **Effect on suppliers (for balancing):** DSR called by other parties, without the knowledge of suppliers, may bring suppliers out of balance. Suppliers may then wish to call counteracting DSR actions to bring themselves back into balance.

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35 As explained in ELEXON (2015), *Maximising the value from Demand Side Response*, conflicting demands for DSR may have a greater impact if they are invisible to the affected party, or the affected party is unable to respond. Workstream 6 of the Smart Grid Forum is currently examining some of the issues that arise from DSR actions not being visible to all parties.

- **Effect on suppliers (for wholesale market):** Significant DSR actions called by other parties may change the profile of demand and prices on the wholesale market. This may either reduce or increase the suppliers' incentive to call their own DSR, depending on whether energy price differentials have decreased or increased.

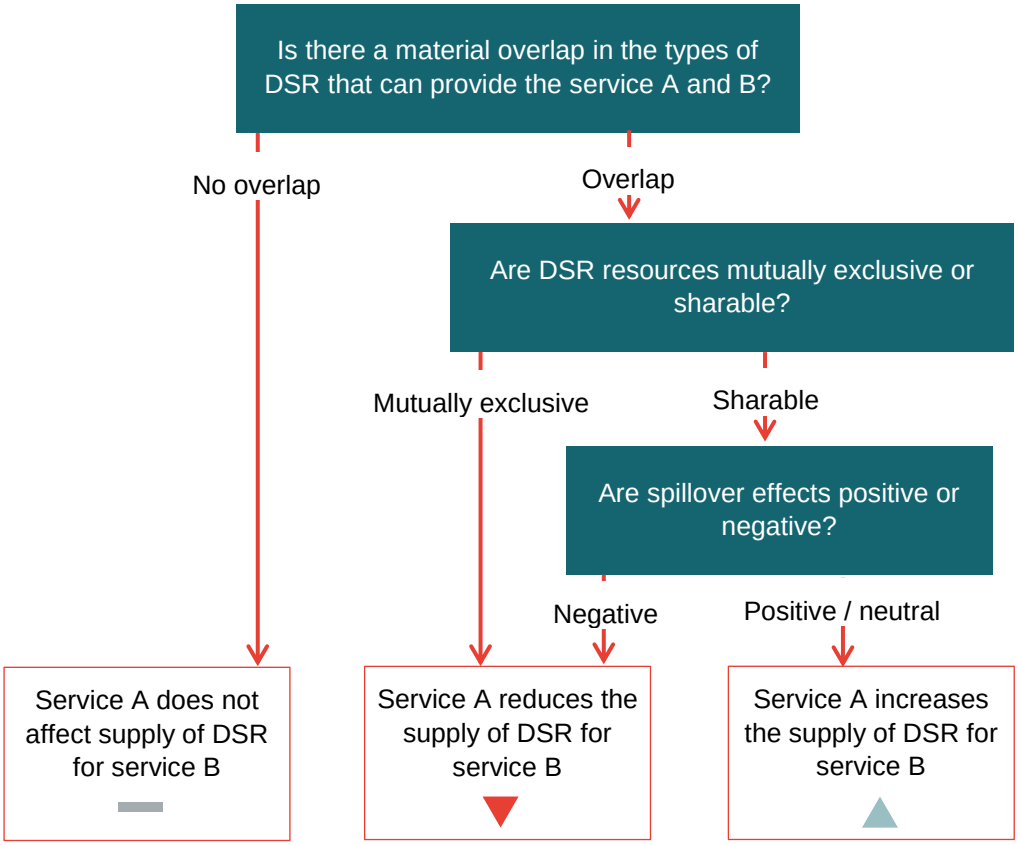
The types of DSR that are likely to have the greatest impact on outcomes in the wholesale market are those that produce regular, significant changes in demand. At present, the main form of DSR that could have this effect is Triad avoidance. The I&C demand profiles we use in section 6 will take account of current levels of these types of DSR, although modelling of future load profiles may need to consider whether there will be significant changes to Triad response.

2.2.2 Effect of different DSR uses on the supply for DSR

The possibility of DSR being used for other purposes may also increase or decrease the **supply** of DSR for any specific use. **Figure 2** summarises some of the interactions[36] which could take place, which are discussed in greater detail below.

[36] This is a simplified overview of what can be extremely complex interactions between parties calling DSR.

Figure 2. Summary of interactions between different DSR demands



Source: Frontier Economics

Three examples of how this framework can be applied in the near-term are as follows:

- **Table 5** showed that National Grid's fast frequency response service requires forms of DSR that can act extremely quickly, but are not required to deliver for more than a few minutes. By contrast, other uses of DSR such as the Capacity Market require a much longer response,[37] with greater notice. There is likely to be relatively little overlap between the types of DSR that can provide these services, and so demand for DSR for frequency response

[37] It would in theory be possible for a party such as an aggregator to break a large fleet of fast-responding appliances (e.g. fridges) into different tranches, calling them sequentially to obtain a longer duration load turn-down. This will spread the payments made to owners of appliances across a smaller capacity available for the Capacity Market. Many aggregators we spoke to indicated that, at present, this was therefore likely to be uneconomic, although one firm stated that this could be possible.

Uses for DSR and the interaction between them

services may not significantly affect the DSR capacity available for the Capacity Market.

- As shown in **Table 5**, STOR and the Capacity Market have similar requirements, and it is therefore likely that many types of DSR could bid for both. However, the current Capacity Market regulations require that units receiving a capacity agreement must withdraw from any long-term STOR contracts.[38] Generators[39] with a long-term STOR contract would therefore be expected to reduce their supply to the Capacity Market (by increasing the price they bid in at, or not bidding altogether), to take account of the opportunity cost of losing the STOR agreement.

- By contrast, standard (shorter term) STOR contracts are compatible with Capacity Market agreements. If investors in new forms of DSR believe they can obtain revenue from both STOR and the Capacity Market then this may increase the supply of DSR spread across between both services.

The following sections provide the rationale for this framework.

Overlapping types of DSR?

As set out in **Table 5**, different demands for DSR may have specific requirements in terms of location, notice period, duration and frequency. If two schemes do not overlap in their requirements, then one scheme will not have a material impact on the supply of DSR for another.

As described above, this means that the existence of services such as fast frequency response, requiring fast-acting short-term DSR, might not significantly affect the supply of DSR for services such as the Capacity Market, which need longer-term responses with longer notice periods.

Are DSR resources mutually exclusive or sharable?

Constraints – whether technical or commercial – may prevent a provider of flexibility from providing DSR to multiple uses. Technical constraints could be relevant if equipment used by one party to control load is not compatible with equipment required by another party. An example of a constraint based on commercial arrangements is the way that generators with long-term STOR contracts must exit these if they win a Capacity Market agreement. Similarly, participants in National Grid's Demand-Side Balancing Reserve (DSBR) are not

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38 These contracts, lasting up to 10 or 15 years, were issued by National Grid in 2009 and 2010. 393MW of long-term STOR was contracted out as far as 1st April 2025 – see National Grid (2010), *Open Letter to Reserve Providers and Interested Parties*.

39 We understand from DECC that the entities with long-term STOR contracts do not provide demand-led DSR.

permitted to take part in other DSR schemes.[40] We discuss the role of the market framework on DSR availability more generally in the following section.

Even if there is no explicit prohibition on the contracting of DSR to multiple parties, one party may find it difficult to obtain DSR resources that another party may find it easy to access. For example, in the absence of changes in the market arrangements, DNOs would likely need to work through a supplier, aggregator or other third party to engage domestic DSR. Under the "supplier hub" model, it is the supplier (rather than the DNO) which has direct contact with consumers.

As summarised in work for ELEXON[41] such contractual inefficiencies can "tie up" DSR resources. From the point of view of a specific demand for DSR services (such as the Capacity Market), competing mutually exclusive demands reduce the supply of available DSR.

Does DSR carried out by one party have a positive or negative effect on the other party?

If DSR resources can be shared, the impact that one use has on the supply of DSR for another will depend on whether the requirements for DSR between the two are aligned.

In many cases, DSR carried out for one demand may have a **positive** spillover on other demands. For example, actions taken to reduce national peak demand on the transmission network may also reduce local peaks, aiding the distribution networks. If DSR providers are able to contract with multiple parties (aggregating the value from multiple demands for DSR), the existence of such spillovers will tend to increase the supply of DSR available for a given use.

Even if the effect of DSR calls by one party upon another are **neutral**, a DSR provider could benefit from availability payments from multiple sources, again increasing the supply of DSR for any one use.[42]

However, DSR calls may potentially have **negative** spillover effects. For example, under scenarios with a high penetration of wind generation, a significant increase in wind output during the evening peak might encourage suppliers to increase demand further, creating further peaks and adversely impacting the distribution and transmission networks. Such competing demands for DSR would reduce the supply of DSR for a specific demand.

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40 Consistent with the principle used at present for other National Grid services whereby energy or service provision should not be double-counted.

41 ELEXON (2015), *Maximising the value from Demand Side Response*

42 A potential criticism is that the pooling of availability (as well as utilisation) payments could be seen as enabling DSR providers to benefit from the same resource multiple times. However, providing this enables the cost of DSR for any single use to decrease, this will help bring forward an efficient quantity of DSR (in economic terms, a positive externality is internalised).

Uses for DSR and the interaction between them

2.2.3 Alternative approaches to market frameworks

Many of the factors described in the previous section (for example, the extent to which DSR resources are mutually exclusive or sharable) will depend on the market arrangements that are in place at the time. Given the potential for competing demands for DSR to produce inefficiencies and informational difficulties, a variety of groups (for example, WS6 of the Smart Grid Forum) have started to consider frameworks that set out how access to DSR can be arbitrated. Some examples of how the market framework could affect access to DSR are described briefly below.

- Market rules may affect the extent to which different entities are able to access DSR, giving rise to **mutual exclusivity**. For example, the Energy Networks Association has proposed[43] a shared service framework, which sets out how DSR from non-domestic customers could be shared between DNOS, the TNO and the SO. This framework would specify a hierarchy of uses for cases where DSR could not be dispatched by multiple parties. This would give DSR uses for local network issues first refusal of DSR services before the SO.

- Market rules may also affect the extent to which parties have to take into account **spillovers**. For example, some consideration has been given to a "central flexibility market", where DSR providers could bid in flexibility products, purchased by users of DSR.[44] Where the DSR requirements of different parties are aligned, then such a market could help provide a way of sharing costs.

This is a complex area: There is not yet certainty regarding the market arrangements for DSR over the next five years, let alone the 20 years to 2035.[45] It is therefore important that DECC's modelling of future DSR capabilities is able to take these uncertainties into account. Three ways in which this could be carried out are:

- Scaling down the capacity of DSR available for a given use (e.g. the wholesale or Capacity Market), to take account of any market frameworks that may give other uses of DSR priority.

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43 ENA (2014) *Demand Side Response Shared Services Framework Concept Paper*

44 See Customer-Led Network Revolution (2015), *Commercial Arrangements Study – Phase 2* and Low Carbon London (2014), *Learning Report - A5 - Conflicts and synergies of Demand Side Response*, both of which describe a number of possible market arrangements.

45 It is outside the scope of this report to come to a conclusion on whether particular arrangements may be more appropriate now or in the future.

- Lowering the investment costs of DSR to reflect the possibility that these may be shared with DSR uses outside the scope of the modelling. In addition, if it is believed that DSR could be utilised to benefit multiple parties at the same time (for example, DSR in the wholesale market also acting as static pre-fault DSR to benefit a DNO), it might be appropriate to share variable costs in this way.

- Increasing the costs of DSR to account for the possibility that different uses of DSR may be mutually exclusive.

3 Framework for the analysis of DSR supply by source

This report covers a wide range of DSR technologies, with greatly varying characteristics. Sections 4 to 8 describe the main types of DSR we consider: distributed generation; I&C back-up generation; I&C demand-led DSR, domestic demand-led DSR, and DNO smart grid technologies. **To provide a consistent overview, each section is structured as follows.**

- First, we describe the **different sources of potentially shiftable load** that could be called. For example, for domestic DSR, this would include electric vehicle load. For each potential source, we present evidence on the potential capabilities and capacities of load-shifting to 2035.

- Second, we consider the **arrangements for calling DSR that might be in place**. DSR can be accessed by a number of routes. For example domestic DSR may be accessed through voluntary response to a time of use tariff, direct control of loads, or other means. The nature of the potential arrangements to deliver DSR will be one of the factors determining both the capacity and capability of DSR.

- Finally, we set out evidence relating to the **cost of building and operating DSR capacity**.

Taken together, these four elements allow us to describe the potential cost and capacity of DSR from each sector out to 2035.

This report provides a broad survey of research in these areas, including references to where more detailed estimates can be found. The evidence we draw on comes from a wide variety of sources, including past literature, trials, public data, as well as less formal interviews with market participants. In many areas, evidence will be scarce, or subject to extremely large uncertainties. Throughout the report, summary tables have been provided which set out the broad types of evidence we have drawn on (for example, empirical trials, if representative, *might* offer a more robust estimate of future customer behaviour than surveys or informed assumptions), as well as the particular uncertainties that exist.

The remainder of this section explains in more detail how this framework has been applied.

3.1 Sources of potentially shiftable load

Where evidence is available, we provide information on the DSR capabilities that each type of DSR could provide (split where appropriate into subtypes), and their potential load-shifting capacity.

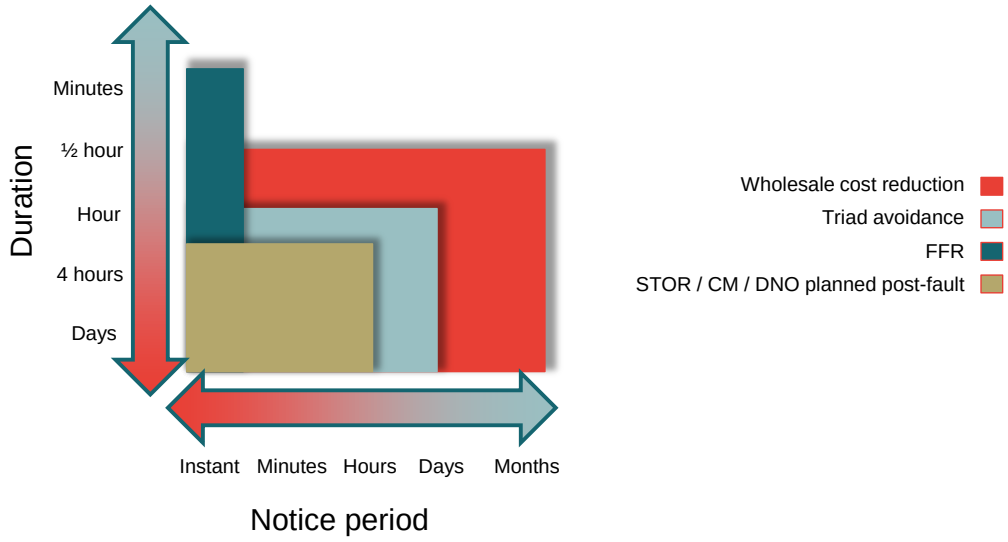
3.1.1 DSR capabilities

We first set out, in broad terms, the capabilities of load-shifting offered by each type of DSR. As explained in section 2, different uses for DSR have different requirements in terms of location, notice period, duration and frequency. We have chosen to focus on notice period and duration. This is since it is difficult to generalise where a particular type of DSR resource might be located,[46] and in many cases the reason why a particular form of DSR cannot be called frequently will be high variable costs (as in the case of diesel back-up generators), which are discussed separately.

These are illustrated with reference to the chart in **Figure 4**, which sets out the broad requirements of a few uses for DSR. This helps to indicate the different markets for which each form of DSR may be suitable. The lower-left of this diagram represents more challenging demands for DSR (longer durations of load reduction, with a shorter notice period).

[46] For example, a DNO may have need for DSR on specific feeders. We have not analysed data which might indicate whether sources of DSR (such as back-up generators, domestic appliances, or distributed generation) would typically be present on these types of feeder.

Figure 3. Duration and notice period requirements for a selection of DSR uses



Source: Frontier Economics

This type of analysis can feed into DECC's modelling in the following ways.

- First, as discussed in section 2, some uses of DSR may require specific capabilities. For example, DSR for frequency response needs to be able to react very quickly, but not necessarily for extended periods. Where the DDM explicitly models a use of DSR, this analysis can inform whether a specific type of DSR is capable of meeting that use. Alternatively, if the DDM does not model a given use of DSR, it may be necessary to adjust the cost and capacity of DSR in line with the discussion on synergies and conflicts in section 2.2.

- Where a form of DSR cannot provide the required duration of load-shifting for a particular DSR use, it may still be possible to sequentially dispatch subsets of the overall DSR capacity. For example, air conditioning units might only be able to be turned off for half an hour, but if half the units are turned off for one period, followed by another half, then an hour of load reduction might be achieved.[47] However, this would effectively halve the amount of DSR that can be called for the same cost. Such adjustments may need to be made to DDM inputs.

[47] If there is a significant amount of "payback" energy consumption after the DSR event finishes then this strategy may be less viable, as ever-increasing units would need to be dispatched to maintain a reduction in demand.

We also note that it may be possible for a portfolio of multiple types of DSR to provide services that no one part of the portfolio could provide in isolation.[48] For example, a quick acting but short-duration asset could be combined with a slower-acting asset capable of longer duration of load shifts. This report does not consider how such "optimal" portfolios of DSR can be built, which would require more complex modelling.

It should be stressed that these diagrams are only intended to be illustrative. For example, the notice period for Triad avoidance is based on the period given by a Triad warning that a supplier or other party may issue the day before they forecast a Triad.

3.1.2 DSR capacity

The type of capacity data that will need to be inputted into the DDM will depend on how far the potential capacity of DSR is likely to be exogenous (independent of the potential revenues from DSR uses) or endogenous (DSR capacity will depend significantly on the revenues that DSR can bring). The two examples below explain this further.

- At one extreme, stand-alone thermal plants (such as "diesel farms") are built purely to take advantage of revenues from DSR, such as STOR contracts, or high peak wholesale prices.[49] The relevant investment decision is whether to build such a plant or not. The DDM could be used to model the level of future investment in plants, given the costs of building and operating plant. **It would not be necessary to include a forecast of capacity in the model** (although, if desired, limits could be placed on how quickly plant could be built).

- At the other extreme, consumers purchase washing machines to do their laundry: it seems unlikely that the uptake and annual energy usage of washing machines will be materially affected by the potential for DSR. The relevant investment decision in this case is whether to enable existing assets (washing machines) for DSR. The DDM could model any investment in required enabling equipment, however **it would need to be supplied with an exogenous limit on capacity**, based on the expected power consumption of washing machines.

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48 As part of this project we spoke to UK startup Origami Energy, which is building a platform to enable a wide variety of demands for DSR to be met by optimising across a portfolio of different types of DSR (including distributed generation).

49 Dispatch of distributed generation during times of peak prices is included in the wide definition of DSR used in this report (see section 1.2).

Framework for the analysis of DSR supply by source

In practice, many forms of DSR will fall between these extremes. For example, the decision by a consumer to purchase a heat pump or an electric vehicle will depend to an extent on the cost of electricity to run it, which will be affected by the presence of time-of-use tariffs.

In this report, we have provided evidence on capacity limits for I&C back-up generation, and many of the forms of I&C and domestic load-shifting. These could potentially be entered into the DDM (subject to the limitations regarding demand profiles discussed in section 9).

We have also provided forecasts of potential distributed generation and grid-level storage uptake. However, since uptake of these technologies will be highly dependent on the revenues available from DSR, it may be more appropriate to let the DDM determine capacity endogenously.

3.2 Arrangements for calling DSR

The extent to which entities are willing and able to carry out DSR actions will depend upon the contractual and technical mechanisms used to bring about load shifting. Any scenarios for future DSR uptake will need to make assumptions regarding how these mechanisms are taken up, and what types of DSR they can facilitate.

We have considered the following broad dimensions along which DSR arrangements can differ:

- First, **the notice period with which DSR can be called**. Static DSR (where the pattern of load-shifting is determined far in advance) is simpler to implement and understand. However, it cannot provide the sort of dispatchable load-shifting required by the Capacity Market during unpredictable stress events, or to account for unforeseen short-term changes in the wholesale electricity market. Dynamic DSR (with very short notice periods) will require the existence of some sort of real-time communications system from those requiring DSR to those that can provide it, as well as a way of verifying that the DSR actually occurred after the event.

- Second, **whether price signals or direct control contracts are employed**. Holders of shiftable load may be encouraged to shift load on a voluntary basis through a price incentive – for example, a time-of-use tariff where the price of electricity varies with time, or a critical peak tariff where a pre-determined high price or rebate is set for periods of exceptionally high demand. Alternatively, a contract may give the supplier (or another entity) the power to directly send instructions to turn appliances on or off.

- Finally, **whether the provider of the DSR resource has a passive or active role**. Arrangements that require a DSR provider to actively adjust the

demand or generation of appliances in a manual way may have fewer technical requirements, but *may*[50] be less likely to produce a firm and predictable response. DSR that gives the provider a passive role will require the existence of automation.

For each type of DSR, we have considered the type of arrangements that might exist, and provided any information on how prevalent they might be in the future.

3.3 Costs

We have considered the three broad classes of cost that would be required for an investment and dispatch model (such as the Dynamic Dispatch Model), or the construction of levelised costs. These are:

- **Capital costs**: The investment (in £/kW) required to add a unit of additional DSR capacity to the system. This may relate to either the construction of an entirely new asset (for example, a battery connected to the distribution network), or the upgrade of an existing asset to enable DSR (for example, the investment needed to dispatch I&C back-up generators on demand).

- **Fixed O&M costs**: The ongoing costs (in £/kW/year) incurred once DSR capacity is added, regardless of whether it is used. These would include fixed running costs of equipment, as well as any fixed availability payments that need to be paid to secure the use of an asset for DSR.

- **Variable costs:** The costs (in £/kWh) required to carry out load reduction. For example, a technology that stores energy may be subject to storage losses, or generators may have fuel costs.

We also discuss the associated greenhouse gas emissions and local emissions associated with the use of each type of DSR.

50 Automation does not guarantee a 100% firm response: DSR actions may not occur when called, due to factors such as equipment failure, or customer override (where permitted).

4 Distributed generation

This section describes the cost and potential of "DSR" that could be provided from generation capacity connected to the distribution networks. The provision of DSR from generation capacity may seem counterintuitive. However, from the point of view of the System Operator, embedded generation (i.e. generation connected to a distribution network rather than the transmission network) offsets demand, and so may be seen as offering DSR.

In this section, we first outline the relevant types of distributed generation that exist, what types of DSR they may be capable of providing, and provide forecasts of future capacity from National Grid. Next, the different arrangements through which DSR may be obtained from these plants are listed. We then briefly set out some information on the plant-level costs arising from these technologies.

This section covers all forms of distributed generation, except backup generators used by I&C firms (typically diesel or gas reciprocating engines). Due to their primary use outside the energy markets, use of such generators for DSR has a different cost structure, and they are discussed in section 5. Reciprocating engines built for other (non-emergency) purposes are nonetheless highly significant, and are considered in this section.

4.1 Sources of potentially shiftable load

There is a wide variety of distributed generation that could potentially provide DSR, ranging from large power stations to much smaller "behind-the-meter" units.

- The largest distributed generators will be over 100MW (a particularly large example is the 400MW CCGT at Shoreham).[51] Such plants will need to have agreements in place with both the DNO (a G59 connection) and the TNO, may participate in the balancing mechanism, and may be registered via the Central Meter Registration System (CMRS) rather than via a supplier. Such generators would be ineligible for the Transitional Arrangements for DSR in the Capacity Mechanism, which exclude generators that are over 50MW or registered on the CMRS.

- Smaller embedded generators (for example a 10MW CHP plant) are likely to supply electricity via a supplier account (the Supplier Meter Registration System, SMRS), and will still require a G59 connection agreement with their DNO.

51 Data from the Capacity Market register for the 2014 T-4 auction.

- The smallest generators (those rated at under 16A per phase or less – i.e. 3.68kW for a single-phase supply or 11.04kW for a three-phase supply)[52] may be eligible for a G83 connection. Most domestic solar panel installations would fall into this category. These could potentially provide DSR in conjunction with domestic electrical energy storage devices, discussed in section 7.1.7.

In most cases, the business case for building any new distributed generation will depend largely on the energy markets. Investments are made in generation on the basis that they will be recouped through the sale of energy (or, for firms owning CHP plants, avoidance of additional energy purchases), the Capacity Market, and the sale of ancillary services such as STOR. A key exception is standby generation, which is primarily purchased for business continuity reasons, but may then be used to generate revenues or avoid costs related to the energy markets. We therefore consider standby generation separately, in section 5.

Not all forms of distributed generation are likely to be suitable for providing DSR. First, the plant will need to be dispatchable (so it can be instructed to provide generation when required). In addition, to provide a decrease in net demand on the transmission network, the generation must not have been running at that time in the first place. Generation types with very low variable costs (such as geothermal technologies) are therefore unlikely to provide DSR,[53] since this would require foregoing significant wholesale market revenues. It is more likely that such technologies could provide flexibility in conjunction with storage (storage at the distribution network level is discussed in section 8).

In addition, dynamically dispatched forms of DSR will require the presence of a system to communicate the need for a DSR event to the plant. This is already likely to be the case for generation built with the intention of participating in the wholesale or ancillary services markets.

For the purposes of its Future Energy Scenarios publications, National Grid divides distributed generation technologies into three groups: Thermal generation, renewable generation, and CHP (which may be powered by conventional or renewable fuels). Below, we briefly set out the types of technologies that these categories include, and a National Grid scenario[54] for

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52 Energy Networks Association (2014) *Distributed Generation Connection Guide*

53 Such technologies could still provide flexibility by *reducing* their output on demand, as is the case with wind curtailment. As described in section 1.2, such actions fall outside the scope of this report, which considers only actions which can reduce demand at a particular moment in time.

54 We have used figures from National Grid's "Gone Green" scenario. This relates to a world of both high affordability (i.e. a strong economy) and sustainability, with an intermediate level of distributed generation compared to the other scenarios considered by National Grid.

Distributed generation

their capacity out to 2035. We provide background (where available from the Capacity Market auction register) on the type of entities that own generation.

National Grid produces separate scenarios for micro-generation, which it defines as units under 1MW in size and consists mainly of solar generation. See section 7 for more information on how domestic micro solar PV installations, in combination with storage technologies, could provide DSR. Under some pathways for decarbonisation in other publications (but not this scenario), uptake of Micro CHP such as Stirling engines installed at the domestic level is significant. Such systems would be able to meet some needs for DSR, either by reducing household net demand, or spilling excess power onto the distribution network. However, we do not consider them in this report.

Summary of the evidence base

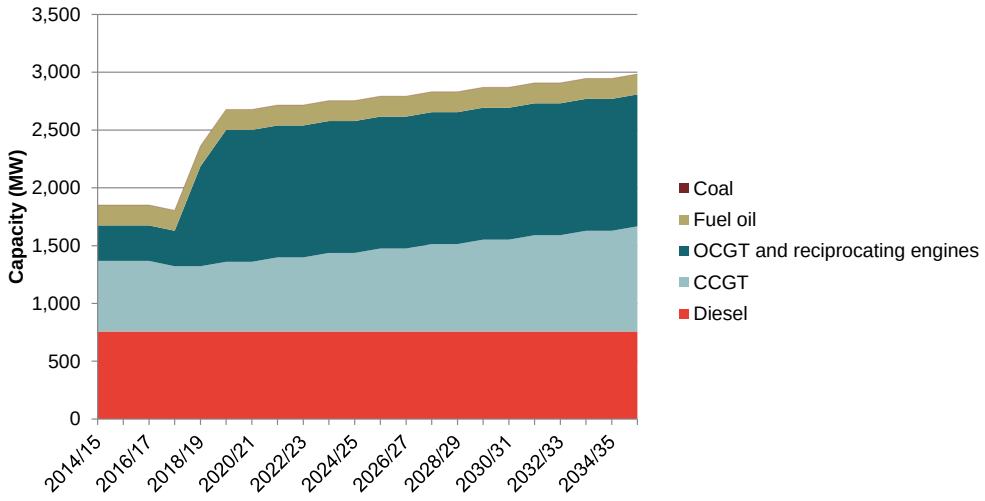
The table below summarises the main types of sources that have been used in this section, and indicates where some of the greatest uncertainties lie.

Area	Main sources of evidence and robustness
Current distributed generation capacity	Figures have been drawn from National Grid's *Future Energy Scenarios*, which are broadly similar to those reported in DUKES. The capacity of larger distributed generators is well understood. However, there are much greater uncertainties associated with smaller "behind-the-meter" generators. We understand that National Grid bases its estimates on a variety of sources (for example, the capacity of "behind-the-meter" generation that engages with STOR or other ancillary services.
Future distributed generation capacity	We have presented a potential scenario ("Gone Green") from National Grid's *Future Energy Scenarios*. There are considerable inherent uncertainties in forecasting the capacity of distributed generation out to 2035 (which will depend on factors such as technological improvements and policy choices), and "Gone Green" is merely one plausible scenario among many. However, as discussed in section 3.1.2, distributed generation investment could be modelled endogenously within the DDM, in which case forecasts would not need to be entered into the model.
DSR capabilities of distributed generation	The technical capabilities of existing technologies are broadly known (in this report, we include parameters for thermal generation from a technical report for DECC). Greater uncertainty may exist for CHP, since the flexibility depends on the configuration and operating regime of each specific installation.

4.1.1 Thermal generation technologies

Figure 4 sets out the "Gone Green" projection used by National Grid for the future capacity of distributed thermal generation.

Figure 4. National Grid "Gone Green" projection for distributed thermal capacity



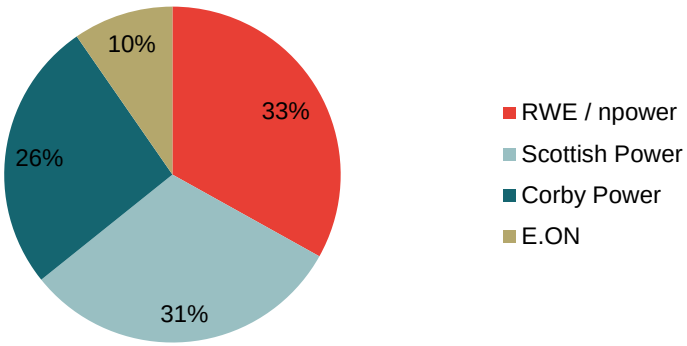
Source: National Grid

The main types of technology included within this scenario[55] are:

- **Combined cycle gas turbines (CCGTs)**. The addition of a steam turbine to a gas turbine leads to greater efficiencies, but also greater capital costs. These are typically large units: Of the 46 existing CCGTs present on the Capacity Market register for the T-4 auction held in December 2014, only 9 were connected to the distribution network. These units had an average de-rated capacity of 152MW. As shown in **Figure 5**, these units are owned by vertically integrated generators (Corby Power is owned by ESB).

55 As shown in the figure, there is also a smaller quantity of fuel oil plant.

Figure 5. Derated capacity of distributed CCGTs in the CM register by owner

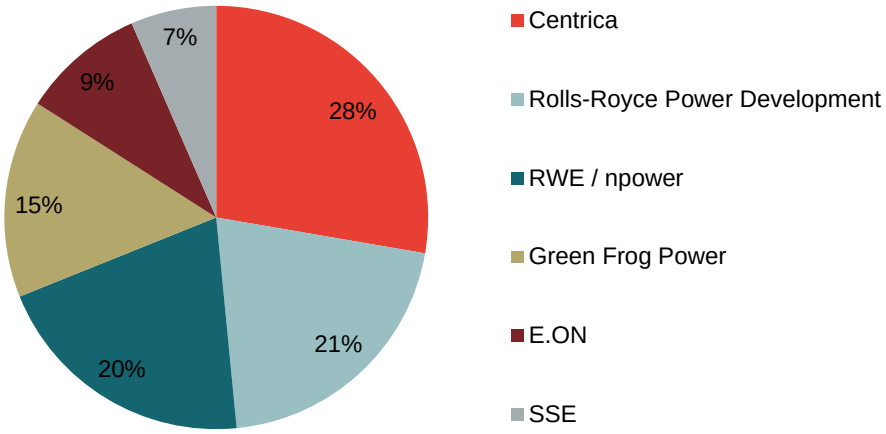


Source: Frontier analysis of CM register

- **Open cycle gas turbines (OCGTs)**. These units are typically much smaller than CCGTs: The average size of existing distributed OCGTs on the capacity register is 42MW.[56] As shown in **Figure 6** (based on the Capacity Market Register), the ownership of existing assets is more diverse than for CCGTs. In addition to the vertically integrated energy firms, these plants are owned by two independent generators (Rolls-Royce Power Development and Green Frog Power).

56 Based on stripping out CMUs identified by DECC as being reciprocating engines.

Figure 6. Derated capacity of distributed OGCTs in the CM register by owner



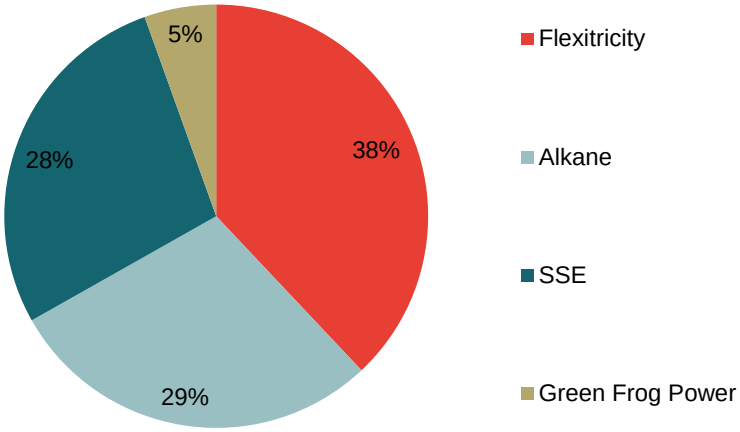
Source: Frontier analysis of CM register.

- **Gas reciprocating engines.** The average size of the six existing gas reciprocating engines on the capacity register is around 8MW. Of these, all but one (accounting for 80% of capacity) are owned by entities related to Alkane, with SSE owning the remaining CMU. It should be noted that UK Power Reserve owns a further 12.3MW of capacity that was entered as refurbishing.

- **Diesel engines**. National Grid will only be aware of diesel engines that are "visible" – i.e. participating in schemes such as STOR or the Capacity Market. This will include both diesel generators purpose-built for such schemes by specialists such as Green Frog Power, as well as a proportion of the back-up diesel generators discussed in section 5. DECC have carried out an analysis of the Capacity Market Register, and have identified 60MW of existing diesel reciprocating engines. **Figure 7** shows how this capacity breaks down by ownership.[57]

[57] The capacity marked "Alkane" is owned by Regent Park Energy Limited, a subsidiary.

Figure 7. Derated capacity of diesel reciprocating engines in the CM register by owner



Source: Frontier analysis of CM register.

All of these types of thermal generation are likely to be able to provide a variety of DSR services. The time taken for a generator to start up (i.e. the notice period required) depends on both the technology, and may also depend on how recently it was running: Start-up times for larger OCGTs and CCGTs are shortest for a "hot start" (if the generator was running within the last few hours), longest for a "cold start" (if it has been at least a couple of days since the generator was running), with a "warm start" in between these extremes.

- Diesel generators typically have a fast start-up time (perhaps as quick as ten seconds);[58]
- gas reciprocating engines also have a fast start-up;'[59]
- a small aeroderivative OCGT (these are units based upon aircraft engines, with a capacity of 60MW-100MW) might take 2-5 minutes to synchronise with the grid, and a further 4-8 minutes to reach full capacity;[60]

58 http://www.dieselforum.org/files/dmfile/dtf_powergen_2013factsheet_fin1.pdf

59 US EPA (2015) *Catalog of CHP Technologies*

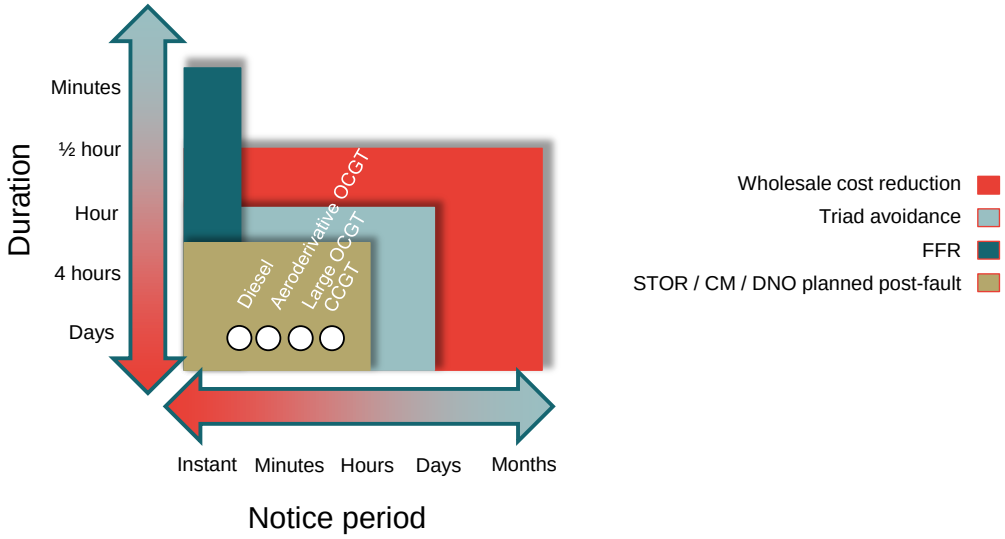
60 Parsons Brinckerhoff for DECC (2014), *Technical Assessment of the Operation of Coal & Gas Fired Plants* – this source also used for large OCGT and CCGT figures

- a large OCGT (with a capacity of between around 125MW and 180MW) could take 15 minutes to synchronise after a warm start, and a further 15-30 minutes to reach full capacity;
- a gas CCGT (of around 160MW-300MW) might take 15 minutes to synchronise, from a warm start, and a futher 80 minutes or more to reach full power.

Once started, the types of thermal generation described above could continue to provide output for many days.

Figure 8 provides an illustrative view of the capabilities of three types of thermal generator, compared to some of the uses of DSR described in section 2.1. Subject to being in an appropriate location, these types of generation are likely to be able to meet most uses for DSR that do not require an extremely rapid start-up. A faster response may also be possible under hot start conditions, or from ramping up generation that is already running (as in the case of spinning reserve).

Figure 8. Illustrative DSR capabilities of distributed thermal generation, based on time to full power from a warm start

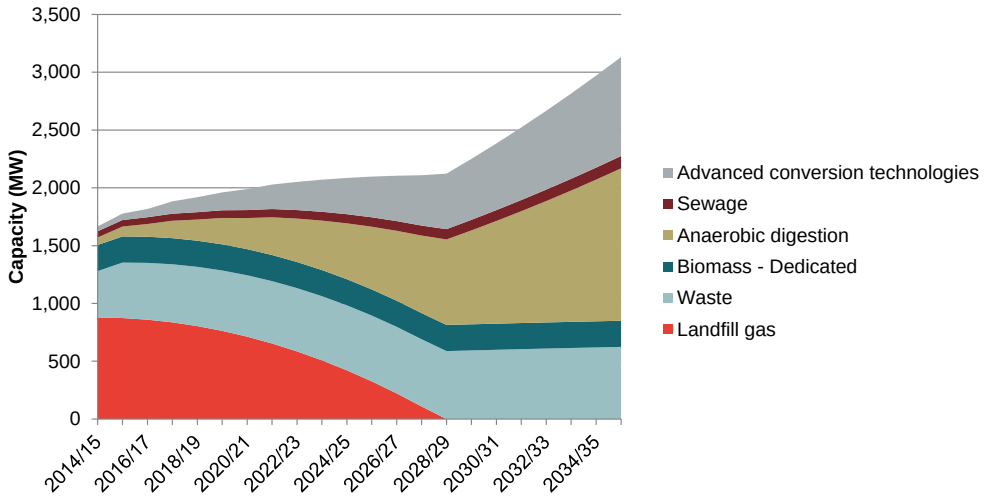


Source: Frontier Economics

4.1.2 Renewable generation technologies

Figure 9 sets out National Grid's "Gone Green" projection for the capacity of distributed renewable generation. We have excluded solar, wind, hydroelectric, marine and geothermal technologies from this chart: As explained above, for commercial reasons, these are unlikely to be able to provide the flexible generation required for DSR.

Figure 9. National Grid "Gone Green" projection for distributed renewable capacity



Source: National Grid

The technologies covered are as follows.

- **Advanced conversion technologies**: Covers a variety of high-temperature processes used to produce fuels from biomass, including gasification and pyrolysis.[61] These fuels can then be burned to produce heat and electricity.

- **Sewage:** Sewage can be used in a variety of technologies, including combustion, gasification, pyrolysis and anaerobic digestion.[62]

- **Anaerobic digestion:** A process where micro-organisms break down the organic matter found in wet biomass waste (such as sewage sludge, animal manure, slurry and waste food), in the absence of oxygen, to produce biogas. This can then be burned to produce heat and electricity.

- **Dedicated biomass:** The direct combustion of biological material to produce heat, and ultimately electricity. The main source of biomass in the UK is timber from forestry.[63] Biomass may also be co-fired alongside fuels

61 DECC website (https://www.gov.uk/generating-energy-from-waste-including-anaerobic-digestion) visited on 11/05/2015

62 Biomass Energy Centre website (http://www.biomassenergycentre.org.uk/portal/page?_pageid=75,18722&_dad=portal&_schema=PORTAL) visited on 11/05/2015

63 Biomass Energy Centre website (http://www.biomassenergycentre.org.uk/portal/page?_pageid=73,1&_dad=portal&_schema=PORTAL) visited on 11/05/2015

such as coal (although the National Grid Gone Green scenario does not include any co-firing capacity connected to the distribution networks).

- **Waste:** The combustion of material such as wood waste, straw, poultry litter, and the biomass portion of municipal waste to produce heat, and ultimately electricity.

- **Landfill gas:** Combustion of methane derived from landfill to produce heat, and ultimately electricity.

Very few biomass generators are present in the CM register. This is likely because generators receiving Renewable Obligation Certificates (ROCs) would not be eligible for a Capacity Agreement (the Capacity Market is designed to avoid such "double" subsidisation).

The start-up time (and thus the notice period required for DSR) will vary by technology. If biogas derived from a process such as anaerobic digestion were used to fuel a gas reciprocating engine, then the start-up time might be short. However, for conventional biomass schemes where the biomass is directly combusted to power a boiler, start-up times may be far longer. For example, a small steam turbine fired using woodchips might take three hours for a warm start.[64]

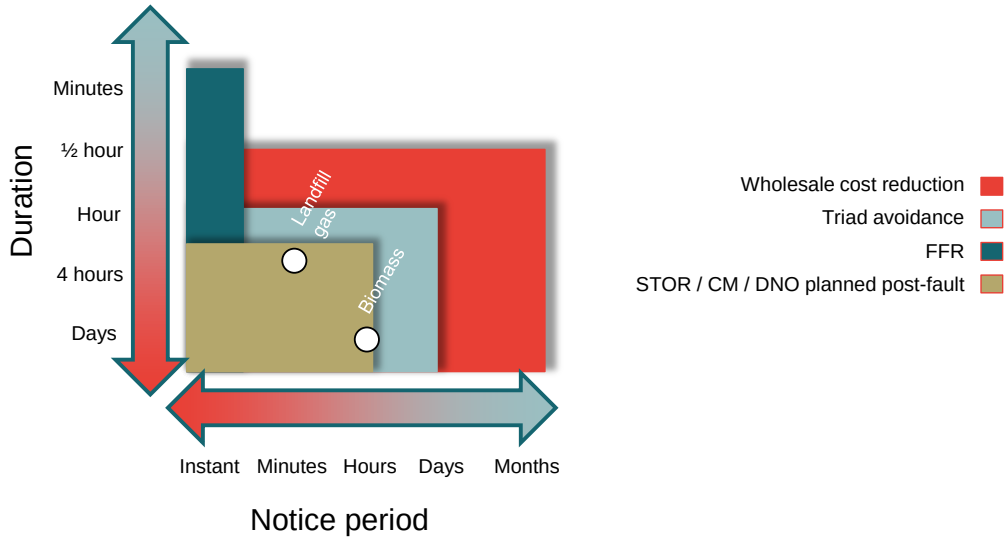
There are also potentially limits regarding the duration of response that could be provided, due to limited potential for storage. For example, a landfill gas site may be able to retain a few hours' worth of gas before flaring is required or gas leaching becomes an issue. Similarly, sewage gas and biogas would require dedicated storage facilities.[65]

Figure 10 provides an illustrative view of the potential DSR capabilities of a conventional solid biomass and a landfill gas generator. Despite their limitations in terms of notice period and DSR duration respectively, these technologies still seem likely to be able to provide for many of the same types of DSR use that thermal generation can supply.

64 Energinet.dk (2012), *Technology Data for Energy Plants*

65 Sustainability First (2013) *What Demand Side Services Does Distributed Generation Bring to the Electricity System?* p23

Figure 10. Illustrative DSR capabilities of distributed renewable generation

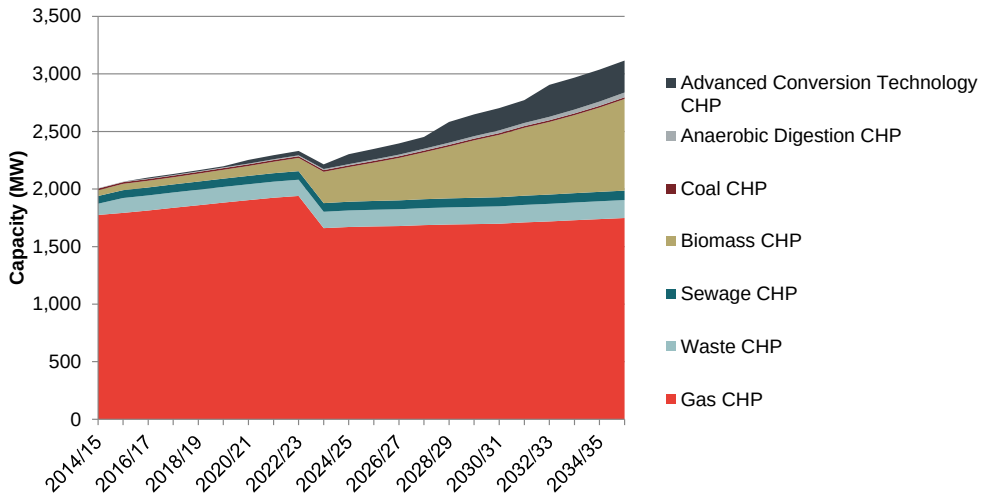


Source: Frontier Economics

4.1.3 CHP generation technologies

As shown in **Figure 11**, the vast majority of current CHP capacity is gas-fuelled (this will be a mixture of gas turbines and gas reciprocating engines). National Grid's "Gone Green" scenario indicates a steady increase in the capacity of renewable CHP (both biomass and advanced conversion technology).

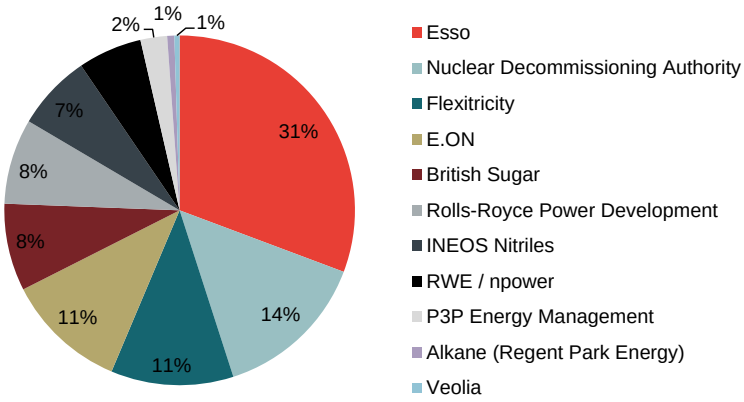
Figure 11. National Grid "Gone Green" projection for distributed CHP capacity



Source: National Grid

Figure 12 illustrates the ownership of CHP capacity that participated in the December 2014 CM auction. This shows a mixture of firms including vertically integrated energy companies, large industrial users (such as British Sugar and INEOS Nitriles) and an aggregator (Flexitricity). It is possible that other CHP capacity may have entered the auction as DSR. In addition, as this data is based on the capacity register, it will only capture those owners of CHP that engaged with the capacity mechanism.

Figure 12. Derated capacity of CHP generators in the CM register by owner



Source: Frontier analysis of CM register. Figures for Alkane include Darent, Regent Park, and Rhymney.

Many operators of CHP plants already participate within STOR, either directly, or through an aggregator. However, not all CHP units will be suited to forms of DSR which require that generation can be *increased* on demand.

- If the CHP unit is already providing power, then there may be little scope to increase generation.[66] It has been indicated to us that this may be a particular issue for smaller (sub-2MW) CHP units, which are often sized to meet on-site demand but no more. Such units may also face additional maintenance costs if they are operated flexibly (rather than as baseload).

- Larger gas turbine CHP units may have more flexibility. For example, these plants can temporarily increase their electrical output through water injection, while steam turbines can utilise an air cooled condenser as an additional heat sink. However, dumping heat in this way lowers the overall efficiency of the unit. This could potentially lead to a loss of "good quality" CHP status, which is a prerequisite for some policy benefits. As a result, some CHP plants may find it difficult to participate in DSR schemes which require frequent load reduction actions.

It is difficult to draw generalisations: Some CHP units are likely to have similar characteristics to the OCGTs and reciprocating engines illustrated in **Figure 8**, but many may be unable to supply DSR as quickly or for as long. The extent to which an individual CHP plant can provide DSR will depend on factors such as the underlying heat demand profile of the site, as well as whether the CHP technology allows the "dumping" of excess heat. Analysis previously carried out for DECC considered 298 different types of CHP plant, each with their own heat demand profile.[67]

4.2 Arrangements for calling DSR

The extent to which distributed generators can provide DSR will depend not only on the technical characteristics of the generator (such as the possible duration and notice period for DSR), but also the arrangements available for calling DSR. **Table 6** summarises some of the different arrangements through which distributed generators can provide DSR.

Most owners of generators are likely to be able to provide DSR with longer notice periods incentivised through mechanisms such as varying wholesale prices, TNUoS (transmission network use of service) and DUoS (distribution network

66 Such units could potentially still enter the Capacity Market as generation.

67 Ricado-AEA for DECC (2014), *Bespoke Gas CHP Policy – Cost curves and Analysis of Impacts on Deployment* p11

use of service) charges. However, the extent to which generators are able to provide dynamic DSR (with short notice periods) is likely to vary significantly.

Generating units dispatched by companies with a focus on the energy sector (such as vertically integrated firms) are likely to have the capability to respond to within-day changes in the wholesale price of electricity. In addition, a large number of flexible plants already contract for services such as STOR, and are therefore likely to have a control capability and metering that can demonstrate they have carried out DSR actions.

It is less certain whether owners of smaller distributed generating units (such as smaller CHP plants) would be able to engage in dynamic DSR in this fashion: It seems unlikely that a company without a primary focus on the energy market would trade in the intraday wholesale market, and we understand from industry sources that the wide range of ancillary services (such as STOR and the Capacity Market) may be confusing for smaller firms. Some services may also have size limits that exclude smaller generators that are not part of a larger portfolio. Dynamic dispatch of DSR for these types of generator is therefore more likely to be mediated by an aggregator, which would need to install equipment to remotely dispatch generation.

Table 6. Methods of calling DSR for distributed generation

DSR arrangement	Description	Notice period	Automation	Contract type
Intraday wholesale price of electricity	Generators may trade in the intraday market, or with a vertically integrated supplier.[68] Where generator owners do not have the facilities to carry out such trading themselves, they may contract out capacity to another entity through a Power Purchasing Agreement (PPA).	1 hour	We are not aware of any explicit automation. However, sophisticated generators are likely to have models that assist them in making dispatch decisions.	Price mechanism
Forward wholesale price of electricity	Generators may sell power on the day-ahead market, or further ahead through forward contracts.	1 day or more		Price mechanism
TNUoS charges	The TNUoS charging structure provides an incentive for generators to produce power during the three half-hour TRIAD periods. In practice, TRIADs cannot be perfectly predicted, and so generators need to generate during a larger number of TRIAD warnings to reliably take advantage of this.	1 day (typical triad warning time period)		Price mechanism

[68] In responses to the Competition and Markets Authority, some large vertically integrated generators indicated that they hedged a large amount of their generation, and consequently only a limited quantity was sold within the intraday market. However, Drax noted that some marginal plants (such as old CCGTs) may not have the opportunity to trade in the forward market. See CMA (2015), *Energy Market Investigation – Market Power in Generation* p25

Table 6. Methods of calling DSR for distributed generation

DSR arrangement	Description	Notice period	Automation	Contract type
DUoS charges	Generators face an incentive to produce power during "red" periods of high demand.	Months ahead		Price mechanism
Direct control	A signal is sent to initiate a DSR event. This includes the systems used to initiate National Grid services such as balancing mechanism call-offs, STOR, Capacity Market warnings, and the systems used by aggregators to dispatch DSR.	Can be in real-time (as for non-dynamic FFR), although schemes such as STOR provide for a notification window	Installed for some arrangements (e.g. FFR and DSR carried out though aggregators), not required under the Capacity Market.	Direct request

Source: Frontier Economics

4.3 Costs

Summary of the evidence base

The table below summarises the main types of sources that have been used in this section, and indicates where some of the greatest uncertainties lie.

Area	Main sources of evidence and robustness
Existing costs of building and running distributed generation	DECC regularly commissions reports on the cost of renewable and non-renewable generation technologies. The costs of existing forms of generation are relatively well understood, and we report some headline figures. The referenced data sources provide bands for cost, which give some indication of the uncertainties. These reports have historically not covered diesel and gas reciprocating engines. However, we understand that the latest iteration of this work will include figures for this technology.
Future costs of building and running distributed generation	DECC's electricity generation cost reports include scenarios for future costs (not reported here). However there are significant uncertainties (e.g. relating to appropriate learning rates).
Current costs associated with enabling "behind-the-meter" generation for DSR	We have interviewed a number of aggregators to discuss the broad costs associated with enabling a unit such as a CHP plant to carry out dynamic DSR (these are reported in the following section on back-up generation). However, these are simply "best guesses", and in any event vary substantially across installations.
Future costs associated with enabling "behind-the-meter" generation for DSR	It is even more difficult to predict how these costs could evolve over time, and we have not provided quantitative forecasts.

Distributed generation will have associated capital, O&M and variable costs. DECC regularly commissions updated cost forecasts for a wide range of generation technologies: **Figure 6** summarises some thermal and renewable technologies from these sources.

Distributed generation

Table 7. Summary of costs for standalone generation

	Capital costs (£/kW)	Fixed O&M costs (£/MW/year)[69]	Variable O&M costs (£/MWh)	Efficiency	Fuel
CCGT[1]	£581	£21,954	£0.08	58.8%	Gas
OCGT (large frame gas turbine)[1]	£295	£9,879	£0.03	39.0%	Gas
OCGT (aeroderivative)[2]	£494	£23,000	£0	35%	Gas
Reciprocating engine (gas)[3]	£263	£10,000	£0.05	36%	Gas
Reciprocating engine (diesel)[3]	£263	£10,000	£0.07	36%	Diesel
Dedicated biomass (<50MW)[4]	£3,696	£110,000	£5.3	31%	Biomass
Anaerobic digestion[4]	£4,180	£300,000	£31.10	37%	Waste material
Advanced Conversion Technologies (advanced)[4]	£7,210	£410,000	£12.90	26%	Biomass
Advanced Conversion Technologies (standard)[4]	£5,960	£430,000	£24.00	22%	Biomass

69 Excludes insurance, connection and UoS charges

Sources:

1) https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/223634/2013_Update_of_Non-Renewable_Technologies_FINAL.pdf (costs are in 2012 pounds)

2) https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/65712/6884-electricity-gen-cost-model-2012-update.pdf (costs are in 2012 pounds)

3) Draft of forthcoming update of DECC's electricity generation cost model for non-renewable technologies (cost figures are in 2014 pounds)

4) https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/223642/UPDATE_OF_THE_COSTS_OF_RENEWABLE_GENERATION_-_FINAL_agreed.pdf (costs are in 2012 pounds)

Distributed generation

We understand that the latest cost update that has been commissioned for DECC will also include diesel reciprocating engines. In general, these units have low capital costs that might be approximately in line with a large frame gas turbine, although the units will typically be of a smaller size.

As described in the previous section, owners of smaller generation (such as smaller CHP plants) may only be able to provide dynamic DSR through an aggregator. This would require costs to be incurred, which would be similar to those for an aggregator to obtain diesel back-up capacity. We discuss these in section 5.3.

Greenhouse gas and local emissions

Combustion-based generation technologies will[70] emit carbon dioxide and other greenhouse gasses. DECC has emission intensity estimates which are used for applications such as levelised costs.[71]

If these emissions are internalised (i.e. paid for by generators), then they will increase the costs of these forms of DSR, potentially decreasing the volume that is utilised. Carbon is priced via the EU ETS, which excludes installation with a thermal input of 20MW or under (and units exclusively burning biomass).[72] Therefore, smaller distributed generation (which will include many reciprocating engines and CHP plants) will not directly face these costs.

In addition, combustion-based technologies will produce air pollutants including nitrogen oxides, carbon monoxide and unburned hydrocarbons, which may adversely affect local air quality. Such local pollution might of particular concern for CHP plants, if the need to co-locate with a source of heat demand means that they are in more built-up areas. The principal pollutants of concern with internal combustion engine or gas turbine CHP plants are nitrogen oxides,[73] and the following table provides a summary of typical emissions from various types of natural gas fired CHP plant. Among these technologies, the gas turbines produce less local nitrogen oxide emissions than reciprocating engines.

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70 Unless fitted with carbon capture and storage.

71 For example, see DECC (2013), Electricity Generation Costs December 2013 p18

72 DECC (2013), *European Union Emissions Trading System – Regulatory guidance for installations (including excluded installations)*

73 Environmental Protection UK (2012), *Combined Heat and Power: Air Quality Guidance for Local Authorities* p23

Table 8. Typical nitrogen oxide emissions from natural gas fuelled CHP systems

Prime mover	Additional technology	Typical NO_x emission (g/kWh)
Gas Turbine		1.1
Gas Turbine	Back pressure steam turbine	0.9
Small Scale Gas Turbine		0.2-0.5
Compression Ignition Engine		5-10
Spark Ignition Engine		5-20
Spark Ignition Engine	Lean burn	3
All CHP plant reviewed in consultation with manufacturers		0.2-22

Source: Environmental Protection UK (2012), *Combined Heat and Power: Air Quality Guidance for Local Authorities* p23. This publication focusses on nitrogen dioxide emissions, and does not cover particulates or sulphur dioxide in depth.

5 I&C back-up generation

I&C sites frequently have back-up generators, typically diesel-fired,[74] for emergency use. This generation falls into the definition of DSR used in this study, as by running the generator during non-emergency periods, it is possible to displace demand that would otherwise have occurred. It is also potentially possible to export electricity to the grid.

Standalone generators were considered in section 3. We are considering back-up generators separately as their participation in DSR is associated with a different cost structure. While investment in standalone generation is driven by potential energy system revenues, the primary driver behind the installation of a back-up generator is usually the need to provide emergency power to a given site. The relevant decision to model is therefore whether pre-existing back-up generators will be used for DSR – for dynamic DSR this may require investment in control systems.

In this section, we first outline the potential capacity and capabilities of I&C back-up generators. We then outline the different arrangements through which DSR may be obtained from these generators (owners of diesel backup generation providing DSR frequently do so through an aggregator). Finally, we provide an overview of the plant-level costs arising from these technologies.

5.1 Sources of potentially shiftable load

An estimate of the DSR capacity that might be obtained from diesel generation can be obtained as follows:

- first, considering the total capacity (in GW) of back-up generation that may exist across the UK over the next 20 years;
- next, looking at what proportion of this fleet might be willing to run their back-up generators for purposes other than emergencies, and how this may change over time; and
- finally, estimating what proportion of back-up generator capacity might be available at any given time.

We provide information on each of these areas below, before summarising the broad DSR capabilities of I&C back-up generation.

74 For example, Element Energy (2012), *Demand side response in the non-domestic sector* states that back-up generators are typically diesel-fuelled, except for the very largest sites which may have OCGTs.

Summary of the evidence base

The table below summarises the main types of sources that have been used in this section, and indicates where some of the greatest uncertainties lie.

Area	Main sources of evidence and robustness
Current capacity of back-up generators	Discussions with a number of stakeholders (including DECC, National Grid, and some aggregators) have indicated that this is an area of particular uncertainty. We have provided scenarios based on previous literature, however it has not been possible to verify how these figures were constructed. Being "behind the meter", back-up generation is inherently difficult to quantify.
Future capacity of back-up generators	We have carried out a simple extrapolation of the scenarios described above using I&C energy projections from DECC's Energy and Emissions Projections. This is a highly simplistic methodology which can only be considered to produce an illustrative scenario. Ideally, a bottom-up analysis would be carried out of how much back-up capacity each I&C sector uses, and how each sector might grow over time.
DSR capabilities of back-up generators	The broad technical capabilities of back-up generators are relatively well understood.

5.1.1 DSR capabilities

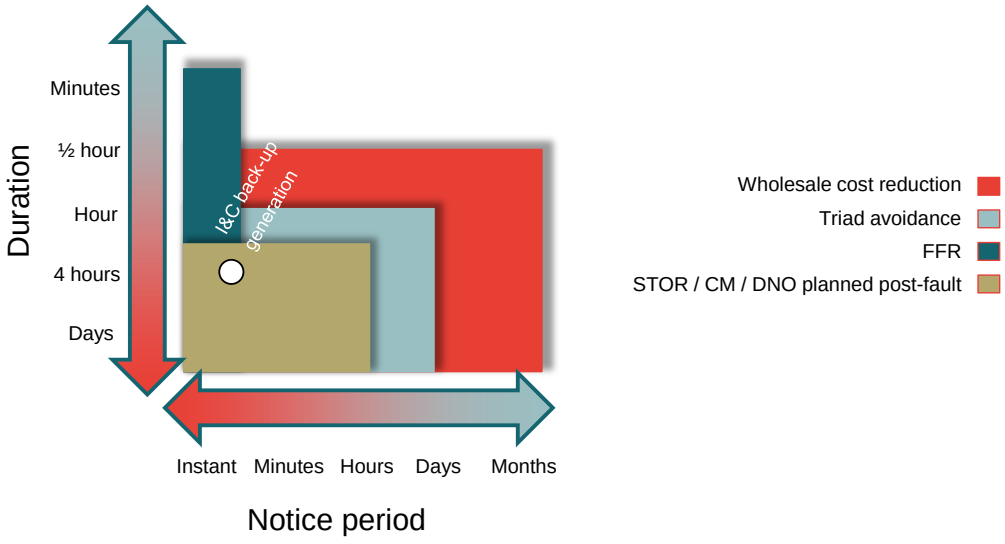
I&C back-up generators can be dispatched quickly. In principle, a unit combined with an uninterruptable power supply (UPS) can switch over instantly (to avoid loss of power), however we are not aware of aggregators currently using back-up generators to provide the extremely quick response required for services such as FFR. Back-up generation used by Wessex Water for reserve services are capable of reaching full output after 15 minutes.[75]

The duration of generation run time is likely to be limited to a number of hours as consumers will wish to avoid running back-up generators (designed for a limited duration of power loss) for extended periods, and might also have limited fuel stores.

75 Sustainability First (2013), *What Demand Side Services Does Distributed Generation Bring to the Electricity System?* p24

As shown in **Figure 13**, I&C back-up generation is therefore likely to be physically suitable for most uses of DSR (except potentially those requiring an instant response). There may be further constraints upon the uses of DSR that can be economically met through back-up generation (given the associated running costs), and we discuss these in section 5.3.

Figure 13. Illustrative DSR capabilities of I&C back-up generation



Source: Frontier Economics

5.1.2 DSR capacity

Back-up generators can be found in the most electricity-critical organisations where the consequences of a loss of power would be severe. Examples that have emerged during this research include entertainment venues,[76] hospitals,[77] banks[78] and telecommunications businesses[79] (including data centres).

While the electricity-critical nature of these businesses may mean they are wary of committing to DSR, many such sites have "overcapacity", in that their generation capacity exceeds typical load levels.[80] In such cases, it may be possible for

76 The FALCON commercial trials explored using MK Dons' football stadium for generation-led DSR

77 Several hospitals use the Crown Commercial Services DSR framework agreement

78 Sustainability First (2013), *What Demand Side Services does Distributed Generation Bring to the Electricity System?* [24

79 Torriti, J. and Grünewald, P. (2013), *Demand Response from the non-domestic sector: early UK experiences and future opportunities*, preprint

80 Torriti, J. and Grünewald, P. (2013), *Demand Response from the non-domestic sector: early UK experiences and future opportunities*, preprint, p14

generators to produce a net export of energy from a site, although this does require an export license to be in place[81] - we discuss this issue below.

Back-up generators are typically found alongside uninterruptable power supply (UPS) systems, which can handle load before the generator starts up. An aggregator we spoke to indicated that UPS units (for example within data centres) could be suitable for use in National Grid's Frequency Control by Demand Management scheme. Although at least one aggregator has indicated there is a potential for data centre UPS to be used in the Capacity Market,[82] this refers to diesel rotary UPS systems – a combination of a large flywheel for instant response, plus a diesel generator to provide back-up for longer periods. Estimates of total UK UPS capacity exceed 4GW.[83]

There does not appear to have been significant recent research into the overall capacity of back-up generation within the UK and estimates vary widely.[84] Many reports[85] refer to a figure of 20GW, which ultimately appears to be derived from a 2000 report for the DTI.[86] However, some aggregators we spoke to felt that 20GW seemed excessive, which seems possible (even accounting for the oversizing of back-up generation described above) given that GB peak load is only approximately 60GW.

Sustainability First have previously concluded[87] that more analysis would be needed to reliably improve on the 20GW estimate. This figure could potentially be improved using a variety of sources.

- A database of generator sales (the GenStat database could be suitable) could be used as a cross-check. However, there is no way of determining whether units sold are used for prime or back-up generation.

- DNOs keep registers of generators connected for synchronous operation (described below). However, this would not include generators that do not

81 Torriti, J. and Grünewald, P. (2013), *Demand Response from the non-domestic sector: early UK experiences and future opportunities*, preprint, p3

82 http://www.flexitricity.com/docLibrary/Capacity%20Market%20Charge%20-%20Data%20Centres.pdf

83 Pöyry (2014), *Storage Business Models in the GB Market p*14

84 In *What Demand Side Services Does Distributed Generation Bring to the Electricity System*, Sustainability First note that estimates range from 1GW to 20GW

85 For example, LSE for RWE nPower (2011), *Demanding Times For Energy in the UK*

86 EA Technology for DTI (2000), *Overcoming Barriers to Scheduling Embedded Generation to Support Distribution Networks* p20

87 Sustainability First (2013), *What Demand Side Services Does Distributed Generation Bring to the Electricity System*

connect synchronously, and there is no requirement for firms to inform DNOs if the generator is removed.

- Ultimately, a survey of firms (and perhaps aggregators) may be the most robust way of increasing the understanding in this area.

Of the 20GW, nPower has previously taken the view that 3GW[88] was technically suitable for DSR (e.g. amenable to the installation of remote dispatch) in 2011. They projected this may rise to 5GW in 2020, although the report also states that this is a conservative figure, and no underlying sources are given. It is also possible that many of the unsuitable installations are smaller generators, which are less likely to provide an economic source of DSR in any event given the cost structure discussed below.

No information is readily available on how this figure has been estimated. This "technical suitability" may refer to the means by which the generator synchronises with the distribution network. There are three types of firm connection available:[89]

- **Long-term parallel (LTP)** connections enable the generator to synchronise to the grid and export electricity for an extended period of time.
- **Short-term parallel (STP)** connections enable the generator to run independently of the grid during an outage, and then briefly synchronise when mains power has been restored to provide a continuous flow of electricity.
- **Standby generation** never runs in parallel with the network, and requires a UPS to provide a transfer from generator to mains power that does not involve a break in the mains supply.[90]

Only generators with a long-term parallel connection are able to export to the grid. Other generators may be able to provide DSR capacity by netting off demand that would otherwise have occurred, however this capacity will be limited to the level of demand connected to the generator, which will be lower than the generator capacity.

In the absence of further information, and to demonstrate the uncertainty in this area, we have produced scenarios with both 5GW and 20GW of diesel back-up capacity in 2020. Scaling in line with DECC's projections on total I&C electricity use yields the capacities shown in **Figure 14**. It should be stressed that this

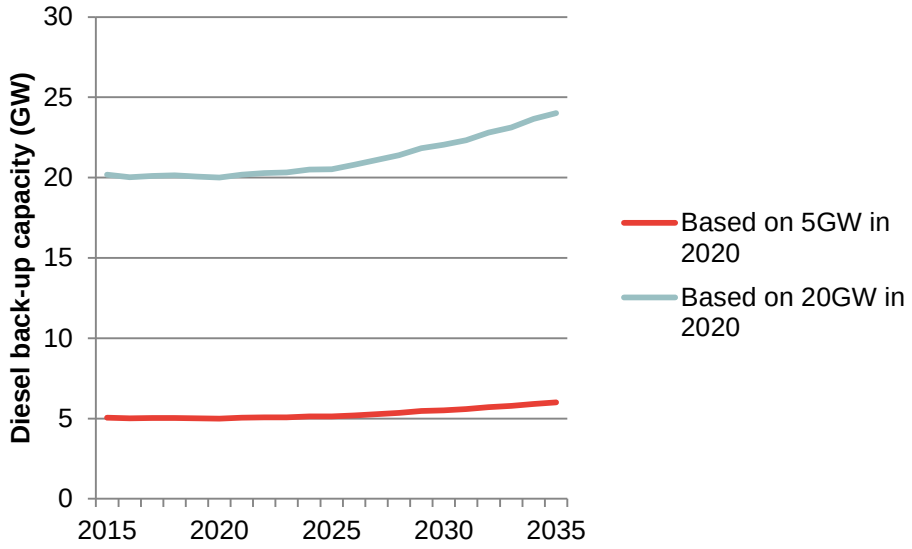
88 LSE for RWE nPower (2011), *Demanding Times For Energy in the UK*

89 UKPN (2014), *Distributed Generation addressing security of supply and network reinforcement requirements* p15

90 Flexitricity website (http://www.flexitricity.com/faq#answer_44), accessed 19/05/2015

assumes that diesel back-up generation will grow approximately in line with total I&C electricity use, which is unlikely to be the case. Some sectors (for example, data centres) will be more reliant upon back-up generation than others, and will grow at different speeds to the average of all firms.

Figure 14. Potential capacity of diesel back-up generation



Source: Frontier Economics

These capacity figures will need to be scaled down further when carrying out modelling, since not all owners of back-up generation are likely to engage in DSR activities, and among those that do there may be a proportion of generators unavailable at any given time.

Engagement with DSR

Many firms perceive there to be risks (and potential issues regarding consequential loss) which form a barrier to using back-up generation for DSR, as opposed to for emergencies only. For example, the Crown Commercial Service, which runs the DSR framework contract for the UK public sector, indicated to us that organisations such as hospitals are sometimes unwilling to engage in DSR due to perceived reliability issues (an additional risk of power failure should the systems to carry out DSR work incorrectly).

The Low Carbon London project interviewed a number of aggregators, which expressed the view that 20% of back-up generation owners might be expected to

participate in DSR services.[91] It is possible that this may understate future engagement for two reasons:

- First, some firms may be unwilling to engage with an aggregator, but would still carry out other forms of DSR (such as Triad avoidance), or be willing to engage with another party. Electricity North West's Capacity to Customers project, found DNO direct engagement an effective route to market.[92]

- Additionally, engagement with DSR may increase in the future if the various uses of DSR become more commonplace, and if overall revenues available from DSR were to increase.

Applying this 20% engagement rate to the 5GW and 20GW capacities discussed in the previous section yields capacities of 1GW and 4GW respectively. DSR capacity in the DDM from back-up generators could be scaled down in this way.

5.1.3 Availability

Even if aggregators can recruit this capacity, there will generally still be generators that for some reason do not respond to a DSR call (for example, if the generator or the control system is inoperable). This is illustrated in Torriti and Grünewald's analysis,[93] which tested the response of standby generation in the Telecoms sector. Across 97 sites, the load reduction was never 100% and was grouped around a reduction of 82%.[94]

The Low Carbon London project produced "F-factors", indicating the proportion of stated capacity that can actually be relied upon. For a group of ten diesel generators (the maximum they considered), the F-factor was 81%.[95] The Customer-Led Network Revolution project obtained an availability of 76%, after removing sites that were unavailable for the duration of the trials.[96] The CLNR project noted that generators located in remote sites (for example, water and telecoms sites) typically had worse reliability than those in urban locations (for example, supermarkets, data centres and hospitals), and so it is possible that

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91 UK Power Networks (2014), *Industrial and Commercial Demand Response for outage management and as an alternative to network reinforcement* p56

92 Electricity North West (2015), *Capacity to Customers Second Tier LCN Fund Project Closedown Report* p4

93 Torriti, J. and Grünewald, P. (2013), *Demand Response from the non-domestic sector: early UK experiences and future opportunities*, preprint p10

94 Interestingly, sites with bigger loads contributed proportionally less electricity. This may simply reflect 'undercapacity' but may also reveal systematic differences in derating.

95 UKPN (2014), *LCL Learning Report A4 – Industrial and Commercial Demand Response for Outage Management and as an Alternative to Network Reinforcement*, p35

96 CLNR (2015), *Developing the Smarter Grid: The Role of Industrial and Commercial and Distributed Generation Customers*, p64

greater overall reliability could be obtained by targeting sites that are more likely to have a higher reliability.

An aggregator that we spoke to agreed that a figure of 80% seemed reasonable, but commented that it could be a lot higher for aggregators that were in frequent communication with clients and placed a high value on knowing the availability of generators – and a lot lower for aggregators that did not do so. Such a figure could be inserted into the DDM as a "forced outage" rate.

5.2 Arrangements for calling DSR

The extent to which the flexibility of diesel back-up generators can be utilised will depend on the arrangements used to call DSR. The different channels by which DSR can be called are likely to be broadly similar to those available to smaller distributed generators, discussed in section 4.2.

Price-based mechanisms can provide an incentive for firms to run their generators, given sufficient notice. TNUoS charges are the most significant example of this at present; some firms use their generation capacity to avoid Triads,[97] based on the receipt of day-ahead warnings.

Larger firms with back-up generators will also be exposed to time-varying retail electricity[98] and DUoS charges, which are known months in advance. However, these arrangements will provide signals for load shifting on many consecutive days, rather than just the occasional use. The high running costs of diesel generators mean that they are unlikely to be used for DSR on a daily basis, and so these incentive arrangements may not be appropriate for diesel generation.

Obtaining dynamic DSR from diesel generators is likely to require **direct control** by an entity such as an aggregator. The section below discusses the additional costs that may be incurred in setting up this arrangement.

5.3 Costs

As with the other forms of DSR considered in this report, we have divided costs into capital costs, fixed O&M costs, and running costs. The costs which are incurred will depend to an extent on the arrangements for calling DSR: DSR that can be called at short notice (such as that provided through an aggregator), is likely to incur higher costs than DSR requiring more notice (such as triad avoidance delivered through day-ahead triad warnings). **Table 9** sets out the

97 Sustainability First (2013), *What Demand Side Services Could Customers Offer – Industrial Electricity Demand* p26 notes that, while the majority of the 13 businesses they surveyed reduced Triad demand using demand-led DSR, two also used their generation capacity.

98 A supplier we spoke to told us that only around 7% of their half-hourly customers were on single-rate tariffs, with the remaining 93% on time-of-use tariffs.

main categories of cost and where they may be required. These are then explained in further detail below.

Summary of the evidence base

The table below summarises the main types of sources that have been used in this section, and indicates where some of the greatest uncertainties lie.

Area	Main sources of evidence and robustness
Current capital costs associated with an aggregator taking on a further site	We have interviewed a number of aggregators to discuss the broad costs associated with enabling a unit to carry out dynamic DSR. However, our assumptions here are simply "best guesses", and in any event vary substantially across installations.
Future capital costs associated with an aggregator taking on a further site	It is even more difficult to predict how these costs could evolve over time, and we have not provided evidence in this area.
Fixed O&M costs associated with back-up generators	Back-up generators need to be run for testing purposes. Any truly fixed O&M costs are therefore (by definition) not incremental to DSR. However, generator owners are likely to require annual availability payments. We provide evidence on existing levels of these payments, but it is difficult to state how these may change in the future.
Variable costs associated with back-up generators	The typical efficiency of back-up generators is well known, and we understand that DECC's latest generation cost report includes diesel generation. The key uncertainty is diesel prices – projections exist, but will vary significantly according to factors including global supply/demand.

Table 9. Summary of costs for back-up generation

Cost and type	Possible value	Required for longer-notice DSR?	Required for short-notice DSR?
Switchgear upgrades and G59 permit to enable parallel running (capital cost)	Potentially up to £50,000 per site in total	**No** – however the DSR capacity will be limited to on-site demand unless the generator is configured for LTP operation	
Communication, metering and control equipment (capital cost)		**No** – static DSR can be carried out through simpler means such as Triad warnings	**Yes** – dynamic DSR requires a system to dispatch generators remotely at short notice
Sales and marketing costs (capital cost)		**Potentially not** – many firms already react to Triad warnings, although raising greater awareness may incur costs	**Likely** – aggregators need to invest in expanding their fleet.[99]
Operating and maintenance costs (fixed O&M cost)	May not be relevant	**No** – we assume that these are not incremental to providing DSR, as the generator owner would need to carry out tests in any event	
A firm source of revenue to motivate commercial engagement (fixed O&M cost)	Roughly £20/kW	**Likely** – interviews with aggregators and industry indicate that firms require additional revenue to be engaged commercially (note that Triad avoidance, while not a direct payment, nonetheless provides considerable cost avoidance)	
Fuel costs (running cost)	Around £132 per MWh at present for diesel	**Yes**	

Source: Frontier Economics

[99] This cost may be lower if DSR was provided by an entity that already worked alongside the firm – for example, a combined supplier/aggregator.

5.3.1 Capital costs

We consider three types of capital cost:

- Switchgear upgrades and G59 permits required to enable generators for long-term parallel operation;
- communication, metering[100] and control equipment; and
- sales and marketing costs.

For the FALCON LCNF project, £20,000 was estimated as the cost of enabling a 400kW generator for DSR[101] (the changes included conversions of the switchgear, controls and connection permissions and an export permit – this covers the first two points above). Wessex Water has previously indicated that conversion of one of their generators for reserve operation could cost £13,000 (although this is from an old source).[102]

We were also able to obtain some information regarding these costs from interviews with aggregators, although it is difficult to disentangle the different elements of cost. One aggregator we spoke to gave a range of between £5,000 and £70,000 for these types of cost, another gave £10,000 to £50,000, and a third aggregator stated that these costs were typically around £50,000 or £60,000 for a 1MW generator. Note that aggregators vary in terms of who bears these costs: some have a business model where the aggregator bears the up-front costs (in return for a proportion of revenues), while another we spoke to placed this setup cost directly on the customer.

Some aggregators we spoke to provided information regarding sales and marketing costs incurred to expand their base of clients. One aggregator indicated that simply acquiring a new site would cost £12,000, but that this would have to be divided by the success rate. Another simply said that the customer recruitment costs were the majority of costs. A third said that taking on a site could take 12 – 24 months, with substantial "hidden" costs. However one aggregator indicated that such one-off sales costs might only account for around £3,000 or £4,000 per site. It seems plausible that aggregators with a more sector-focussed approach to recruitment may have lower sales and marketing costs than those which approach many different types of customer.

Clearly, these costs cover an extremely wide range. Many aggregators informed us that while the switchgear costs could vary hugely depending on how the clients'

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100 Required to verify that the DSR event has taken place.

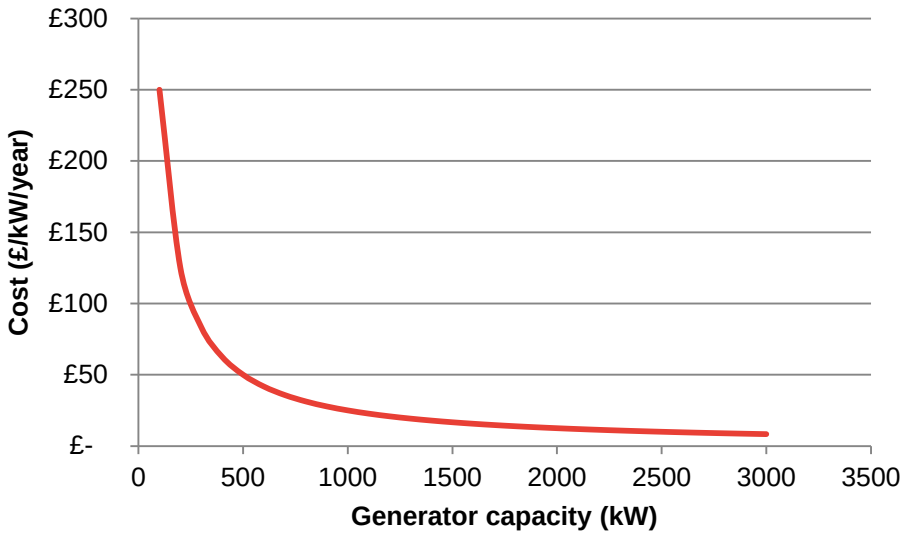
101 Western Power Distribution (2014), *FALCON Commercial Trials Season 1*, p50

102 David Andrews, Wessex Water presentation Open University Conference on Intermittency, 24th Jan 2006. These costs consist of £3,000 to fit a PLC controller, £5,000 for paralleling gear to allow a grid connection, and £5,000 for "tidying up" the generator set.

electrical system was set up, there was no simple relationship between the capacity of a generator and the overall costs of adding it to their portfolio. For the purpose of producing an illustrative scenario, we have taken a figure of £50,000 per site[103] to cover the total costs of an aggregator setting up dynamic DSR.

The effect of these high set-up costs is to make the addition of diesel back-up generators to an aggregator's portfolio uneconomic for all except the largest generators. **Figure 15** expresses these costs on a per-kW-per-year basis for different sizes of generators. On this basis, an aggregator might need a payment of £250/kW/year to sign up a 100kW generator, but only £25/kW/year for a 1MW generator. This is consistent with the comment by one aggregator that their fleet mainly consisted of generators in the 1MW to 2MW range, and another two who stated that their smallest single asset was around 500kW.

Figure 15. Illustrative set-up costs per kW per year for diesel back-up generation



Source: Frontier Economics

This cost structure means that the distribution of diesel generator sizes will be significant to any modelling – however information on this point is scarce. We have constructed a Pareto distribution[104] of generator capacity, with a lower bound of 10kW (the smallest available generators appear to be approximately this

103 These costs will also need to pay back in a relatively short period: one aggregator indicated that they would need payback periods of one to two years, while another gave a payback target of two or three years.

104 A power-law distribution that has been used to model the distribution of the size of units such as settlements and businesses.

size) and a "shape" parameter of 0.9. Such a distribution would suggest that around 62% of generator capacity is accounted for by generators above 300kW (this is consistent with other research).[105] However, it must be stressed that this is merely an illustrative assumption.

5.3.2 Fixed O&M costs

There are relatively few ongoing availability costs for diesel generators. In any event, generator owners would be required to carry out operational tests in the absence of a DSR contract, and so these costs are not incremental to providing DSR.

However, the aggregators that we have spoken to have highlighted the need to provide a guaranteed payment, to give customers a clear incentive to engage with them.

KiWi Power's website indicates that such payments could range from £20,000 pa for medium-sized businesses to £100,000 pa for larger businesses.[106] Based on discussions with KiWi, we understand that a "large" business might be above 5MW – for example a large hospital, shopping centre, or office. £100,000 for 5MW equates to an average of £20/kW.

We have therefore assumed that an availability payment of around £20/kW might be required by businesses holding back-up generation to engage with DSR. Note that increased availability payments may be able to bring forward greater participation, although we have not seen sufficient evidence to construct a supply curve for I&C backup generator DSR.

5.3.3 Running costs

The main running cost will be the cost of diesel, which is expected to vary significantly over time. To give a current example, in February 2015, UK red diesel prices were 48.80ppl (down from 67.07pl in February 2014).[107] A 1MW generator running at full capacity might consume 270l of fuel per hour,[108] resulting in running costs of £132/MWh. However, given these costs, it is likely

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105 Sustainability First compared the GenSet database with another source from 2006 that indicates that Western Europe annually installed in the region of 8GW of diesel units. Assuming a uniform pattern of sales, they found that genset sizes in excess of 375kVA would make 60% of the total. See Sustainability First (2013), *What Demand Side Services Does Distributed Generation Bring to the Electricity System*. Based on http://www.dieselserviceandsupply.com/Power_Calculator.aspx, 375kVA equates to approximately 300kW.

106 http://www.kiwipowered.com/faq.html, accessed on 25/03/2015

107 DECC figures, taken from http://www.dairyco.org.uk/market-information/farm-expenses/monthly-fuel-tracker/monthly-fuel-tracker/#.VQc5K7FFBO8

108 http://www.dieselserviceandsupply.com/diesel_fuel_consumption.aspx, converted from US gallons to litres with Google

that diesel back-up generators will be run infrequently, and so running costs will be a small proportion of *overall* costs.

5.3.4 Greenhouse gas and local emissions

Diesel back-up generators are a relatively carbon-intensive form of generation. National Grid has calculated that the emissions intensity of diesel back-up generation used for STOR is 0.735kgCO_2e/kWh, compared to 0.402kgCO_2e/kWh for a CCGT, and 0.777 kgCO_2e/kWh for an OCGT.[109] However, National Grid also note that the alternative means for them to obtain flexibility would be to keep CCGTs part-loaded as spinning reserve, which would have greater carbon emissions than the current mix of STOR providers. National Grid calculate that, if all STOR were provided by back-up diesel generation, annual emissions would be 170,237 tonnes CO_2e, compared to 683,213 tonnes CO_2e if synchronised CCGTs were used.

If these emissions are internalised (i.e. paid for by generators), then they will increase the costs of these forms of DSR, potentially decreasing the volume that is utilised. Carbon is priced into costs via the EU ETS, which excludes installation with a thermal input of 20MW or under (and units exclusively burning biomass).[110] Backup generators may therefore not face these costs, providing they are on a site which does not have a total thermal combustion capacity (including boilers) of above 20MW.

Standby generators, whether running on diesel or natural gas, produce other local emissions, including nitrogen oxides, carbon monoxide and unburned hydrocarbons.[111] Diesel engines also produce particulate matter.

Such emissions can be abated through measures such as catalysed diesel particulate filters (which can reduce emissions of particulate matter, carbon monoxide and non-methane hydrocarbon by 90%), and selective catalytic reduction (which can reduce emissions of nitrogen oxide by 90%).[112] In addition, the impact on local air quality can be minimised through a sufficiently tall chimney, where planning permission permits.[113]

Restrictions on such emissions might reduce the scope of back-up generation to take part in some forms of DSR. For example, the City of London's guidance on standby generation states that "*Standby generators in the City should not be used to feed*

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109 National Grid (2015), *Short Term Operating Reserve Carbon Intensity Report*

110 DECC (2013), *European Union Emissions Trading System – Regulatory guidance for installations (including excluded installations)*

111 US EPA CHP Partnership (2015), *Catalog of CHP Technologies Section 2. Technology Characterization – Reciprocating Internal Combustion Engines* p 2-21.

112 Warner, J. and Bremigan, C. (2010), *System Solutions for Optimising Exhaust Emission Control Systems*

113 City of London, *Guide to minimising the local air quality impact of standby diesel generators in the City of London*

I&C back-up generation

electricity into the utility grid. They should be used in emergencies only."[114] Pressure to curb emissions may be increased following the April 2015 Supreme Court ruling for Defra to prepare new air quality plans by the end of 2015.[115] However, we do note that the European Medium Combustion Plants Directive, covering combustion plants of between 1MW and 5MW in capacity, would exclude plant that did not run for more than 1,000 hours per year.[116] Such a restriction would cover most conceivable uses of diesel backup generators for DSR.[117]

114 City of London, *Guide to minimising the local air quality impact of standby diesel generators in the City of London*

115 https://www.supremecourt.uk/decided-cases/docs/UKSC_2012_0179_Judgment.pdf

116 Eurelectric (2015), *EURELECTRIC views on the Council's general approach on the Medium Combustion Plants Directive*. At the time of writing, the full text of the directive was still being finalised.

117 Even if a generator was run for 4 peak hours over 120 days within winter, this would only equate to 480 hours.

6 I&C demand-led DSR

I&C customers account for roughly half of peak demand.[118] This section considers the potential of I&C customers to shift or temporarily reduce their electricity demand.

We first set out some of the broad types of I&C load which may be amenable to DSR, including the capacity and capabilities of demand response they may be able to provide. Shifting demand without adverse impact to businesses will typically require that the activity is either discretionary, or inherently includes some form of energy storage (for example, heating, cooling, or pumping water against gravity).

Second, we briefly consider the different arrangements through which this DSR potential could be unlocked.

Finally, we set out the types of cost that may be incurred for these types of DSR, and what some of the impacts on the wider energy system may be.

6.1 Sources of potentially shiftable load

In this section, we provide a summary of the potential for DSR from each type of potentially shiftable I&C load.[119]

For each source, we first set out the **capabilities of DSR** (in terms of notice period and event duration) that each type of load might be able to provide.

We then consider the **potential capacity of DSR**. To do this, we have undertaken the following steps.

- **Total I&C electricity consumption.** We start with DECC's Energy and Emissions projections for I&C electricity consumption.[120] These provide a breakdown of projected electrical energy consumption, by sector to 2035. To convert this sector-level breakdown to one that is based on end use, we have taken the figures for end-use of electricity by sector from Energy Consumption in the UK. This calculation provides a figure for the total electrical energy consumption by end-use for each year, based on the assumption that the split of end uses by sector does not vary over time.

118 Ofgem (2010), *Demand Side Response – A Discussion Paper*

119 It should be noted that I&C users are extremely heterogeneous - we have provided a high-level breakdown since data on electricity use by end-use is not available at a more disaggregated level.

120 https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2014

- **Demand profiles.** We have then applied load profiles used in Brattle's 2012 modelling for Sustainability First[121] to determine the profile of electricity demand across the day and the year.

Only a proportion of this load may be suitable for DSR – we summarise some of the evidence around this, however note that there is relatively little in this area. More generally, I&C DSR is an area where the evidence base is relatively poor, as discussed in the box below.

Summary of the evidence base

The table below summarises the main types of sources that have been used in this section, and indicates where some of the greatest uncertainties lie.

Area	Main sources of evidence and robustness
DSR capabilities for I&C demand-led DSR	HVAC, refrigeration, and water pumping are already used for DSR by UK aggregators, so it is reasonable to assume they are (at least to some extent) flexible. We have set out examples of DSR capabilities drawn from UK examples and elsewhere, although these may not necessarily be representative. For lighting, we have referenced North American studies that show users may tolerate temporary reductions in light levels even in the absence of sunlight. However, we have not seen equivalent evidence from the UK, and the potential for lighting DSR through temporary dimming in this country is not widely recognised.
Current energy usage by I&C end-use	Splits by broad end-use are available from Energy Consumption in the UK. Industrial energy consumption is derived from the Purchases Inquiry, which has not been updated since 2007. We understand that DECC's Building Energy Efficiency Survey will provide more detailed information energy use relating to buildings (e.g. heating and lighting).

121 For a description of the methodology underlying these load profiles, see Sustainability First (2012) *Initial Brattle Electricity Demand-Side Model – Scope for Demand Reduction and Flexible Response*. It should be noted that this model was produced as an initial tool to help inform debate, and the resultant load profiles should be seen in this light. In particular, the average load profile for half-hourly metered customers was inferred by subtracting the standard ELEXON load profiles from nationwide demand , which may bias the results. The modelling we have undertaken is flexible to allow other load profiles to be inserted should they become available.

	A key issue is the sheer heterogeneity of many industrial processes, which ECUK does not break out. Additionally, ECUK does not include a figure for commercial refrigeration, which may be a significant potential source of DSR.
Future energy usage by I&C end-use	We have extrapolated the ECUK end-use figures using sector consumption projections from DECC's Energy and Emissions Projections. However, these projections only represent one plausible scenario for future energy use, which will be affected by factors such as technological, economic and policy developments. For example, changes in the electrification of heating or efficiency of lighting could have a significant impact on energy usage. In addition, the simple extrapolation assumes no change in end-use intensity by sector.
Current profile of I&C power consumption over the year/day	We are not aware of a source for average half-hourly load profiles by end-use based on metered data.[122] We have then applied load profiles used in Brattle's 2012 modelling for Sustainability First to determine the profile of electricity demand across the day and the year. It should be noted that the model was produced for Sustainability First as an initial tool to help inform debate, and the resultant load profiles should be seen in this light. In particular, the average load profile for half-hourly metered customers was inferred by subtracting the standard ELEXON load profiles from nationwide demand , which may bias the results
Future profile of I&C power consumption over the year/day	In the absence of further data, we have applied the same profiles used for 2015 to other years.
Proportion of potential capacity which might be used for DSR	There is very little evidence in this area. The Low Carbon London project carried out interviews with aggregators to determine the overall proportion of demand customers that might be expected to sign up for DSR (see the section on HVAC), however it seems likely that this figure will vary by sector and over time.

122 The Customer-Led Network Revolution project carried out circuit-level metering across a number of SMEs – see Customer-Led Network Revolution (2015), *Insight Report: Small and Medium Enterprises*. However, given the heterogeneity of end-uses, these cannot be used to generalise across I&C users.

6.1.1 Heating, ventilation, and air conditioning (HVAC)

Due to the inherent thermal storage within buildings, it is possible to turn down HVAC services for a period without occupants being adversely affected.

DSR capabilities

HVAC can generally not be shifted for long periods of time, but is capable of extremely quick turn down times.

The potential duration of HVAC DSR is limited since turn-down comes at the expense of comfort. A report by Element Energy[123] assumes that most businesses would not tolerate reducing HVAC load for more than 15 minutes, while one aggregator we spoke to (which has a large proportion of HVAC in its portfolio) gave a figure of 30 minutes. The duration for which HVAC can be turned off might be longer for highly insulated buildings, although this might only relate to a small proportion of the current stock of buildings. Thermal storage systems can vastly increase the duration of HVAC reduction but these systems are not very widespread at present (although they are being encouraged by schemes like DECC's Advanced Heat Storage Competition). One example (which SSEPD propose to install as part of the Thames Valley Vision LCNF project)[124] is a US unit which freezes water overnight and can then supply cooling for six hours.[125]

By contrast, HVAC is capable of extremely quick response times, and is being used by at least one aggregator to provide frequency response services to National Grid.

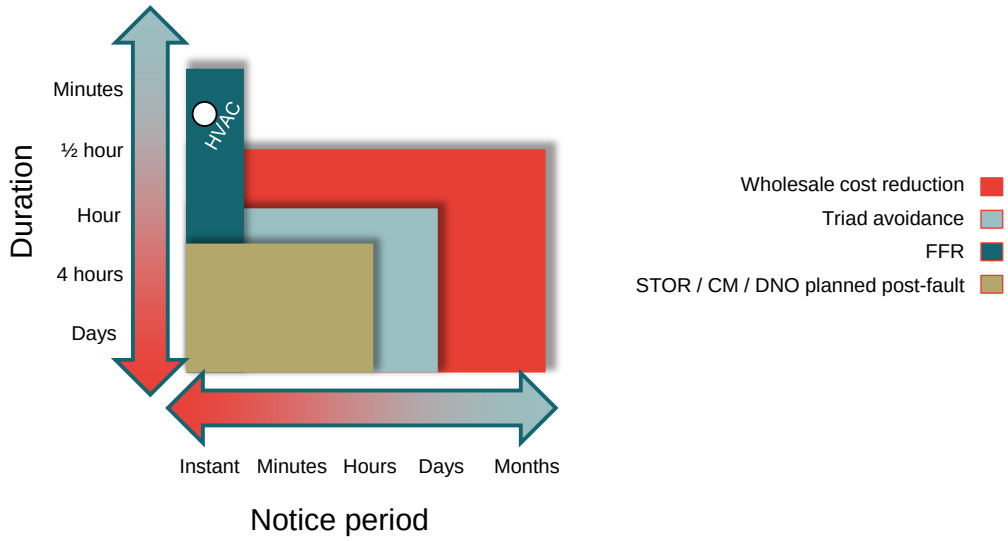
As illustrated in **Figure 16**, I&C HVAC is therefore likely to be best suited for DSR uses such as FFR which require a rapid turndown for a short period of time, though we note it may also be possible to aggregate multiple HVAC loads together to provide a longer duration of response (at the expense of spreading availability payments over a larger number of units).

123 Element Energy for Ofgem (2012), *Demand side response in the non-domestic sector*

124 SSE, *New Thames Valley Vision Modification to the Deployment of Cold Thermal Storage*. It should be noted that this project did not identify buildings with existing cold thermal storage within the Bracknell area, and that surveyed consumers were unwilling to install such units by themselves.

125 http://www.ice-energy.com/technology/ice-bear-energy-storage-system/, accessed on 11/06/2015

Figure 16. Illustrative DSR capabilities of HVAC

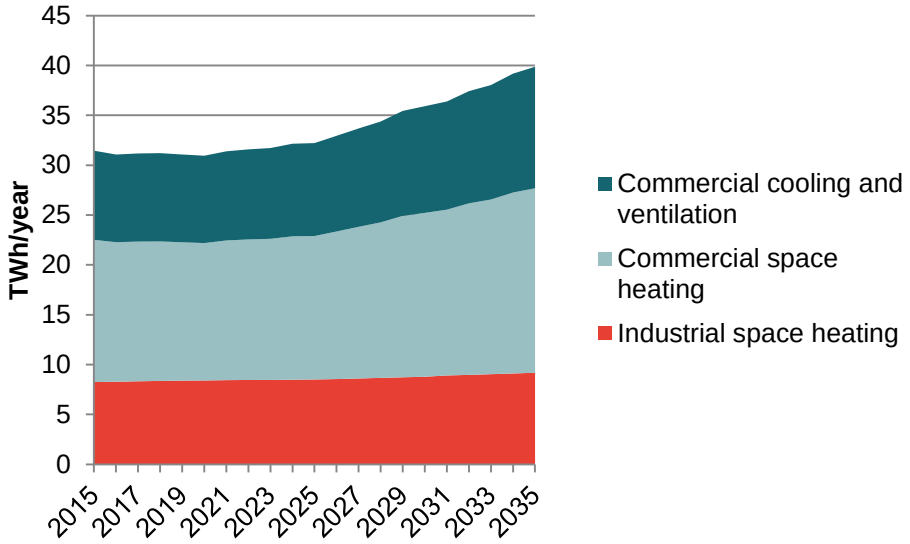


Source: Frontier Economics

DSR capacity

Using the methodology described above (scaling the ECUK end-use figures according to EEP sector-by-sector projections), **Figure 17** provides an indication of how I&C HVAC electricity usage might change over time. It should be stressed that this is an extremely basic approximation that does not take into account factors such as changing end-use intensity by sector over time. The overall yearly energy usage accounted for by HVAC can be seen to increase from around 30TWh in 2015 to 40TWh in 2035.

Figure 17. Indicative yearly energy usage for HVAC



Source: Frontier analysis of ECUK and EEPs

These figures represent a maximum potential for DSR from HVAC, as in reality not all of this total HVAC-related electricity consumption will be suitable for DSR. For example, National Grid has previously assumed that 30% of thermal and air conditioning load can be engaged in DSR by 2020,[126] and Element Energy's 2012 research for Ofgem assumes 20% of HVAC demand in commercial buildings could be shifted (under their 'moderate scenario'. [127]

The Low Carbon London trial also found that HVAC load reduction was far less reliable in the winter than the summer. Of the 45 DSR events called across hotels during the summer, 66.7% displayed a compliance of 90% of higher[128] (the "compliance" is calculated as the proportion of the time for which the contracted load reduction was met). By contrast, of the 15 DSR events called across hotels during the winter, only 6.7% displayed a compliance of above 90%. Lower compliance during winter (although to a lesser extent) was also observed in the one office that had HVAC DSR events called. The project noted that the low

126 National Grid (2011) *Operating the Electricity Transmission Networks in 2020*. Note that the 30% figure is a broad assumption.

127 Element Energy's 2012 paper also examines the potential for DSR in commercial buildings. Under their 'moderate' assumptions, 20% of HVAC demand can be reduced. The corresponding percentage is 10% and 30% under their 'conservative' and 'stretch' assumptions, respectively. Element Energy for Ofgem (2012), *Demand side response in the non-domestic sector*

128 Low Carbon London (2014) *Distributed Generation and Demand Side Response services for smart Distribution Networks*, p34

winter compliance figures might be driven by the predominance of gas in the heating of buildings, leading to relatively little electric flexibility in the winter.[129] Across all demand-led DSR sites (including both HVAC as well as water pumps), this project found a reliability for demand reduction (stated as an f-factor) of 64%.[130]

Finally, any modelling will need to make assumptions on the proportion of HVAC users which can be engaged to provide DSR. The Low Carbon London project interviewed a number of aggregators, who expressed the view that just 5% of demand customers might currently be expected to participate in DSR services.[131] Reasons for a lack of participation might include split incentives – for example, landlords of office buildings may face conflicts if tenants do not believe they will benefit from DSR, while in general DSR may not currently be seen as a part of the role of building facilities or energy managers.[132]

We have applied the energy figures to the load profiles used in Brattle's modelling for Sustainability First. This suggests a peak (16:00 – 19:00) power usage of around 6GW in 2015, (the vast bulk of which is estimated to come from heating), rising to 8GW in 2035.

If 25% of this 2035 load were flexible (based on the information above), this might suggest a total potential DSR capacity from HVAC in the order of 2GW.

6.1.2 Hot water

The vast majority of I&C hot water demand is currently met through the use of gas. However, where they exist, hot water immersion heaters often operate alongside a storage tank and so may be amenable to load-shifting.

DSR capabilities

We do not have specific data relating to the DSR capabilities of immersion heaters alongside hot water storage. **Figure 18** assumes that the use of hot water storage can delay immersion heater power consumption by several hours (as would be the case for an SME using an immersion heater during the off-peak portion of an Economy 7 or Economy 10 tariff) and that – subject to appropriate

129 Low Carbon London (2014) *Distributed Generation and Demand Side Response services for smart Distribution Networks*, p4

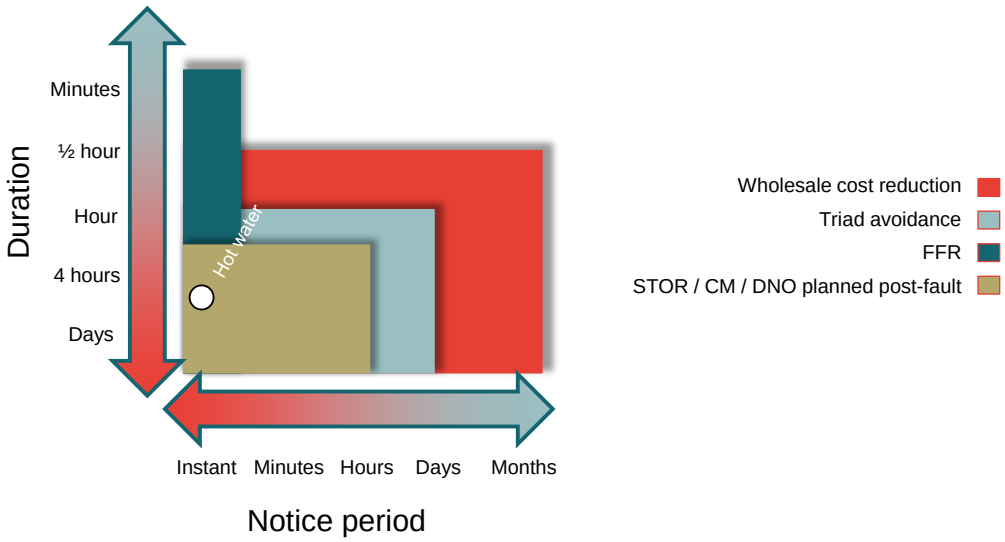
130 Low Carbon London (2014), *Industrial and Commercial Demand Response for outage management and as an alternative to network reinforcement* p35

131 UK Power Networks (2014), *Industrial and Commercial Demand Response for outage management and as an alternative to network reinforcement* p56

132 UK Power Networks (2014), *Industrial and Commercial Demand Response for outage management and as an alternative to network reinforcement* p59

technical and contractual arrangements being in place – DSR could be called with a short notice period.

Figure 18. Illustrative DSR capabilities of immersion heaters with storage

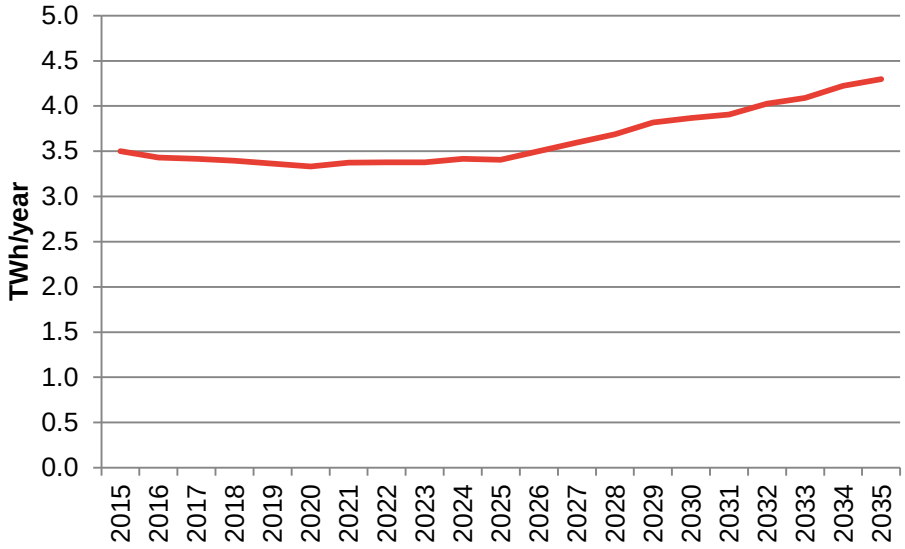


Source: Frontier Economics

DSR capacity

Using the methodology described above (scaling the ECUK end-use figures according to EEP sector-by-sector projections), **Figure 17** provides an indication of how commercial hot water electricity usage might change over time. No figures are available for industrial hot water usage, which in any event is likely to be low at present due to the prevalence of gas-fired heating. It should be stressed that this is an extremely basic approximation that does not take into account factors such as changing end-use intensity by sector over time. The overall yearly energy usage accounted for by commercial hot water can be seen to increase from around 3.5TWh in 2015 to just under 4.5TWh in 2035.

Figure 19. Indicative yearly energy usage for commercial hot water



Source: Frontier analysis of ECUK and EEPs

We have applied these energy figures to the load profiles used in Brattle's modelling for Sustainability First. This suggests a peak (16:00 – 19:00) power usage of around 300MW in 2015, rising to 350MW in 2035.

As with other forms of DSR, these figures would need to be scaled down to represent the proportion of load suitable for DSR (and that may engage with an aggregator). Given the storage potential for immersion heaters in hot water tanks, Element Energy's 2012 analysis for Ofgem assumes that water heating is most flexible end use. On their conservative, moderate and stretch assumptions, they assume that 25%, 50% and 75% of hot water consumption can be reduced.[133] If 50% of 350MW were available for DSR, total I&C hot water DSR capacity might be in the order of 175MW.

6.1.3 Refrigeration

Refrigeration (both commercial fridges and industrial cold-stores) is another area that is technically capable of providing DSR, as units can be interrupted for a period while maintaining temperatures within an acceptable level.

133 Element Energy for Ofgem (2012), *Demand side response in the non-domestic sector,* p32

DSR capabilities

Past literature in this area has noted that, although refrigeration load-shifting may be technically feasible,[134] the extent to which this can be realised will depend importantly on customer acceptance.[135] Many businesses may be reluctant to turn down refrigeration units due to perceived business impacts. For example, Low Carbon London found that some businesses refused to turn down chillers, deeming the practice to be too high risk.[136] Many papers highlight the external as well as internal constraints on refrigeration turn down, citing stringent health and safety requirements, and managerial concern that these must not be put at risk.

Element Energy's 2012 report, based on discussions with DSR providers and organisations, assumes that 20% of refrigeration load can be shifted in their moderate scenario. The corresponding percentage is 10% and 30% for conservative and stretch assumptions. National Grid's previous assumptions are consistent with Element's conservative assumptions, applying 10% flexibility to their forecasts.[137] For the purposes of creating a scenario, we have adopted the 20% figure here.

The 2012 Element Energy report suggests that retail refrigeration can be "easily" interrupted for 15 minute periods and that 30 minutes is possible but extreme.[138] Furthermore, it notes that cold stores and freezers can be pre-super-cooled, allowing 30-60 minute interruptions

Some trials suggest that the capability for load-shifting may be greater for particular uses of refrigeration. For instance an ice manufacturer involved in the CLNR trial provided 0.6MW of DSR over a 4-hour timespan, while the CLNR SME trials successfully obtained reliable load-reduction of a cellar chiller in a hospitality SME for four hours at a time, using a restricted hours tariff.[139] However, these may not represent typical capabilities for refrigeration loads.

Figure 20 illustrates potential DSR capabilities of different types of I&C refrigeration, drawing upon the figures in the 2012 Element Energy report, and assuming that contractual and technical arrangements exist that would facilitate dynamic DSR.

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134 See for example IHS (2009), *Demand Side Market Participation Report for DECC*

135 Sustainability First (2012), *GB Electricity Demand – 2010 and 2025*

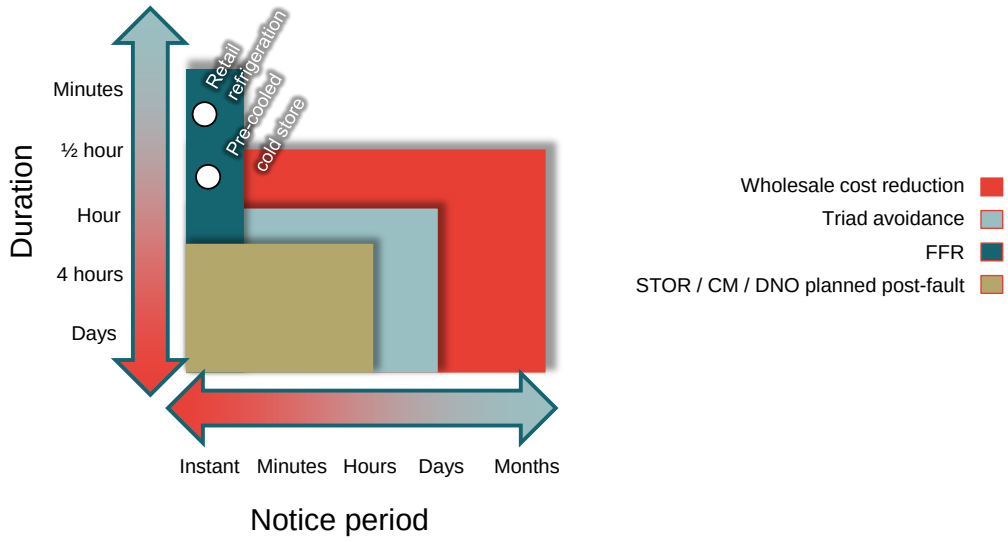
136 Low Carbon London (2014) *Distributed Generation and Demand Side Response services for smart. Distribution Networks* p51

137 National Grid (2011) *Operating the Electricity Transmission Networks in 2020*

138 Element Energy for Ofgem (2012), *Demand side response in the non-domestic sector,* p32

139 CLNR (2015), *Insight Report: Small and Medium Enterprises (SMEs) – Disaggregated Load, Time of Use Tariff and Restricted Hours Trials.*

Figure 20. Illustrative DSR capabilities of I&C refrigeration



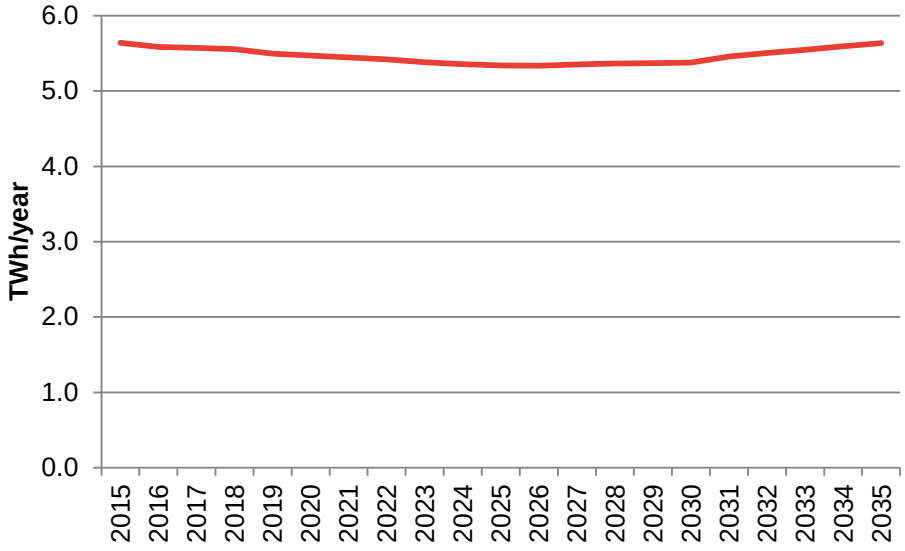
Source: Frontier Economics

DSR capacity

Using the methodology described above (scaling the ECUK end-use figures according to EEP sector-by-sector projections), **Figure 17** provides an indication of how industrial refrigeration electricity usage might change over time. No figures are available for commercial refrigeration, since ECUK does not split out this end-use. **This is potentially an important omission, since retail refrigeration may be a significant source of DSR.** It should be stressed that this is an extremely basic approximation that does not take into account factors such as changing end-use intensity by sector over time. The overall yearly energy usage accounted for industrial refrigeration can be seen to stay roughly constant at around 5.6TWh [140]

140 This may be a particular area where government policy on energy efficiency could have a significant effect.

Figure 21. Indicative yearly energy usage for industrial refrigeration



Source: Frontier analysis of ECUK and EEPs

We have applied these energy figures to the load profiles used in Brattle's modelling for Sustainability First. This suggests a peak (16:00 – 19:00) power usage of around 600MW. If 20% were flexible, this would imply a DSR capacity of 120MW. **Again, it should be stressed that this figure excludes commercial (including retail) refrigeration**.

6.1.4 Lighting

Much focus has been placed on the potential for permanent efficiency gains from lighting (which could potentially take part in DECC's Electricity Demand Reduction Pilot). However, some trials have also taken place to assess the potential for temporary reductions in lighting energy consumption.

DSR capabilities

Several North American studies have been carried out to determine the potential for demand-responsive lighting. For example, a Canadian study carried out dimming of lighting at a federal government office building and a college campus in southern Ontario.[141] During a number of summer afternoons, lighting across entire areas of the building was gradually dimmed and then kept at a reduced level for up to a few hours. The two events in the office building produced reductions in lighting power of around 23% and 24%, while the three trials on

141 NRC-IRC (2010) *Demand-responsive lighting: a field study*

the campus yielded reductions of between 14% and 18%. No lighting-related complaints were made, leading the authors to suggest that dimming lighting is a viable demand response strategy.

It is important to note that these trials relate to an area where the electricity demand peak occurs during the summer during daylight hours. In the UK, where peak winter demand will typically occur during hours of darkness, the potential might be considerably lower. However, the authors of this study, based on previous laboratory work, believe that in areas with no daylight:[142]

- a dimming of 20% over 10 seconds would be unnoticeable by the large majority of occupants;
- as would a dimming of 30% over 30 minutes or more;
- while dimming of 40% over 10 seconds or 50% over 20 minutes or more may be noticeable, but still acceptable to the large majority of occupants.

In any case, the study's authors note that dimming should not prevail for more than a few hours, as there is evidence that standard North American guidelines for light levels are appropriate to ensure long-term occupant satisfaction.

Assumptions made on the flexibility of lighting within the UK vary. Within the UK, a 2009 IHS report assumed that both industrial and commercial lighting is inflexible.[143] A 2012 Element Energy report, citing Californian studies, notes that technology such as dimmable lighting and advanced controls might lead to potential from DSR, but states that few consultees suggested lighting as a potential target for DSR measures. As a result, that report produced overall DSR potential figures both with and without lighting (the figures with lighting assume that 10%, 20% and 40% of lighting might be flexible under conservative, moderate and stretch scenarios respectively).

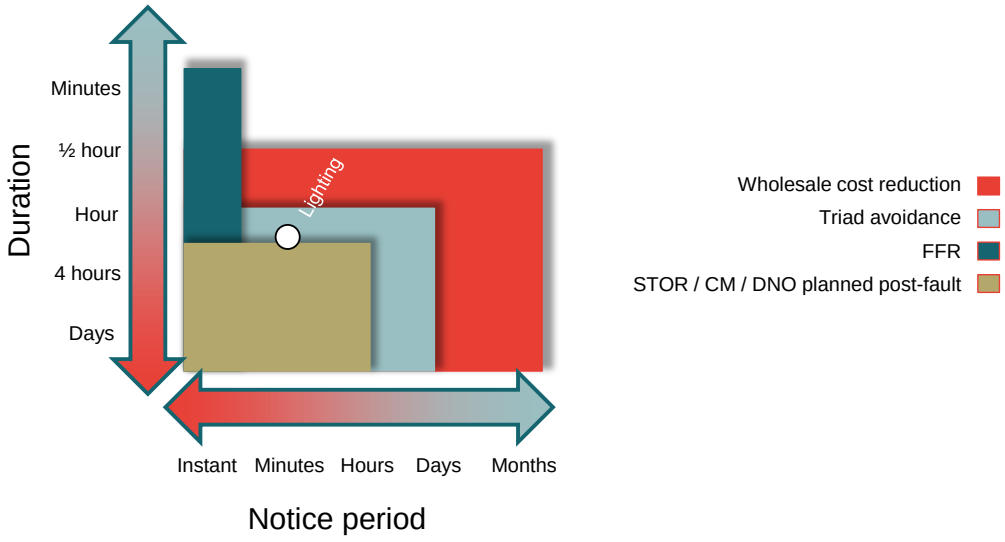
Emergency battery-backed up lighting might provide another source of flexibility. However, this again seems to be an area where there is not a significant evidence base.

The Canadian study cited above suggests that dimming of lighting may need to take place over 10 minutes or more (since sudden switching of light levels would cause dissatisfaction among occupants) and that it should not be used for more than a couple of hours or so. **Figure 22** illustrates these capabilities. However, it should be stressed that there is little UK-specific evidence regarding this type of DSR.

142 NRC-IRC (2010) *Demand-responsive lighting: a field study* p23

143 IHS (2009), *Demand Side Market Participation Report for DECC*

Figure 22. Illustrative DSR capabilities of I&C lighting

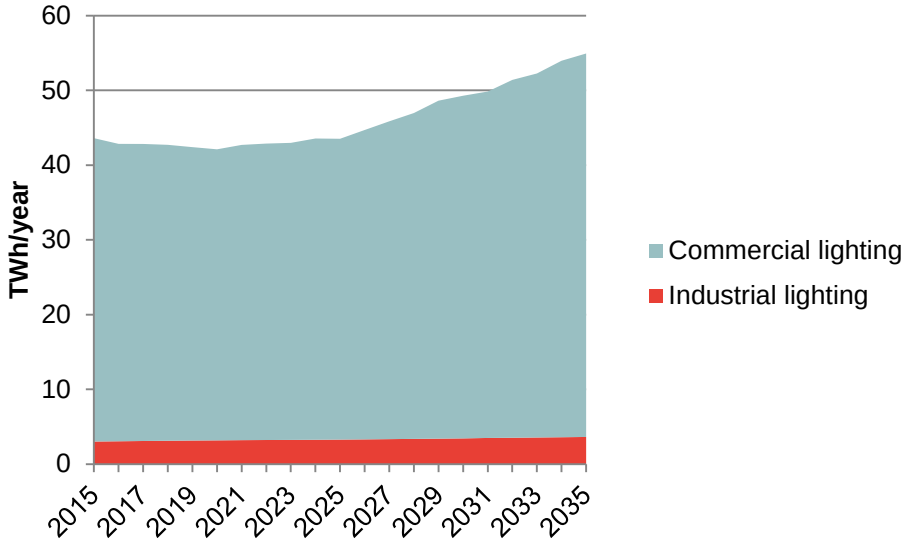


Source: Frontier Economics

DSR capacity

Using the methodology described above (scaling the ECUK end-use figures according to EEP sector-by-sector projections), **Figure 17** provides an indication of how industrial and commercial lighting electricity usage might change over time. It should be stressed that this is an extremely basic approximation that does not take into account factors such as changing end-use intensity by sector over time. The overall yearly energy usage accounted for I&C lighting can be seen to increase from about 43TWh to around 55TWh.

Figure 23. Indicative yearly energy usage for I&C lighting



Source: Frontier analysis of ECUK and EEPs

We have applied these energy figures to the load profiles used in Brattle's modelling for Sustainability First. This suggests a peak (16:00 – 19:00) power usage of around 5GW in 2015, rising to approximately 7GW by 2035.

As described above, only a portion of this would be available for DSR (which involves dimming lights, not turning them out altogether). For example, if a dimming of 30% were possible, the technically feasible capacity might be 2GW. Customer take-up would also be a highly significant driver of capacity, however it is difficult to estimate the take-up of a technology which is not (at least currently) used within the UK.

6.1.5 Water pumping

Water pumping is one specific industrial process which is already being used for DSR.

DSR capabilities

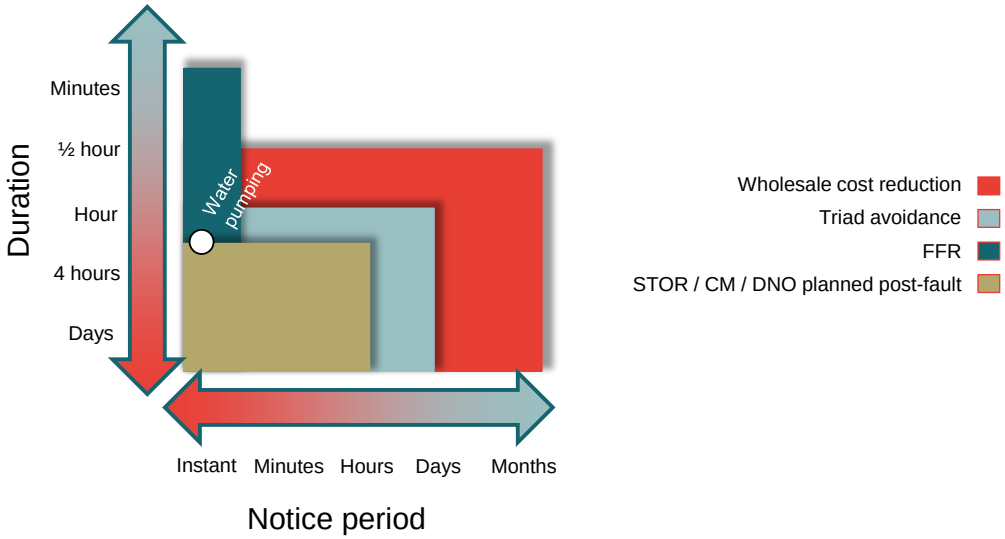
Like lighting, this is another area where evidence from North America exists: the potential for water pumping to contribute to DSR was trialled at El Dorado Hills Raw Water Pump Station and Water Treatment Plant in California.[144] In response to the signal the demand was reduced from around 1,550KWh to 600KWh, a reduction of over 60%. Clearly this signals enormous potential for DSR in water-

144 Edison (2007) , *Demand response for well water pumping systems*

intensive industries, although there may be important differences between the technologies in the UK and US.

It has not been possible within the scope of this project to carry out detailed research into DSR capabilities within the water sector. **Figure 24** provides one illustrative example, which assumes that pumping loads can be curtailed for up to two hours,[145] at very little notice.[146]

Figure 24. Illustrative DSR capabilities of water pumping



Source: Frontier Economics

DSR capacity

According to aggregator Open Energi, United Utilities expects to have a total of 50MW of flexible capacity to offer up to National Grid. United Utilities are responsible for water across roughly 3m[147] properties, roughly 11% of the GB total. A simple scaling would imply GB-wide potential of just over 450MW.

145 This is consistent with publicly available information regarding an automated demand response platform run by Actility, a Belgian aggregator. In this scheme, water companies curtail their demand for up to two hours – see http://www.energy.actility.com/en/news/actility-sees-live-activation-its-dynamic-profile-users-belgian-grid-demand-response accessed 25/03/13. Research carried out for the DTI in 2006 also indicates that water pumping stations are likely to be able to sustain a duration of load cut of 3 hours (1 hour for waste water pumping stations) – see IPA Consulting, Econnect & Martin Energy for DTI (2006), *Reducing the Cost of System Intermittency using Demand Side Control Measures* p19.

146 This is consistent with the use of water pumping by UK aggregator Open Energi to provide services such as Frequency Response.

147 Based on table 7 the 2011 June Return data, counting households and non-households billed for water.

I&C demand-led DSR

However, water and sewage processes vary substantially by region, so this extrapolation should only be seen as an indicative figure.

As a cross-check, we have used Energy Consumption in the UK to determine the total energy usage for motors in the water industry, scaling over time in line with UK population. This would suggest a total energy usage of 3.3TWh in 2015, rising to 3.7TWh by 2035. If power consumption were flat across the year and day, this would imply UK-wide power consumption of just over 400MW by 2035.

6.1.6 Other industrial processes

There is a vast array of other industrial uses of electricity which are specific to the production process for particular products. However, the electricity demands for such processes are highly heterogeneous, and it has not been possible within the scope of this report to carry out a detailed sector-by-sector study of DSR potential. Instead, we have summarised the characteristics of load which may be flexible, and report some top-down estimates of the overall quantity of load that may be flexible.

DSR capabilities

The flexibility of industrial processes varies from industry to industry. DSR potential is likely to be greater for two forms of process.

First, processes that involve some degree of storage. This could be energy storage (in the same way that HVAC, hot water, and refrigeration depend on thermal storage). There may also be multi-stage production processes where the output from one stage is stored, permitting production to be paused while the store is depleted. Some examples[148] include:

- the interruption of pulp production within the paper industry (paper can still be produced for a period from a store of pulp);
- certain multi-stage chemical processes where the output from one process can be safely stored; and
- the interruption of the grinding of raw materials into cement powder which is stored and then fired in a kiln.

Other processes may occur infrequently and can be rescheduled: The CLNR project provides the example of high power machines for activities such as welding that are used intermittently during the day[149] (the project also procured

148 Drawn from Sustainability First (2012), *What Demand Side Services Could Customers Offer? Industry Electricity Demand*

149 CLNR (2015), *Key Social Science Findings: Domestic and SME Customers*

DSR from a compressed gas supply firm, with a motor that could be operated at a discretionary time)[150] although the extent to which such processes can be rescheduled will depend on the constraints of business requirements and the working day. As another example, electric arc furnaces used in the production of steel are highly energy-intensive appliances that will be operated several times a day. Although it is difficult to provide an immediate load reduction from these types of load once they are running, given sufficient notice period, periods of use could be planned to avoid peak times.[151]

Given the heterogeneous nature of these processes, it is not possible to provide a general picture of the types of DSR capabilities that can be provided.

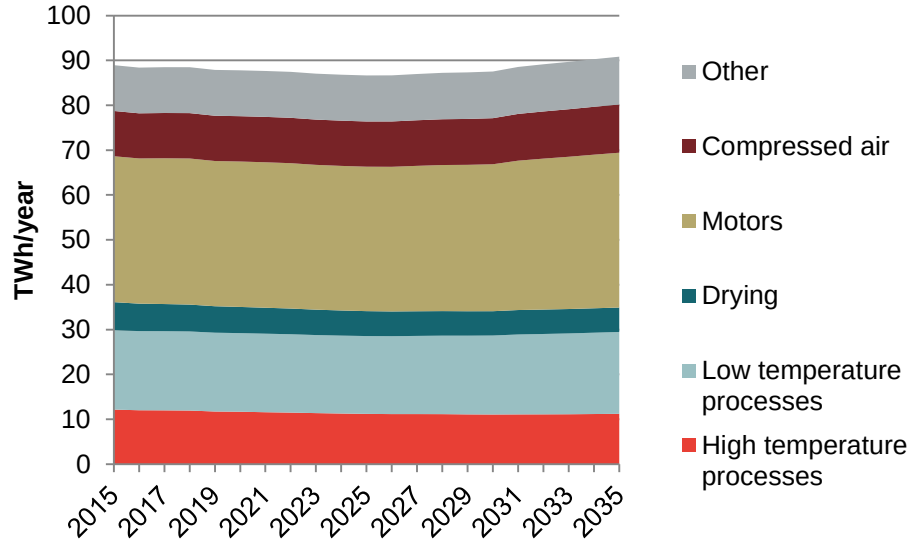
DSR capacity

Using the methodology described above (scaling the ECUK end-use figures according to EEP sector-by-sector projections), **Figure 17** provides an indication of how various industrial end-uses might change over time. It should be stressed that this is an extremely basic approximation that does not take into account factors such as changing end-use intensity by sector over time. The overall yearly energy usage accounted for these processes can be seen to stay constant at around 90TWh or just under.

150 CLNR (2014) *Developing the smarter grid: the role of industrial & commercial and distributed generation customers* p89

151 Sustainability First (2012), *What Demand Side Services Could Customers Offer? Industry Electricity Demand* p41

Figure 25. Indicative yearly energy usage for other industrial processes



Source: Frontier analysis of ECUK and EEPs

We have applied these energy figures to the load profiles used in Brattle's modelling for Sustainability First. This suggests a peak (16:00 – 19:00) power usage of just around 12GW for these uses during the peak in 2015, increasing by about 0.25GW by 2035.

The extent to which this load is flexible will vary significantly by sector. For example, in a survey conducted by Capacity to Customers, participants were asked whether their electricity load was essential. Responses varied substantially between industrial sectors: 38% of participants from Manufacturing and Processing stated that some of their capacity could be managed, compared to 25% in Mining and Quarrying and 0% from the Agriculture, Forestry and Fishing industries. However, insufficient evidence is available to generalise this one survey across all sectors.

6.2 Arrangements for calling DSR

The overall level of demand-led DSR available from the I&C sector will depend upon both the underlying energy uses (described above), but also on the arrangements used to call DSR.

A variety of **price-based arrangements** exist for incentivising DSR in the I&C sector. None of these are capable of facilitating dynamic DSR (i.e. DSR that responds with a short notice period), and at present these apply primarily to larger I&C customers.

- A retail price of electricity that varies over the day may help incentivise load shifting: This would currently apply to many[152] half-hourly metered customers, as well as SMEs on Economy 7 and Economy 10 tariffs.

- Half-hourly metered customers have banded DUoS charges which also have a time-of-use element (although customers may not necessarily see these charges unless they have opted to do so with their supplier).

- For many 100kW-plus customers, TNUoS charges are directly passed through into bills.[153] A significant number of I&C customers take part in Triad avoidance,[154] turning down demand in response to warnings received the previous day.

However, to produce a dynamic response to DSR, it is likely that some form of **direct control** (from a party such as an aggregator, or a supplier[155]) would be required. We discuss the costs of implementing this in the following section.

It should be noted that the arrangement for calling DSR will affect both the proportion of businesses that engage with DSR, and the amount of load-shifting that they produce when signalled to do so. For example, the previous section reported some availability figures (the proportion of load shifted when it is called) relating to direct control. This might be lower if a price-based arrangement were used.[156]

6.3 Costs

We have considered three types of costs that may be associated with I&C demand-led DSR:

152 A supplier we spoke to told us that only around 7% of their half-hourly customers were on single-rate tariffs, with the remaining 93% on time-of-use tariffs.

153 Sustainability First (2012), *What Demand-Side Services Can Provide Value to the Electricity Sector?* p24. A supplier we spoke to indicated that this was the case for almost two-thirds of their half-hourly volume.

154 Sustainability First (2012), *What Demand Side Services Could Customers Offer – Industry Electricity Demand* p26 notes that the majority of the I&C firms interviewed who did take part in Triad avoidance, did so by actively reducing demand (as opposed to running generation).

155 For example, new entrant Tempus Energy operate a model where they act as supplier, but also control flexible load in the same way an aggregator would.

156 See for example Redpoint (2012), *Electricity System Analysis – future system benefits from selected DSR scenarios*, which provides figures on the proportion of technical potential which may be achievable through time-of-use pricing.

- **Capital costs** – i.e. costs incurred in order to bring a unit of DSR capacity on to the system. The two types of capital cost considered below are relevant to an aggregator seeking to enable a site for dynamic DSR.
- **Fixed O&M costs** – costs incurred each year for a given amount of capacity.
- **Running costs** – costs incurred for each kWh of demand that is reduced or shifted.

Summary of the evidence base

The table below summarises the main types of sources that have been used in this section, and indicates where some of the greatest uncertainties lie.

Area	Main sources of evidence and robustness
Current capital costs associated with an aggregator taking on a further site	We have interviewed a number of aggregators to discuss the broad costs associated with enabling a unit to carry out dynamic DSR. However, the figures in this paper are simply our "best guesses", and in any event vary substantially across installations.
Future capital costs associated with an aggregator taking on a further site	It is even more difficult to predict how these costs could evolve over time, and we have been unable to provide evidence in this area.
Current fixed yearly costs associated with demand-led DSR	We understand from aggregators that fixed availability payments are often key to attracting businesses, and provide an approximate figure for the size of payment currently provided.
Future fixed yearly costs associated with demand-led DSR	It is even more difficult to predict how these costs could evolve over time, and we have been unable to provide evidence in this area.
Variable costs associated with back-up generators	Energy "payback" and opportunity costs to businesses will vary substantially across end-uses and sectors. There is no systematic source of evidence covering all these areas, although we do provide evidence from a single study that demonstrates "payback" may be relatively low for HVAC.

6.3.1 Capital costs

Dynamic DSR, if called by an entity such as an aggregator, requires investment in physical hardware including:

- communications equipment, to be able to remotely send instructions to the assets providing DSR;
- control equipment, to automatically carry out load reduction upon receipt of a signal; and
- metering equipment, to be able to verify whether the load reduction took place.

Relatively little information is publicly available regarding the costs of setting up a site for demand-side response. However, we understand from discussions with aggregators that the costs of commissioning a demand-led DSR site are typically lower than for back-up generation, as there is no need to adjust switchgear to enable parallel running.

One aggregator indicated to us that hardware costs might be £1,000 for a site. Another provided a figure for average hardware, installation and commissioning costs of £200/kW which, combined with an average site size of 50kW, would imply costs of £10,000. The hardware costs alone for this aggregator were in the range £1,500 - £2,000.

As with diesel back-up generation, there may also significant marketing and sales costs associated with attracting firms to an aggregator.

6.3.2 Fixed O&M costs

In addition to these costs, an aggregator will also need to ensure that firms have a sufficient annual availability payment for the proposition to be commercially viable. As stated in section 5.3, these costs are currently in the order of £20/kW, however this is an extremely approximate figure.

The availability payment required to incentivise uptake will undoubtedly vary from firm to firm. In an LCNF funded survey,[157] Capacity to Customers attempted to elicit the elasticity of take up for demand side response. By asking respondents the amount of DSR they would provide for the same contract at different prices, C2C found that a 1% increase in payment increases take up by 0.3%.

We have no evidence on how these costs may change in the future.

157 Capacity to Customers (2012), *Customer Segmentation Report* p33

6.3.3 Running costs

The running costs of I&C demand-led DSR can be divided into those that arise from the postponed consumption of energy, and business impacts from the postponement of processes.

"Payback" of energy consumption

Most of the sources of I&C demand-led DSR considered above involve the postponement of demand to a later period (one exception is any DSR that can be undertaken through dimming of lighting). A key variable cost for these types of DSR is the cost to the business consumer of the postponed energy consumption, which will depend on both:

- the extent to which the "payback" energy consumed after the load turn-down finishes is greater than or less than the energy consumption foregone during the load turn-down; and
- variations in the price of electricity over the day.

Relatively little information is available regarding the extent of "payback" for different I&C energy uses. However, for some applications, this could be quite low. Low Carbon London found[158] that HVAC payback energy ranged from 6% to 36% of turn-down energy in their sample of 11 hotels and 1 office (i.e. for every 1kWh of electrical energy reduced, at worst only 0.36kWh of additional energy would need to be added after the event). This is corroborated by one of the aggregators we spoke to (which has a large HVAC portfolio), which stated that any payback can be managed with good algorithms and is therefore not a problem.

Business impacts

Where industrial processes are postponed, this may have a direct impact upon firms' revenue.

For previous research, Sustainability First carried out face-to-face interviews with a variety of large industrial energy users. Respondents from a number of sectors (brick manufacturing, food, and steel manufacturing), noted that the lost production time caused by DSR would lead to revenue impacts that were greater than the financial incentives currently on offer for DSR.[159] Nevertheless, it is worth noting that 13 out of 19 respondents to Sustainability First's survey

158 Imperial College London (2014), *Distributed Generation & Demand Site Response Services for Smart Distribution Networks* p43

159 Sustainability First (2012), *What Demand Side Services Could Customers Offer – Industrial Electricity Demand* p30

currently took part in Triad avoidance, with the majority of these doing so by reducing demand (rather than using back-up generation).

6.3.4 Greenhouse gas and local emissions

Greenhouse gas emissions from I&C demand-led DSR will depend upon:

- the "payback" of energy consumption required after the DSR event (this will be zero for technologies that involve curtailment of load rather than shifting); and
- the relative carbon intensity of grid electricity during the period of demand reduction, compared to an increase in demand.

In many instances (for example, DSR to reduce wholesale electricity costs), the carbon intensity will be lower during the period where demand is shifted to. Providing the "payback" energy is not significantly greater than the original reduction in energy, these forms of DSR will be associated with a decrease in carbon emissions. The updated version of the DDM can calculate the carbon emissions increase or decrease associated with DSR.

If changes in emissions are internalised, then they will affect the costs of these forms of DSR, potentially altering the volume that is utilised. Carbon is priced via the EU ETS, and the vast majority of electricity is generated by larger generators which face these costs. Carbon costs and benefits for demand-led DSR are therefore priced in to the cost of electricity.

Unless a specific industrial process is associated with emissions, I&C DSR will not be associated with changes in local emissions where the responsive load is located.

7 Domestic demand-led DSR

Domestic demand-led DSR refers to actions which shift or reduce domestic electricity use at particular moment in time. Here, we consider the long-term potential for this form of DSR in the UK and provide a scenario for how it might grow to 2035.

First, we estimate the potential capacity of shiftable load that may exist (by category), and the DSR capabilities it may offer. This is based on a consideration of the potential flexibility of each type of domestic appliance, the overall amount of energy it may use, and how this is distributed across the year, week and day.

The next section addresses the potential contractual arrangements available to call domestic DSR, as well as the technology requirements, and the degree of consumer engagement that would be needed.

We then present the available evidence on the types of cost that may be incurred for domestic demand-led DSR.

7.1 Sources of potentially shiftable load

To estimate the long-term potential for domestic DSR up to 2035 we follow a similar approach to that used for I&C demand-led DSR. This involves the following steps:

- First, we identify the domestic appliances that have **flexible capacity** for the purpose of DSR. By "flexible" we mean capable of being reduced or shifted without unacceptable consequences to a household, given a reasonable monetary incentive and a willing consumer.

- Second, we have used publically available statistics to determine **total electrical energy consumption** per annum for each type of domestic appliance considered.

- We have then applied load profiles (or reported results from analysis which does so) to determine the **profile of electricity demand** across the day and the year. When reporting results, we have focussed on winter evenings where possible.

Summary of the evidence base

The table below summarises the main types of sources that have been used in this section, and indicates where some of the greatest uncertainties lie.

Area	Main sources of evidence and robustness
DSR capabilities of different types of appliance	There is a relatively broad agreement regarding the types of appliance that might be amenable to DSR.
Current energy usage of different domestic appliances	This has been quantified through surveys, with results reported in sources such as Energy Consumption in the UK and Defra's Market Transformation Programme.
Future energy usage of different domestic appliances	Forecasts exist, although will depend heavily upon assumptions regarding technological progress, consumer acceptance, and the extent to which government product policy enforces efficiency standards.
Load profiles for domestic appliances	Current load profiles for widely available technologies (e.g. cold and wet appliances) have been quantified through monitoring surveys, such as the Household Electricity Survey (HES) and work undertaken for the Customer-Led Network Revolution (CLNR) LCNF project. There is greater uncertainty in how these profiles may change in the future. The HES contains only a very small sample of households with electric resistive heating as a primary heat source. We have used data collected by the CLNR project, although this too is subject to sample size issues. Data on technologies that have not yet been widely taken up (air source heat pumps and electric vehicles) have been collected by the CLNR and Low Carbon London LCNF projects. However, these may not be representative of the types of EVs and how they are used in the future.

7.1.1 Identifying potentially flexible appliances

The first step is to determine the appliances that may be able to provide DSR.

Table 10 summarises the extent to which various categories of domestic appliance may or may not be flexible. We consider an appliance to be flexible if either:

- the appliance has some degree of energy storage (separating appliance usage from energy consumption); or
- consumers may be willing to postpone use of the appliance.

Note that appliances which are not flexible (for example lighting) may still be able to provide an overall reduction in demand and could potentially be eligible for DECC's Electricity Demand Reduction Pilot.

There is not a universally recognised distinction between which loads are "flexible" and which are not (flexibility will vary significantly within these categories across households and models of appliance). In developing scenarios for flexible load to 2035, our focus will be on the following types of appliance, which appear to show the greatest scope for flexibility:

- Electric resistive heating with storage;
- heat pumps (with storage or gas hybrid systems);
- electric vehicles;
- wet appliances;
- cold appliances; and
- electrical energy storage.

Table 10. Flexibility of domestic appliances

	Appliance	Rationale for why flexible/inflexible
More flexible	**Electrical energy storage**	Battery can be charged and discharged at different times of the day
	Electric vehicles	Battery storage gives some flexibility of charging time
	Electric resistive water and space heating (with storage)	Thermal storage enables electricity use to be separated from heat production
	Heat pumps (with storage / gas hybrid models)	Thermal storage enables electricity use to be separated from heat production (alternatively, gas could possibly be substituted for electricity at specific times)
	Wet appliances	Appliance operation could be postponed[160]
	Cold appliances	Thermal storage means device can be turned off for a period while remaining within temperature limits
	Consumer electronics (inc TVs, computers and audio equipment)	Patterns of use may be inflexible, although some devices have associated battery storage, which we discuss briefly in the section on electrical energy storage
	Ovens	Some uses (e.g. baking) might be postponable,[161] although some research shows consumers are generally unwilling to alter their cooking behaviour[162]
	Lighting	Research has generally concluded that domestic lighting is inflexible,[163] although *permanent* reductions in demand may be attainable through more efficient lamps or technologies such as proximity sensors to turn off lighting when not required
Less flexible	**Kitchen appliances (e.g. microwaves)**	Research shows consumers are generally unwilling to alter their cooking behaviour[164]

Source: Frontier Economics, based on Cambridge Architectural Research, Element Energy and Loughborough University (2013), *Further Analysis of the Household Electricity Survey Early Findings: Demand side management*

160 For example, qualitative research for Northern Powergrid's Customer Led Network Revolution found that found some groups of respondents (most typically working families) felt laundry could be shifted within a 24 hour time-frame, or even between days. Powells and Bulkeley (2015) *Key Social*

In aggregate, Sustainability First has previously suggested that between 5% and 25% of total domestic peak load could be potentially flexible.[165]

We now consider each of the potentially flexible loads in turn, considering the nature and extent of the flexibility, the likely future capacity associated with each and the proportion that may be engaged and available for DSR.

7.1.2 Electric resistive storage heating

Electric resistive heating uses electric resistance in wires to generate heat – for either space heating or water heating. In the UK for space heating, it is used most commonly as a secondary heat source (to back up gas boilers for example), but it is also used as a primary heat source (particularly for dwellings without access to the gas grid or in flats or smaller dwellings).

Electric resistive heating with an element of storage allows some form of DSR. This typically takes the form of hot water tanks for water heat, and heaters with built-in thermal stores for space heat.

DSR capabilities

Electric resistive storage heating can be used to postpone demand for several hours (existing E7 and E10 tariffs incentivise the charging of the heaters at night, for use during the day). With suitable technical and contractual arrangements, it would in theory be possible to call storage heating DSR with very little notice (for example the existing dynamic teleswitching system installed in some properties, discussed in section 7.2.2, can carry this out). As shown in **Figure 26**, these capabilities mean that domestic electric storage heating is potentially well suited to a wide range of DSR uses.

Science Findings: Domestic and SME Customers. Similarly, UK Power Networks' Low Carbon London report found that consumers felt that wet appliances were the easiest to shift. Imperial College London (2015), *Residential consumer attitudes to time-varying pricing.*

161 Cambridge Architectural Research, Element Energy and Loughborough University (2013), *Further Analysis of the Household Electricity Survey Early Findings: Demand side management* p18

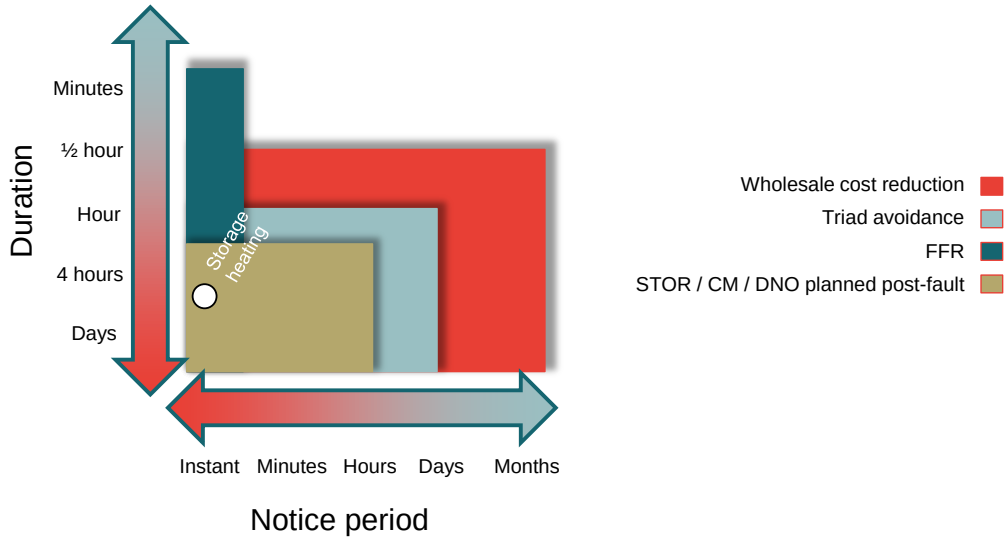
162 Customer-Led Network Revolution (2013), *Insight Report: Enhanced Domestic Monitoring* p31

163 In research for UK Power Networks' Low Carbon London. Lighting, cooking and showering were reported as the hardest to shift, though even here, some evidence of consumer willingness to be flexible was found. Imperial College London (2015), *Residential consumer attitudes to time-varying pricing.*

164 Customer-Led Network Revolution (2013), *Insight Report: Enhanced Domestic Monitoring* p31

165 Sustainability First, (2012), *Paper 3: What demand side services could household customers offer?*

Figure 26. Illustrative DSR capabilities of domestic electric storage heating



Source: Frontier Economics

DSR capacity

There are around two million homes,[166] or 8% of dwellings in Great Britain with electric storage heaters. This proportion has remained relatively constant since at least 1996.[167] It is likely that most of these households will be part of the 3.5 million households with an Economy 7 tariff, or on an alternative time of use tariff, in order to take advantage of the storage capability of their heating system.[168]

As shown in **Figure 27**, electric resistive heating is found most commonly in flats (flats account for 65% of English properties with electricity as the main heating fuel, even though these properties only account for 20% of UK dwellings).[169]

166 CLNR (2013), "Insight Report: Enhanced Domestic Monitoring – Disaggregated Load, Hot Water and Storage Heating"

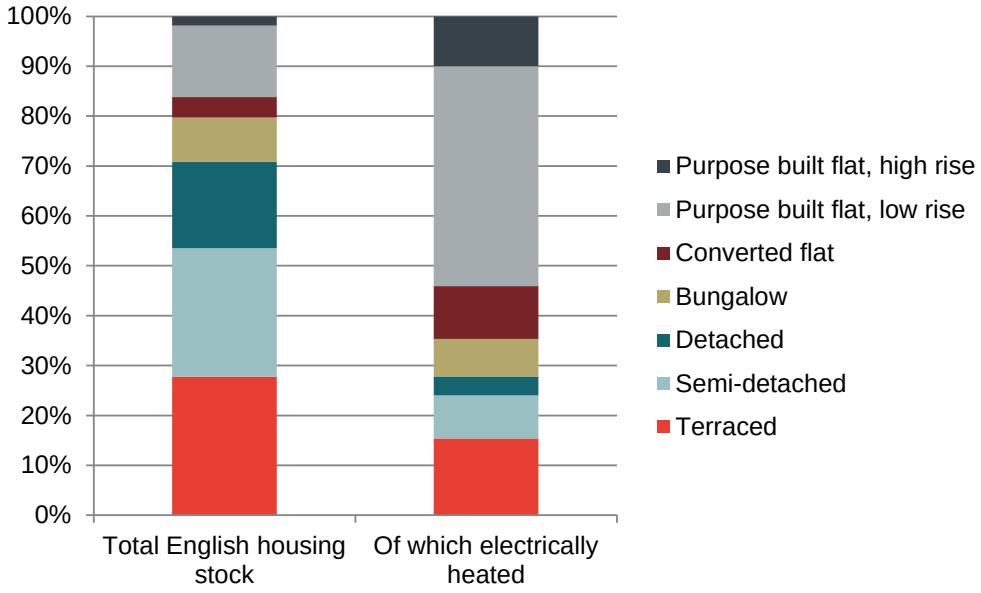
167 DCLG (2015), *English Housing Survey Headline Report*

168 CLNR (2013), "Insight Report: Enhanced Domestic Monitoring – Disaggregated Load, Hot Water and Storage Heating"

169 English Household Survey 2012 Table DA6101 (SST6.1)

Domestic demand-led DSR

Figure 27. Electric heating by housing type



Source: English Household Survey 2012 Table DA6101 (SST6.1)

Future electricity demand for electric resistive heating will therefore depend on the mix of property types. 16.4% of English housing built since 1990 has had electricity as the main heating fuel (compared to 9.1% of the total housing stock),[170] a trend which suggests a gradually increasing number of installations.

Heat pumps and district heating may prove particularly attractive to properties with electric resistive heating, owing to the higher running costs of electric resistive systems over gas boilers. This would be particularly the case for off gas-grid homes, which may have installed electric resistive heating due to the lack of a cost-effective alternative. Where new homes with electric resistive heating are being built on the gas grid, though, this may suggest other barriers (for example capital costs) to the installation of a central heating system, which might also limit the uptake of heat pumps. In any case, the future uptake of electric resistive heating is heavily intertwined with the uptake of alternative systems.

Drawing on a report for the CCC, Drysdale, Wu and Jenkins consider that annual demand for electricity for space and water heating in the UK was 31TWh in 2012.[171, 172] Virtually all of this will relate to electric resistive heating. That paper

170 English Household Survey 2012 Table DA6101 (SST6.1)

171 Drysdale, B., Wi, J., and Jenkins, N. (2014), *Flexible demand in the GB domestic electricity sector in 2030*, Applied Energy (in press) p4

172 This is broadly consistent with figures from ECUK, which include an estimated total consumption of 2,705ktoe (around 29GWh) of electricity for heat and water in 2012.

assumes that, by 2030, all electric heating will be delivered by heat pumps (implying zero demand for electric resistive heating).[173] However, this forecast will be dependent on a large number of external factors (for example, technological development and government policy). In addition, this forecast may not be compatible with the DECC forecast we use for heat pumps in section 7.1.3.

Load profiles

Figure 28 shows average winter weekday heating profiles collected as part of the Customer-Led Network Revolution project.[174] These are based upon extremely small sample sizes – 4 customers for the line marked "TC10aHW hot water", 8 for "TC11aSH Hot Water" and 13 for "TC11aSH storage heater".[175]

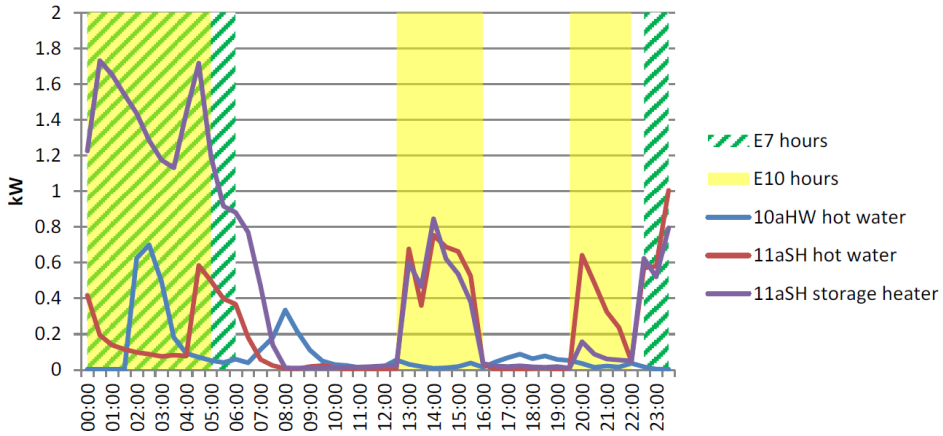
The profiles show demand that is broadly in line with typical Economy-7 and Economy-10 tariff off-peak hours (indicated by the shading). However, there is evidence that at least some customers may also use hot water heaters in the morning after these periods end.

173 Similarly, the pathways for domestic electric resistive heating used in Barton, J. et al (2013*) The evolution of electricity demand and the role for demand side participation*, in buildings and transport. Energy Policy, 52, pp. 85 – 102 show a substantial reduction in energy usage by 2020.

174 Customer-Led Network Revolution (2015), *Insight Report: Enhanced Domestic Monitoring*, p45

175 Note that the Household Electricity survey only appears to include data on one household with electric resistive primary heating for December weekdays, and it is not possible to view this data directly due to anonymity concerns. The data can be displayed after it is averaged over households without electric resistive primary heating, and shows a storage heater profile that runs only overnight, and an immersion heater profile with peaks in the morning and evening.

Figure 28. Electric resistive space heating load profile



Source: Customer-Led Network Revolution

The profile for storage heating has an off-peak value of around 1.4kW (note that these are averages across multiple households, and that the individual peak per household is likely to be considerably higher). If this were representative of the roughly 2m homes with storage heating (this may well not be the case given the extremely small sample size),[176] this would suggest a night-time demand of nearly 3GW.

However, if heat pumps were to eventually largely displace electric resistive heating by 2035 (as implied in the Drysdale, Wu and Jenkins paper), there might be limited potential for DSR from this source by 2035.

7.1.3 Heat pumps

Heat pumps are a low-carbon renewable technology, which can be used for both space and water heating in homes.[177] They have potential for DSR as they can be turned-off for a period of time without affecting the temperature in the home, where they are accompanied by a storage system,[178] are installed in a very well-

176 This figure is broadly consistent with p28 of Barton, J. et al (2013) *The evolution of electricity demand and the role for demand side participation*, in buildings and transport. Energy Policy, 52, pp. 85 – 102. That analysis determined heating profiles for E7 consumers by subtracting an unrestricted profile from an E7 profile, and shows average winter space heating power consumption of between 1kW and 2kW for the period between 00:00 and 06:00.

177 Heat pumps use compression and expansion of gases or liquid to draw heat from the natural energy stored in the ground or air. http://www.theccc.org.uk/glossaryitem/heat-pumps/

178 For example, the heat pumps used within Northern Powergrid's Customer-Led Network Revolution project had a thermal store that enabled the heat pump to be turned off for two hours. Customer-led network Revolution (2015), *Developing the Smarter Grid: The role of Domestic and Small and Medium Enterprise Customers* (p13)

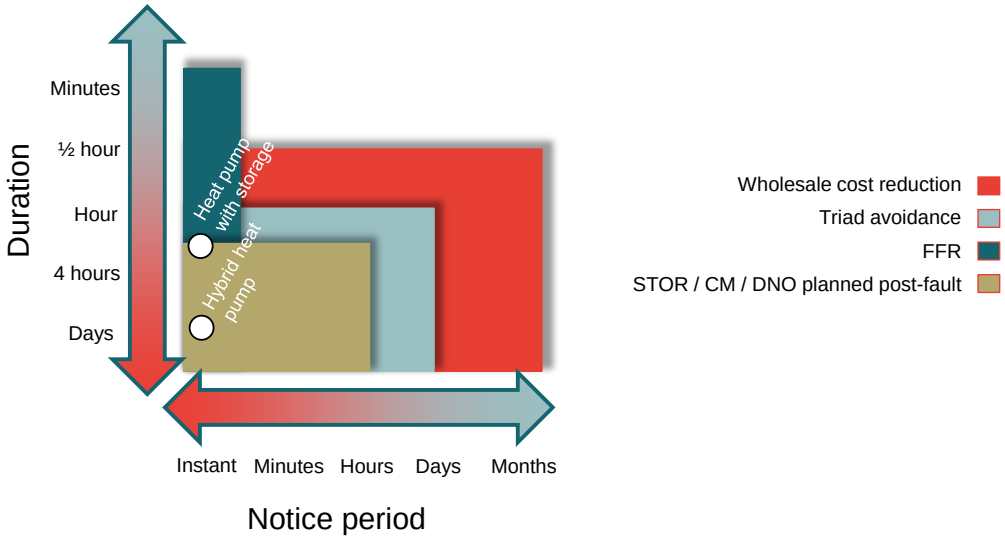
insulated property, or are part of a hybrid system that also includes a conventional boiler.

Heat pumps can use heat energy within the air, ground, or water as source of heat, and can release this heat into water (for central heating) or the air. The studies discussed here relate to air-to-water heat pumps, and other forms of heat pumps may have different DSR capabilities.

Potential flexibility

Figure 29 plots the DSR capabilities of these types of appliance (the notice period could be short providing that technical and contractual arrangements for dynamic DSR are in place).

Figure 29. Illustrative DSR capabilities of domestic air-source heat pumps



Source: Frontier Economics

Capacity

The electrification of heat through the uptake of heat pumps is likely to be an important part of the Government's strategy to meet carbon budgets. We have used figures prepared for Workstream 7 of the DECC / Ofgem Smart Grid forum, which suggest that there could be around 6.4m residential heat pumps installed across GB by 2030 under a "Central" scenario (0.8m under a "Low" scenario, and 7.8m under a "High" scenario). Extrapolating linearly to 2035 yields figures of 9.6m and 0.85m respectively. Figure 30 below plots these uptake

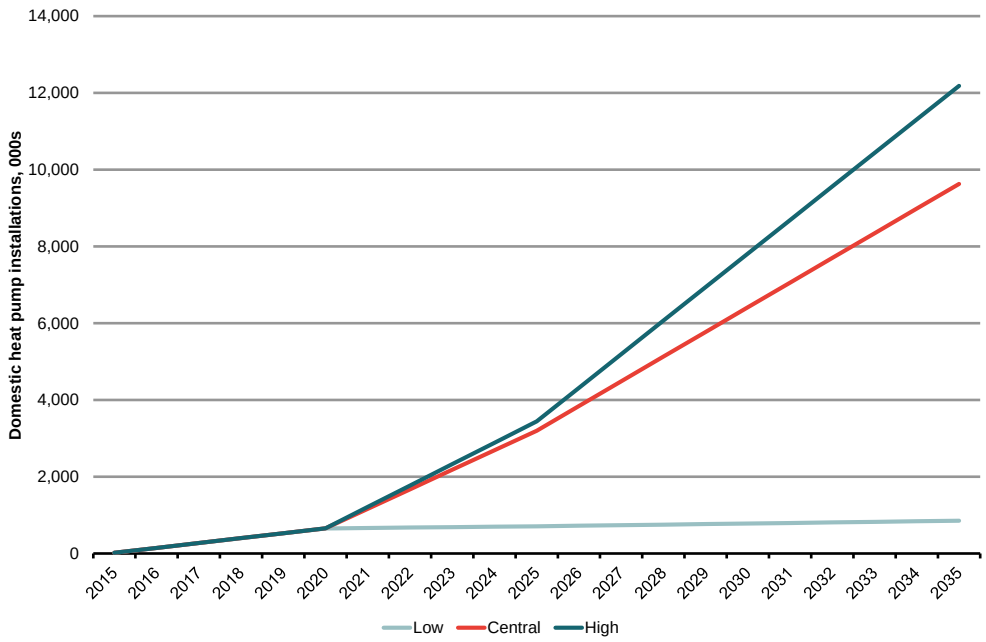
Domestic demand-led DSR

figures.[179] For the purposes of estimating DSR up to 2035 we will use DECC's central scenario, in addition to the low scenario as for sensitivity.

The wide range covered by these scenarios demonstrates the uncertainty in the future uptake of heat pumps. When looking out as far as 2035, it is extremely difficult to forecast the types of technical progress that may affect the demand for different types of domestic heating. For example, a greater than expected rollout of district heating through CHP could reduce the demand for heat pumps. SPECIFIC, an academic and industrial consortium based at Swansea University, is researching other technologies which could help reduce the reliance on heat pumps as a means of decarbonising heating. One output of the project so far has been a demonstration site which uses collected solar thermal energy to boost the coefficient of performance of a heat pump (connected to a storage system). The project is now looking at demonstrating a thermochemical interseasonal heat storage system. This could theoretically remove the need for the heat pump entirely, with all the space heat requirements of a property met via stored solar thermal energy (potentially with some electric resistive heating for additional comfort). If such technology was economic for a large number of households, it could considerably reduce the demand for electricity for heating.

179 We have applied a linear interpolation to the five-yearly dataset. The uptake graphs on some other documents (e.g. p28 of the DS2030 stakeholder engagement event slides for 27/04/15 at http://www.smarternetworks.org/Files/Smart_Grid_Forum_Work_Stream_7_150428102211.pdf) appear to use a different method of interpolation.

Figure 30. DECC heat pump scenarios, cumulative installations



Source: DECC; Note: DECC provides data from 2021 and 2030. Data has been interpolated between 2010 and 2021, and linearly extrapolated from 2030 onwards.

Load profiles

The Customer-Led Network Revolution LCNF project has analysed electricity usage data for 89 domestic customers with air-source heat pumps.[180] **Figure 31** plots the mean profile per heat pump in January and June (solid lines). This load profile exhibits:

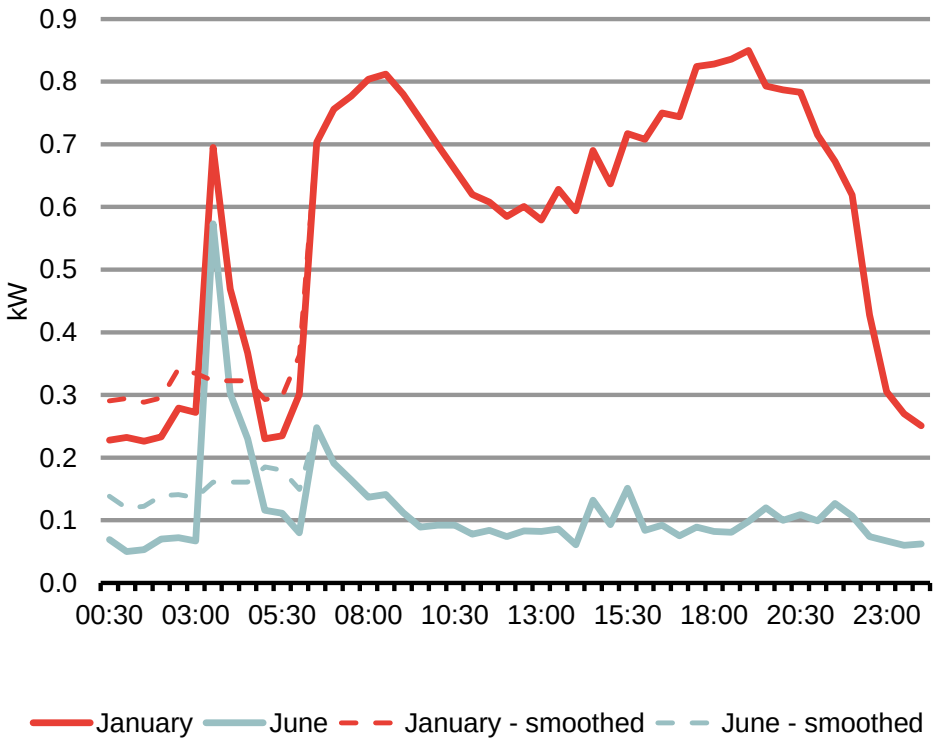
- considerably lower mean demand during the summer (where there is less need for space heating);
- a broadly load-following profile, which peaks in the morning and evening and is lowest at night; and
- a sharp 3am spike in demand, which was due to all heat pumps used in this trial having a hot water timer set for this period.

We have smoothed out the 3am peak across the period between midnight and 6:30am, as it is unlikely to the entire GB fleet of heat pumps would be configured with a 3am timer. The resulting load profiles are illustrated with a dashed line in **Figure 31**.

180 Customer-Led Network Revolution (2015), *Insight Report: Domestic Heat Pumps*

Domestic demand-led DSR

Figure 31. Heat pump profiles from CLNR project



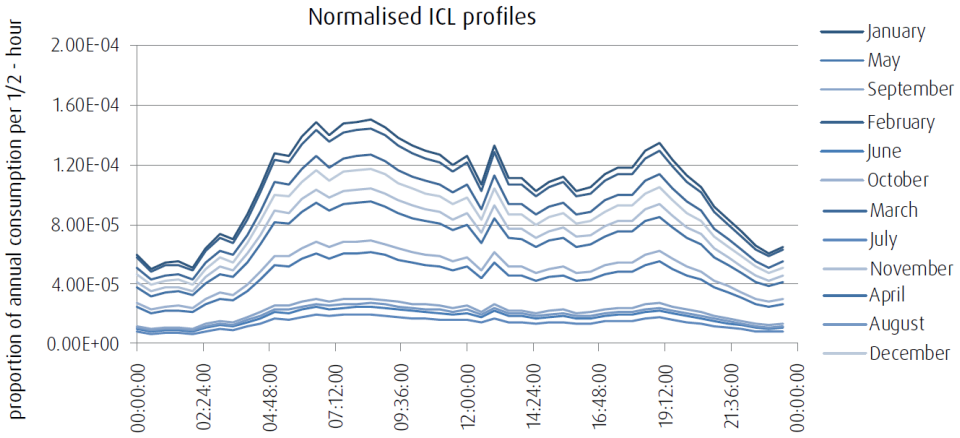
Source: Customer-Led Network Revolution

The shape of the profile is consistent with those obtained from a trial of 18 heat pumps for Low Carbon London, shown in **Figure 32** (these are normalised – the y-axis gives consumption as a proportion of the yearly total).[181]

It must be stressed that this was a relatively small trial of one model of heat pump among consumers in one region of the country, and is therefore unlikely to be representative of the average load profile of all future GB air-source heat pump users. For example, the overall UK housing stock may be less well insulated than the specific homes used for this trial. However, we are not aware of more appropriate UK datasets for heat pump profiles.

181 UK Power Networks (2014), *Impact of Electric Vehicle and Heat Pump loads on network demand profiles* p41

Figure 32. Normalised heat pump profiles



Source: Low Carbon London

If the 9.6m heat pumps of the "Central" scenario described above were all of the variety used in the CLNR trial, this would suggest a potential winter peak demand of roughly 7.7GW. Under the 0.85m "low" assumption, the equivalent would be 0.68GW. As discussed above, these figures are a "starting point" only, and subject to considerable uncertainties and biases.

7.1.4 Electric vehicles

Electric vehicles (EVs) are powered by an electric motor that runs off a rechargeable electric battery (hybrid electric vehicles have an electric motor and battery, but also have an internal combustion engine – this may present further potential for DSR, but is not discussed in this report). Like heat pumps, EVs are likely to be a key part of the Government's strategy to meet carbon targets and numbers of EVs in the UK are projected to increase in the coming years. The rechargeable batteries, and the potential flexibility in when this battery is charged, may mean EVs are an important source of DSR.

Potential flexibility

A typical residential electric vehicle might be plugged in to charge overnight, but could only require a few hours to charge to capacity.[182] Charging could be delayed or interrupted, providing that there is sufficient total charging time that the customer is reassured that the battery is at the required capacity in the morning. In principle, EV batteries could also be discharged using "vehicle-to-grid"

182 UK Power Networks (2014), *Impact of Electric Vehicle and Heat Pump loads on network demand profiles* p26 shows a typical demand profile.

systems, although repeated charging and discharging of EV batteries may shorten their lifetime.

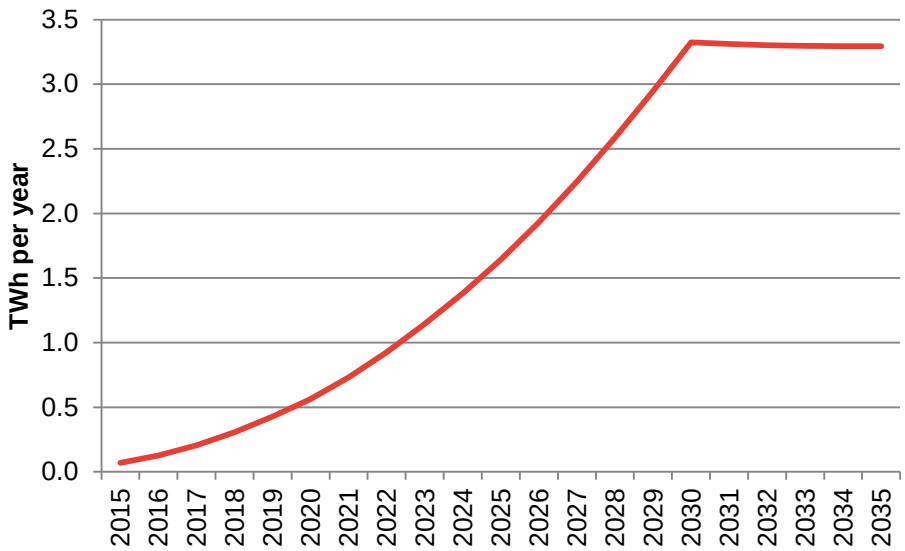
Further information on the real-life DSR capabilities of EVs in the UK will become available as results are published from EA Technology and SSE's *My Electric Avenue* project.

Capacity

DECC's Energy and Emissions Projections contain a "reference scenario" for EV energy usage, increasing from 68GWh in 2015 to 3.3TWh in 2035. These are plotted below in **Figure 33**. Note the slight decrease in energy consumption from 2035 onwards, which is consistent with increased energy efficiency of EVs once uptake has plateaued.

As with any projections of nascent technology use, this scenario will be subject to a huge amount of uncertainty, relating to factors such as policies, costs and consumer demand.

Figure 33. EV electricity consumption scenario



Source: DECC

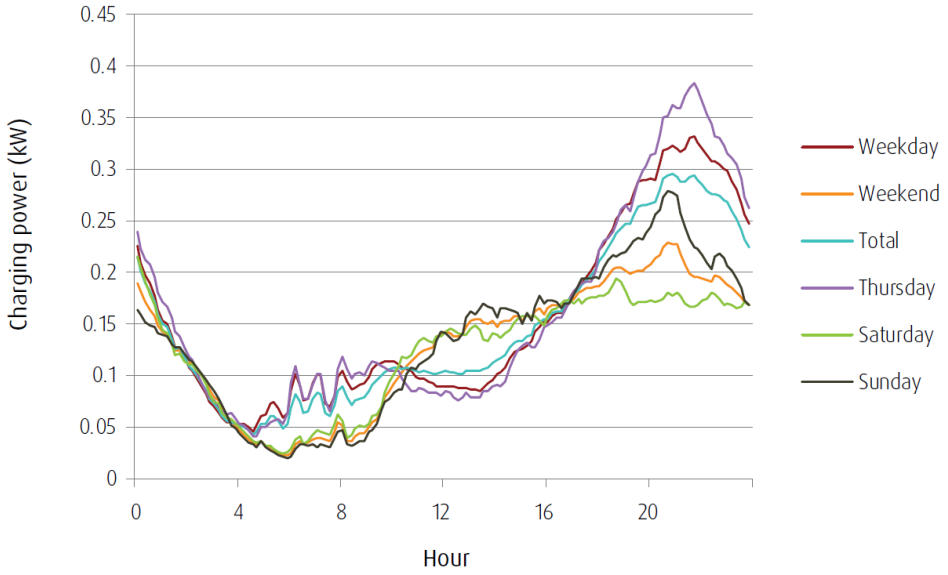
Load profiles

UK Power Network's Low Carbon London project monitored charging data from a sample of 72 residential[183] and 54 commercial participants, in addition to public charge points. **Figure 34** shows the average load profiles for residential

183 47 existing EV users, and 25 with an EV leased on a 1-year basis.

EVs on this trial. Peak demand occurs around 9pm in the evening, with the bulk of charging energy requirements supplied between 6pm and Midnight.[184]

Figure 34. Average charging profiles per EV for different days of the week - residential



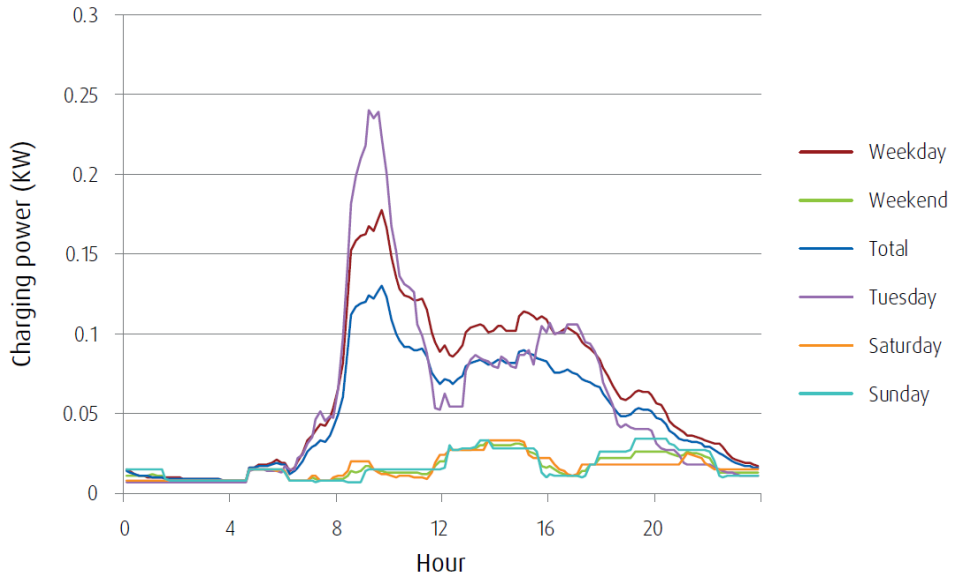
Source: Low Carbon London

Figure 35 shows average charging profiles for commercial EVs connected to single-phase supplies. Here, peak demand occurs at around 10am, with a secondary peak around 5pm and very few vehicles charging later at night.[185]

184 UK Power Networks (2014), *Impact of Electric Vehicle and Heat Pump loads on network demand profiles* p27

185 UK Power Networks (2014), *Impact of Electric Vehicle and Heat Pump loads on network demand profiles* p30

Figure 35. Average charging profiles per EV for single-phase commercial vehicles for different days of the week

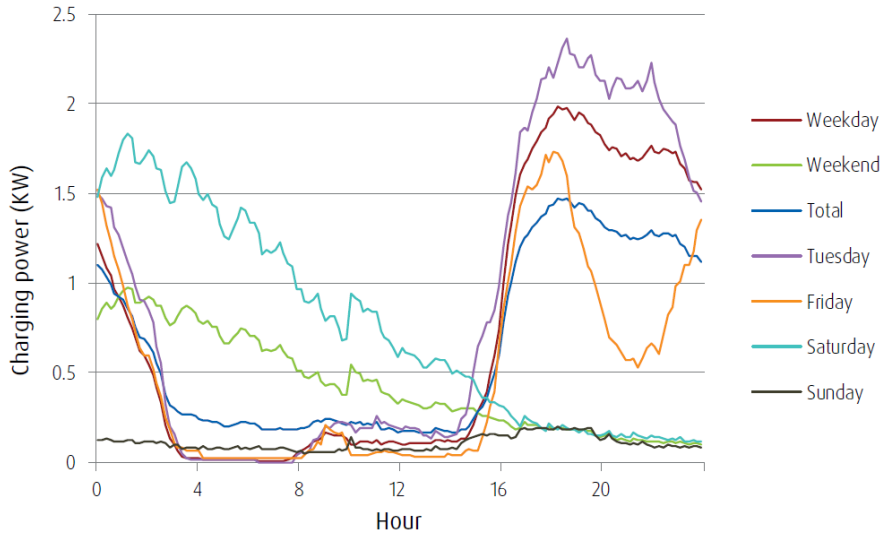


Source: Low Carbon London

Finally, **Figure 36** shows monitored average demand for commercial vans connected to a three-phase supply, which demonstrate a higher afternoon peak.[186]

186 UK Power Networks (2014), *Impact of Electric Vehicle and Heat Pump loads on network demand profiles* p31

Figure 36. Average charging profiles per user among the 3-phase commercial participants (delivery vans) for different days of the week



Source: Low Carbon London

Northern Powergrid's Customer-Led Network Revolution project monitored electricity usage for 143 domestic charge points in the North-East, with data available for the period January-June 2014. It should be noted that 108 of the EV owners in this study are employees, or friends and family of employees, of Nissan, and so are unlikely to be representative of UK households as a whole.[187] Key findings include:[188]

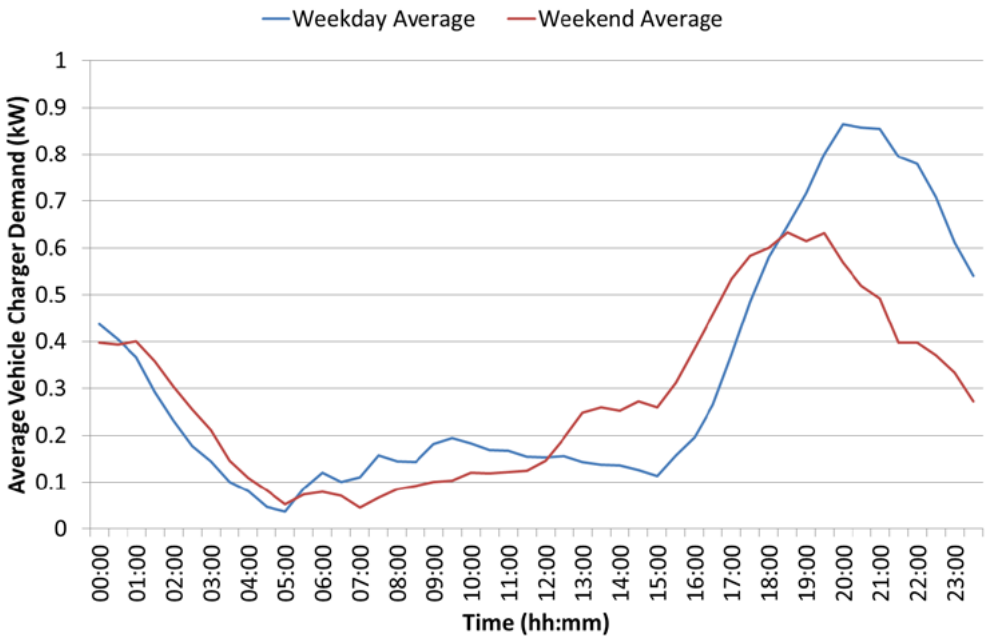
- Charging is concentrated in the evening;
- weekend charging is lower than week-day charging; and
- charger demand is lower in the summer, which may reflect a reduced need for in-car heating and lighting.

Figure 37 and **Figure 38** show the average load profiles obtained from this trial for weekdays and weekends in February and June.

187 Customer-Led Network Revolution (2015), *Insight Report Electric Vehicles* p8

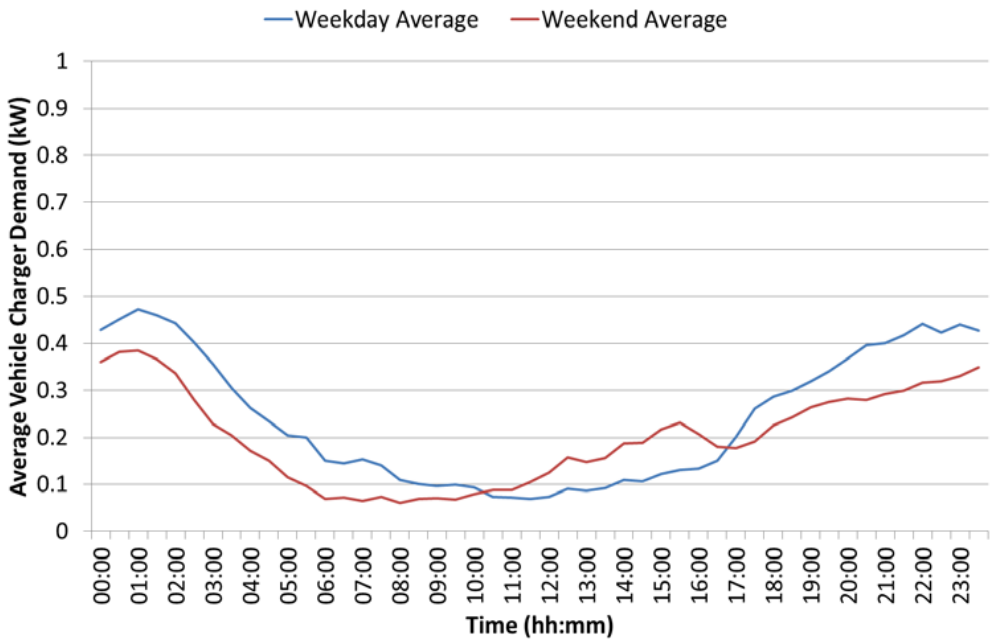
188 Customer-Led Network Revolution (2015), *Developing the Smarter Grid: The role of domestic and small and medium enterprise customers* p9

Figure 37. February 2014 EV Charger Weekday and Weekend Average Diurnal Profile



Source: Customer-Led Network Revolution

Figure 38. June 2014 EV Charger Weekday and Weekend Average Diurnal Profile



Source: Customer-Led Network Revolution

Compared to the Low Carbon London profiles, the CLNR profiles display a similar pattern, but a higher peak demand (even in June). This may be due to the different mix of vehicles and users: It seems possible that EV users in London may drive shorter distances than those in the North-East.

For the purpose of populating the DDM, we require only a *profile* of demand from the trial data (the absolute level of energy will be set based on the EEP scenario). We have therefore used the CLNR trial data, due to the ability to provide a seasonal breakdown.

Applying the CLNR February weekday load profile to the EEP energy figures yields a peak demand of around 1.2GW by 2035.

7.1.5 Wet appliances

Wet appliances include washing machines, tumble dryers, washer-dryers and dishwashers. Wet appliances are heavy users of domestic electricity while in use and can run for up to several hours, although electricity use will vary by length of cycle and temperature, and these appliances will often be idle.

Potential flexibility

Wet appliances frequently have a delay feature built in, which can be used by consumers to postpone the start of a cycle. The flexibility of this load may be

increased with the application of smart technology to wet appliances. The Customer-Led Network Revolution project carried out two trials relating to washing machines.[189]

- In one trial, consumers were placed on a time-of-use tariff (with higher prices from 4pm to 8pm on weekdays) and given smart washing machines. Consumers were able to engage an energy control mode on the machine, which would automatically schedule it to not operate during the high tariff period. However, two-thirds of participants never used the energy control function.

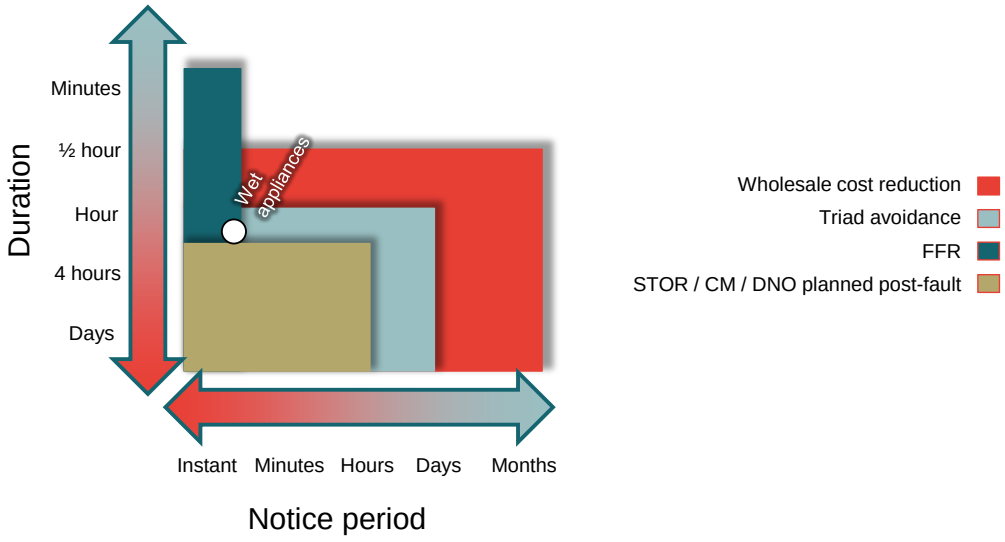
- In another trial, the DNO could remotely send a signal to washing machines, which would them prompt the user to delay the cycle until after a critical period on the network.[190] Under this trial, a statistically significant reduction in peak power consumption was observed, with some participants actively choosing to delay the start of the wash cycle during DSR events.

Figure 39 provides an illustrative view of the type of DSR capability that this trial provided.

189 Customer-Led Network Revolution (2015), *Developing the Smarter Grid: The role of domestic and small and medium enterprise customers*

190 See Customer-Led Network Revolution (2015), *Insight Report: Domestic Direct Control*

Figure 39. Illustrative DSR capabilities of domestic wet appliances



Source: Frontier Economics

Capacity

Drysdale, Wu and Jenkins (2015)[191] estimate that 2012 UK domestic wet appliance consumption was around 15TWh, and they forecast it to increase to around 23 TWh per year in 2030. Extrapolating from 2012 and 2030 implies that by 2035 this will increase to 25 TWh per year.[192] This is only one potential forecast (based on past data on consumption per appliance, appliances per household, and household projections): developments in areas such as energy efficiency could lead to quite different figures.

Some forms of DSR (notably those involving automation of response) may require "smart" appliances which can be notified when to start a wash cycle. The roll-out of smart appliances will, in part, depend on product policy. However, even if a hypothetical product policy were to mandate that all new wet appliances must be smart, slow turnover of appliances would limit the initial effect. Washing

191 Drysdale, B., Wi, J., and Jenkins, N. (2014), *Flexible demand in the GB domestic electricity sector in 2030*, Applied Energy (in press). The increase is accounted for by increased numbers of household and ownership levels (particularly for tumble driers), outweighing efficiency gains.

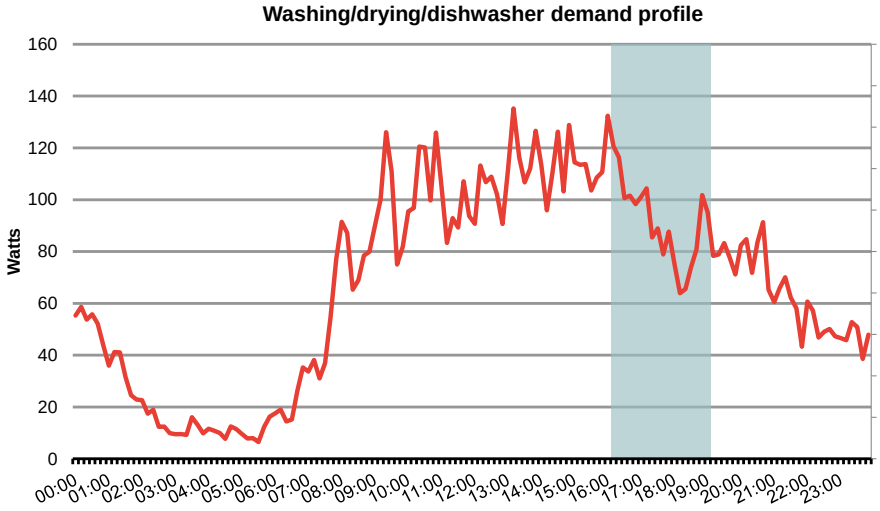
192 As a cross-check of these forecasts, applying the share of household electricity used for wet appliances today (13%) to DECC's forecasted domestic electricity consumption in 2035 of 131 TWh, implies demand of 17 TWh per year which is lower than the estimate above.

machines may typically last for around 7 years,[193] but replacing the entire UK stock of white goods could take as long as 20 years.[194]

Load profiles

Figure 40 below shows the load profile for domestic wet goods in a typical December based on the Household Electricity Survey,[195] showing an average demand of up to around 120W during the 16:00-19:00 peak period (shaded).

Figure 40. Domestic wet goods load profile



Source: Frontier analysis of Household Electricity Survey data.
Note: wet goods refer to washing, drying and dishwasher appliances; load profile for weekday in December.

Using a similar load profile from HES, Drysdale, Wu and Jenkins (2015) estimate that by 2030 there will be 3.8 GW of flexible domestic demand available from wet goods at 17.30 on a typical winter day.

7.1.6 Cold appliances

Cold appliances include refrigerators, freezers and combined fridge-freezers. Households are likely to have one or more of these appliances. As shown in the

193 Based on a 7 year average lifetime for white goods (http://www.whitegoodstradeassociation.org/index.php/for-public-mainmenu-43/how-long-should-it-last-)

194 Cambridge Architectural Research Limited, Element Energy and Loughborough University (2012), *Further Analysis of the Household Electricity Survey – Early Findings: Demand side management* p2

195 The profile available from National Grid is similar, but only at a four-hour resolution.

load profiles below, cold appliances operate consistently throughout the day consuming electricity at a fairly constant rate.

Potential flexibility

Cold appliances have thermal storage properties which allow load to be reduced for a period: electricity supply can in principle be interrupted for a short period of time while maintaining temperature at an acceptable level (indeed, these appliances typically maintain a temperature by cycling the compressor on and off). However, it is unlikely that lengthy periods of postponement would be possible, especially for fridges, where the scope for pre-cooling is limited by the need to avoid freezing and damaging the fridges' contents.[196] Consumer concerns (and issues around liability for spoilage of food) may also limit the extent to which direct control is accepted: In a recent survey of over 2,000 UK consumers, only 30% indicated they would find external control of a fridge-freezer acceptable (20% were neutral, 50% said it was unacceptable).[197]

Figure 41 shows how, given the physical characteristics of appliances, domestic refrigeration is likely to be suited to uses of DSR requiring only a short interruption from individual appliances (a rapid response would be possible providing that arrangements are in place that support dynamic DSR).

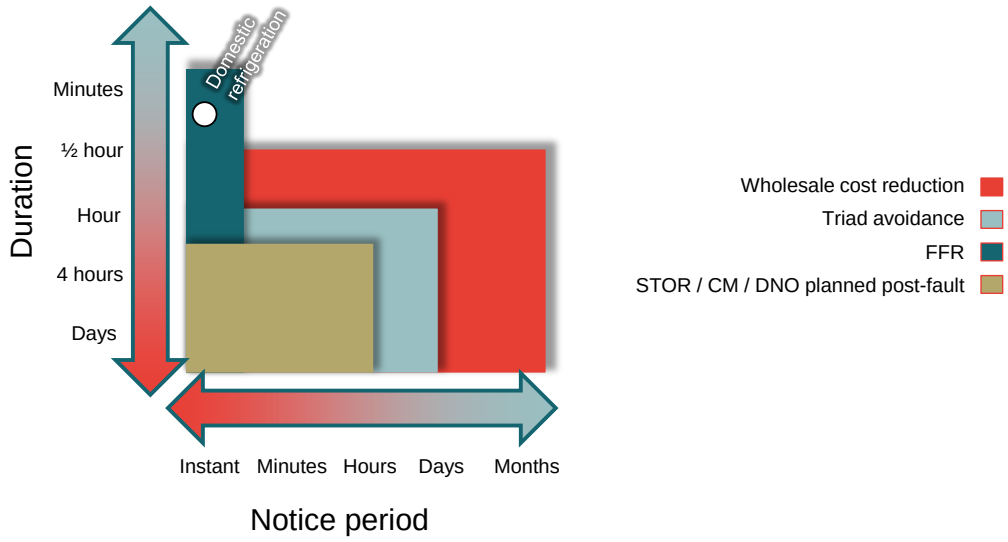
For example, in a study carried out between 2010 and 2012, Open Energi installed "smart" domestic fridges and freezers, which could provide demand response (both increasing and decreasing load) for frequency response purposes. The minimum duration of response for load reduction was 8 minutes, with load reduction durations sometimes longer than this period.[198]

196 Customer-Led Network Revolution (2015), *Insight Report: Enhanced Domestic Monitoring*

197 Spence, A., Demski, C., Butler, C., Parkhill, K. and Pidgeon, N. (2015), *Public perceptions of demand-side management and a smarter energy future* in Nature Climate Change

198 Open Energi (2012), *Cert Final Report,* p10

Figure 41. Illustrative DSR capabilities of domestic refrigeration



Source: Frontier Economics

Capacity

Electricity consumption from cold appliances will depend upon the number of cold appliances in use, their size and their energy efficiency. The more energy efficient appliances become, then the lower electricity consumption (both at the peak and elsewhere) all else equal. This suggests there is a trade-off between lower overall electricity consumption from improved energy efficiency, and the amount of flexible load available during the winter peak.

The energy efficiency of many household appliances, including cold appliances, is expected to increase over time.[199] The speed of this trend may increase depending on product policy relating to minimum efficiency standards, or initiatives to incentivise development of more efficient products. Product policy could also potentially affect the introduction of smart cold appliances, which might provide increased potential for DSR.

Drysdale, Wu and Jenkins (2015)[200] estimate that by 2030 domestic cold appliances in the UK will consume around 11 TWh per year, down from around 14GWh in 2012 (the decrease due to efficiency improvements). Linearly

199 For example, DECC, (2014), "Energy efficient products - helping us cut energy use"

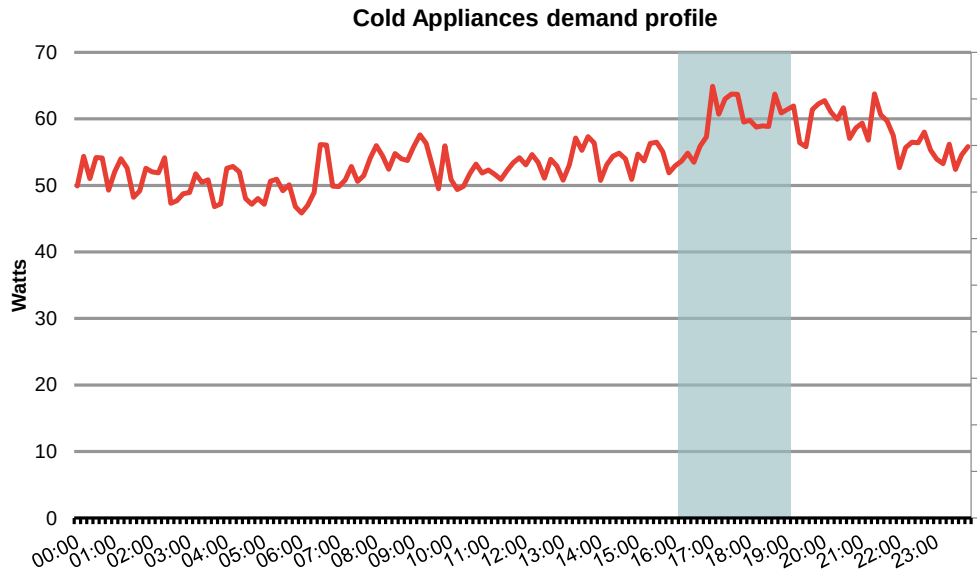
200 Drysdale, B., Wi, J., and Jenkins, N. (2014), Flexible demand in the GB domestic electricity sector in 2030, Applied Energy (in press)

extrapolating from 2012 and 2030 implies that by 2035 this might decrease to 10 TWh per year.

Load profiles

Figure 42 below shows the load profile for domestic cold goods in a typical December based on the Household Electricity Survey (HES). It shows that demand is spread fairly evenly throughout the day (the evening peak period of 16:00 to 19:00 is shaded).

Figure 42. Domestic cold goods load profile



Source: Frontier analysis of Household Electricity Survey data.
Note: load profile for weekday in December.

Using a similar load profile from HES, Drysdale, Wu and Jenkins (2015) estimate that by 2030 there will be 1.1GW of flexible domestic demand available from cold goods at 17.30 on a typical winter day.

7.1.7 Electrical energy storage

A large number of appliances may not be suitable for DSR in themselves. For example, lights and TVs do not have any inherent energy storage, and consumers are unlikely to accept postponement of these activities. However, electricity usage associated with such activities may be used for DSR if it is cost-effective for consumers to install batteries within their homes. As noted in section 7.1.4,

batteries used within electric vehicles could serve this purpose. However, similar batteries could also be installed on a stand-alone basis.[201]

At present, domestic electrical energy storage appears to offer particular promise alongside installations of solar photovoltaics and for the future development of direct current (DC) networks.

- Solar photovoltaic panels will tend to produce the greatest output during the middle of the day, at a time when domestic weekday energy usage can be relatively low. Any resulting net exports of power can potentially be problematic for the distribution network, and electricity is being exported during period when prices are relatively low. The installation of battery storage at the household level – providing costs are not prohibitive – allows surplus PV output to be stored for use by the household during the evening.

- An increasing proportion of household electrical appliances run off DC power – for example, consumer electronics such as computers, as well as LED lighting. Currently, such equipment requires the use of individual AC/DC convertors, which can be inefficient.[202] Once a battery is installed, an in-house DC power network could potentially be installed to power such devices (albeit at some initial upfront cost).

An example of a project combining storage with solar PV and DC networks is Western Power Distribution's SoLa Bristol project.

Although domestic electrical energy storage is not yet a mature technology, it is a highly active area. Below, we summarise information on two systems under development.

- Moixa technology has developed the Maslow, a 1kWh or 2kWh wall-mounted lithium ion battery with an output of 430W. The Maslow has DC outputs, but can also include a micro-inverter to power AC devices. It integrates software and communications that could be used by entities such as DNOs to call DSR. This device is currently being used in several demonstration projects.

- In May 2015, Tesla Motors announced the Powerwall, a wall-mounted rechargeable lithium ion battery currently available for reservation in the US.[203] The battery was announced as coming in two models – a 10kWh model for back-up applications, and a 7kWh model for daily cycle

201 Indeed, home electricity storage could be a use for recycled EV batteries which no longer hold sufficient charge for a vehicle.

202 LCNF submission form for project BRISOL

203 http://www.teslamotors.com/powerwall accessed 18/05/2015

applications, both capable of outputting 2kW of power (3.3kW peak). The two models are priced at $3,500 and $3,000 respectively, although this does not include installation or a DC-AC invertor. It was subsequently announced that the power rating of the 7kWh model would be increased to 5kW (7kW peak), and that total installation was expected to cost $4,000.[204]

In addition to such stand-alone batteries, many consumer electronics devices have inbuilt batteries. For example, some TV viewing has migrated to devices such as tablets and laptops.[205] In principle these could also be used for DSR (for example, one of the businesses we spoke to for this project had connected employees' laptops to smart plugs, which turned off during times of high power prices to use the inbuilt batteries instead).

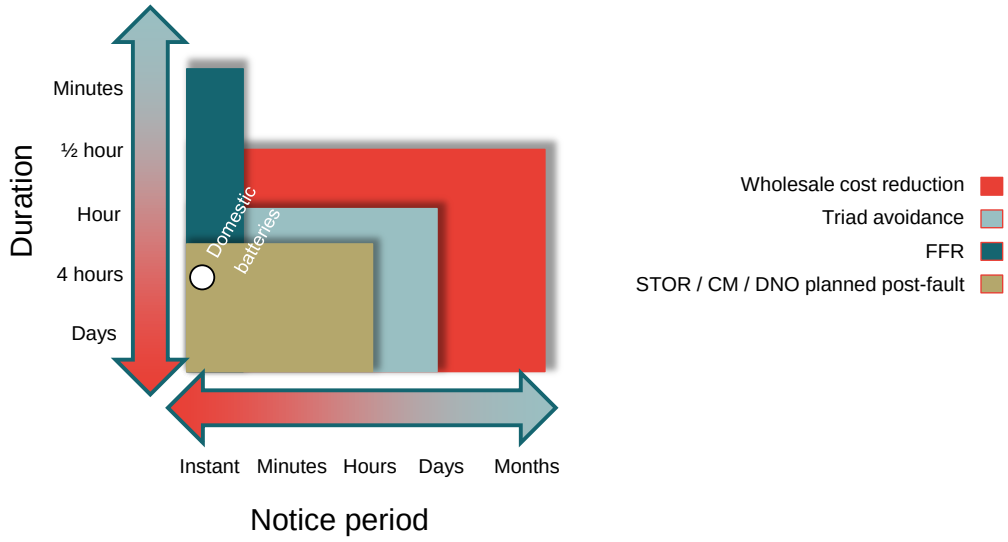
Potential flexibility

Both of the battery systems described above would be capable of discharging at maximum capacity for around five hours (assuming the battery was full). Combined with what are likely to be short notice periods, domestic electrical energy storage is likely to be suitable for a wide range of DSR uses, as shown in **Figure 43**.

[204] Elon Musk announcement in June 2015, reported in http://www.businessspectator.com.au/news/2015/6/15/policy-politics/tesla-lifts-powerwall-capacity-2kw-5kw among other sources.

[205] Customer-led Network Revolution (2015), *Insight Report: Enhanced Domestic Monitoring* p43 notes that some TV viewing has migrated to devices such as tablets with inbuilt batteries.

Figure 43. Illustrative DSR capabilities of domestic batteries



Source: Frontier Economics

Capacity

A large part of the reason for consumers to purchase electrical energy storage devices is the potential revenues from DSR (an example of a non-DSR benefit is the ability to operate electrical appliances during a power-cut). As a result, to a far greater extent than the other domestic appliances considered in this report, the uptake of these devices will be highly dependent on the demand for DSR. It is therefore appropriate to model uptake endogenously within the DDM.

As described above, these devices may be particularly cost-effective for homes with solar photovoltaic (PV) panels. A forecast for PV uptake could therefore help provide an indication of those properties where EES may have the greatest benefits.

7.2 Arrangements for calling DSR

Section 7.1 presented our estimates of the overall quantity of flexible load likely to be available from domestic properties. In this section we consider how much of this load is likely to be accessible to the energy sector as DSR.

The extent to which consumers are willing and able to carry out DSR actions will depend upon the contractual and technical mechanisms used to call this DSR. Any scenarios for future DSR uptake will need to make assumptions regarding how these mechanisms are taken up, and what types of DSR they can facilitate.

In this section we discuss:

- the potential DSR contract types; and
- some of the enablers required for these arrangements (both technology and consumer willingness to engage).

7.2.1 Potential DSR contract types

Table 11 summarises the main types of domestic DSR contract and describes:

- the notice period with which they enable DSR to be called;
- whether the consumer has a passive or active role; and
- whether price signals or direct control contracts are employed.

This is in line with the framework set out in more detail in section 3.2.

Table 11. Methods of calling domestic demand-led DSR

DSR arrangement	Description	Notice period	Active or passive consumer?	Incentive type
Static time-of-use tariff without automation	Consumers face an electricity price schedule which charges different unit rates according to the time of day/week/year. This schedule is set in advance.	Months ahead	Active	Price mechanism
Static time-of-use tariff with automation		Months ahead	Passive	Price mechanism
Dynamic time-of-use tariff without automation	Like static time-of-use tariffs, but the tariff can change in real-time.	Up to real-time	Active	Price mechanism
Dynamic time-of-use tariff with automation		Up to real-time	Passive	Price mechanism
Critical peak pricing/rebates without automation	Under critical peak pricing, consumers face a pre-determined high price during times of exceptionally high demand. Under critical peak rebates, consumers receive a rebate for reducing their energy use below a baseline during a critical peak event.	Up to real-time	Active	Price mechanism
Critical peak pricing/rebates with automation		Up to real-time	Passive	Price mechanism
Direct load control	Another entity (which may or may not be the supplier) sends a signal (which the consumer may have the option to override) to automatically carry out DSR.	Real-time	Passive	Direct request

Source: Frontier Economics, based on Frontier Economics and Sustainability First for DECC (2012), *Demand Side Response in the domestic sector- a literature review of major trials*

There are at least four important enablers for domestic DSR.

- First, dynamic DSR will require some form of **communications system** to inform customers of prices or direct load control instructions;
- second, DSR which is "passive" from the point of view of consumers requires **automation technology**;
- third, many forms of DSR will require **a metering system** in place to verify that load turndown took place; and
- finally, consumers will need to be **willing to accept changes to time of their electricity consumption.**

We consider each of these enablers in turn below.

7.2.2 Communications system

Any form of dynamic DSR, where events are called at short notice, requires that suppliers (or other actors) can communicate in real-time to consumers. These communications could consist of either pricing information (in the case of dynamic time-of-use tariffs and critical peak pricing) or DSR calls (for direct load control).

We have considered the potential for three types of communication system: dynamically teleswitched meters, the communications system developed for smart meters, and solutions using the internet for communication.

Long-wave radio (dynamically teleswitched meters)

Historically, some UK customers have used dynamically teleswitched meters, which use long-wave radio to control appliances such as electric storage heaters and immersion heaters. Such an approach could in theory be used to call DSR events through direct load control (it would not enable the communication of tariff information).

However, we understand teleswitching is a legacy technology and that the great majority of meters are now set up to follow a static or semi-static schedule.[206] Teleswitching is therefore unlikely to unlock future DSR capacity.

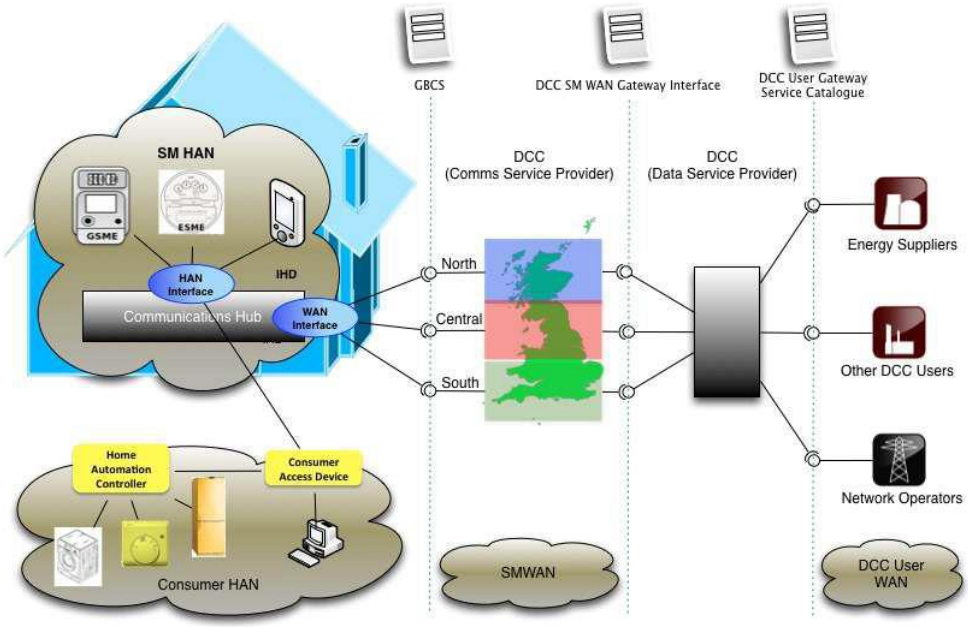
Smart meters and associated infrastructure

The infrastructure developed for smart meters will be capable of facilitating dynamic DSR, both via direct load control and with dynamically updated tariffs. **Figure 44** illustrates how the Data Communications Company (DCC) provides a

206 Ofgem (2013) *The state of the market for customers with dynamically teleswitched meters*

network allowing entities such as suppliers to send signals to consumers' smart meters.

Figure 44. Smart meter communications infrastructure



Source: DECC (2014), *Third annual report on the roll-out of Smart Meters*

For direct load control, the auxiliary load control switches on a smart meter (discussed in the following section on automation) can be activated by the supplier.[207] We understand that the delay between the supplier sending a signal and the Smart Meter responding is likely to be in the order of tens of seconds or a few minutes.

At present, the security model envisaged for Smart Meters mandates that the supplier would be the only entity able to send these instructions (other parties could theoretically contract with the supplier, which would then act as an aggregator). If this security model were to be changed, the DCC infrastructure is technically able to give DNOs (or other actors) control over the auxiliary load control switches.[208]

As an alternative to direct load control, a supplier would be able to send a signal to their customers to indicate a change of price. SMETS2 smart meters support up to 48 prices per day. By sending signals, a supplier can change which price

207 DECC (2014) *How GB Smart Metering Will Support Demand Side Response*

208 Worksteam 6 of the Smart Grid forum has a Smart Meter Sub-Group, which has been considering the potential barriers to DNO use of the auxiliary load control switches.

register is active for a particular time period. This would enable various types of tariff, including dynamic (and static) time-of-use tariffs, in addition to critical peak pricing.

At present, the DCC is building its systems, and envisages that it will need until April 2016 to be ready to offer live services, with a potential six months' contingency time after this.[209] At this point, all consumers with a smart meter could in principle receive communications from suppliers using this channel.[210] The main installation phase of smart meters will also begin in 2016, with all domestic consumers having a smart meter by the end of 2020.

Internet-based communications

The internet offers an alternative way of communicating prices and load control events to consumers. Prior to the full rollout of the DCC and smart meters, this will be the only way of establishing communications, used by demonstration projects such as Northern Powergrid's Customer-Led Network Revolution.[211]

Theoretically, a time-of-use tariff could be communicated by simply uploading information to a website that the customer can read. However, installations involving some form of automation (discussed in the following section) typically require the installation of a gateway. This is a device which connects to a consumer's broadband, and acts as an interface for smart home devices that connect to it via a wireless protocol such as ZigBee or Thread.

In the future, it may be more likely for a gateway to be integrated within another product. Possibilities include:[212]

- Within a home router (we understand that T-Mobile is currently exploring this);
- within a smart TV; or
- within an energy appliance (for example, the Nest learning thermostat can act as a gateway for other Thread-enabled appliances).

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209 Letter from Teresa Camey, DECC to Jonathan Simcock, Smart DCC Ltd, on 5th March 2015

210 Consideration should be given as to whether there are any single points of failure (for example within the DCC if being used to directly control load) that could disable DSR across a large number of households simultaneously – this will be relevant when calculating the maximum simultaneous loss of power to the grid.

211 Customer-led Network Revolution (2015) *Insight Report: Domestic Direct Control*

212 Based on a webinar on the Connected Home given by Delta-EE on 12/05/2015

7.2.3 Automation system

Any DSR arrangement which is seen as "passive" from the point of view of the customer will require some form of automation. Here, we consider three means[213] by which this automation can be carried out: the auxiliary load control switches within smart meters, timer switches, or through a home energy management system.

Smart meter auxiliary load control switches

Smart Meters following the SMETS2 specification will allow the connection of up to five auxiliary load control switches (ALCS). Although not physically present on the basic smart meter models, "variant" meters will include them, adding a small additional cost to the meter. Basic meters could be upgraded by adding an auxiliary load control switch connected via the Home Area Network.

The auxiliary load control switches are simple on/off connections (like the existing switches used for dynamically teleswitched meters). These would be directly suitable for controlling a device such as a storage heater, and could potentially be used for controlling heat pumps or electric vehicles.[214] However, the simple on/off nature of the ALCS may make it less suitable for some appliances. For example, obtaining the greatest capacity of DSR from a domestic battery would involve sending an instruction to the battery to discharge, rather than simply turning it off. It is nonetheless possible that devices might exist which sit between the ALCS and a device such as a battery, to interpret the simple on/off signal. The extent to which such issues may or may not limit the applicability of the ALCS may be a suitable topic for further research.

Timers

Timers can provide a simple means of automation to reduce energy costs in the presence of a static time-of-use tariff. For example:

- Existing customers on E7 and E10 tariffs with storage heating make use of timers to ensure these appliances use cheap night-time electricity;
- devices such as heat pumps or electric vehicles may come with built-in timers; or
- plugs with built-in timers can be used to turn appliances on and off at pre-set times.

213 Dynamic teleswitching also offers a means of automation, and is discussed above.

214 Presentation by Peter Morgan and Tim Bailey of DECC to Smart Grid Forum WS6 on 25/03/15

Home energy management systems

More advanced devices would be needed to provide automation in the presence of dynamic time-of-use tariffs. A Home Energy Management System (HEMS) could dispatch appliances (such as heat pumps) in such a way as so minimise consumer costs, given the tariff in operation.

To be amenable to control by a HEMS, appliances will either need to have "smart" controls built in to them,[215] or be amenable[216] to connection to a smart plug (Western Power Distribution's Echo LCNF project will soon be trialling the use of smart plugs to mediate domestic DSR).

7.2.4 Metering system

An adequate metering system to verify load reduction took place is an important pre-requisite for most forms of domestic DSR.

Customers facing time-of-use tariffs will need a metering system that can apportion load throughout the day to the correct price. Smart meters, discussed above in section 7.2.2, are capable of this. However, suppliers themselves may not be able to benefit from any savings from load-shifting if they continue to settle against the standard, fixed, load profiles. Full half-hourly settlement would be one way for suppliers to obtain these benefits: At present, suppliers can opt particular customers into this, although we understand that there are costs associated with this. Alternatively, it is possible in the near-term that the meter registers in SMETS 1 & 2 meters allow some forms of DSR to be recorded, which could then be settled via an adjustment to the Standard Settlement Configuration in Load Profile 1.[217]

It may also be necessary to carry out some form of monitoring for customers on direct control contracts, to determine the extent to which "override" functions are used.

7.2.5 Consumer acceptance of contracts

When calculating what proportion of DSR potential is available, it is necessary to estimate:

- the proportion of consumers that might take up a DSR contract (such as a direct control scheme or a time-of-use tariff); and

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215 For example, this was the case for the heat pumps and washing machines used for the CLNR trials.

216 As with smart meter ALCS, it is possible that some appliances may not be suitable for use with a basic smart plug that only offers on/off functionality.

217 This is discussed on p35 of Sustainability First (2014), Paper 12. *The Household Electricity Demand-Side & Participation in the GB Electricity Markets.*

- the effect that the contract has on the demand of those customers that take it up.

These figures are likely to vary depending on the form of tariff (for example, direct control compared to time-of-use tariffs), the exact nature of the contract (such as the extent to which it is financially beneficial), as well as the specific appliances that are in use. As an example of the latter, uptake of Economy 7 and Economy 10 tariffs currently tends to be limited to consumers with electric resistive heating. Similarly, Smart Energy GB found that electric vehicle owners were more willing (15% more likely) to switch to static time of use tariff compared to the general population.[218]

Table 12 summarises some of the evidence that currently exists on the take-up of DSR contracts and their effect on participants. This is not intended to be a complete literature review,[219] but highlights some of the recent research relating to the UK (and one Irish trial). This has been drawn from trials, customer surveys, and modelled scenarios. Trials (demonstrating actual consumer behaviour) may have more evidential weight and are listed first, although their applicability will depend on how representative they are of any future DSR rollout.

Some tentative conclusions that can be drawn from this data are as follows.

- It is difficult to estimate the **uptake of time-of-use tariffs** contracts, either now or in the future (trial uptake figures may be affected by incentives). Survey data indicates that 25% or more of people would be interested in taking up these tariffs. We note this is broadly consistent with the assumption made in DECC's Smart Meter Impact assessment that 20% of consumers would take up a static time-of-use tariff, in addition to those currently on Economy-7 and Economy-10 tariffs.[220]

- It is similarly difficult to estimate the **uptake of direct control contracts,** although survey evidence suggests that willingness to take up direct control varies strongly by technology, with automation of wet goods perhaps more acceptable than of cold goods.

- **Recent trials on the effect of time-of-use tariffs** have tended to show a modest overall demand shift (up to 10%) for participants. There is less evidence available on the specific types of load that are being shifted or reduced, although the CLNR trial does indicate (among the small proportion

218 Smart Energy GB (2015), *Is It Time? Consumers and Time of Use Tariffs* p27

219 Frontier Economics and Sustainability First (2012), *Demand Side Response in the Domestic Sector – a Literature Review of Major Trials* provides a summary of many more international trials

220 DECC (2014), *Smart meter roll-out for the domestic and small and medium non-domestic sectors (GB)* p59

of participants engaging with this particular trial) that wet good demand can be moved, consistent with survey results.

- It is even less certain how the **effect of time-of-use tariffs might change in the future**. Developments such as smart meters, appliances and greater consumer awareness might lead to higher levels of demand-shifting, as assumed in Redpoint and Element's 2012 modelling described in **Table 12**.

- The CLNR trials have demonstrated an **effect of direct control**, which may already be able to significantly reduce demand for specific appliances (smart washing machines and air-source heat pumps).

Summary of the evidence base

The table below summarises the main types of sources that have been used in this section, and indicates where some of the greatest uncertainties lie.

Area	Main sources of evidence and robustness
Current levels of consumer acceptance of DSR contracts	Likely to be highly dependent on the types of appliance that consumers have (for example, E7 and E10 tariffs generally appeal to those with electric heating). Difficult to apply trial take-up to the whole population since many trials have incentives for participation.
Future levels of consumer acceptance of DSR contracts	It is extremely difficult to forecast how consumer acceptance of contracts may change over the next 20 years, due to factors such as: A changing mix of home appliances; potential new non-traditional business models; and increasing familiarity of consumers with DSR. We have presented assumptions made in previous research which appear reasonable. However, this is certainly an area where significant sensitivity checks should be used for modelling.
Current effect of DSR contracts on consumer demand	Time-of-use tariff trials are consistent with a small overall effect on consumption. It is less clear which forms of load are being shifted. The small number of small-scale trials of direct load control indicate that it can be effective at reducing demand for specific types of appliance (heat pumps and smart washing machines), although it is unclear how widely applicable these figures are.
Future effect of DSR contracts on consumer demand	It is extremely difficult to forecast how the effect of time-of-use tariffs might change over time. We have presented assumptions made in previous research which appear reasonable. *If* direct control is already effective, it seems reasonable to assume this would be the case in the future. But again, there is no specific evidence that is applicable.

Table 12. Summary of evidence on engagement and availability of domestic DSR

Tariff type	Evidence type	Source	Take-up	% of participants that changed behaviour	% of demand shifted, for participants	Appliance
Static time of use	Trial	**Energy Demand Research Project (EDF and SSE time-of-use trials)**[221]			Up to 10%	Total household load
Static time of use	Trial	**CLNR (2015) Domestic Time of Use tariff**[222]			1.5% - 11.3%[223]	Total household load
Static time of use	Trial	**Irish Smart Meter Trial**[224]	30%[225]		8.8%	Total household load
Static time of use tariff	Trial	**CLNR Smart Washing Machine Restricted Hours trial** [226]		10%[227]	100%[228]	Wet goods

221 AECOM for Ofgem (2011), *Energy Demand Research Project: Final Analysis* p8

222 CLNR (2015), "Insight Report: Domestic Time of Use Tariff - A comparison of the time of use tariff trial to the baseline domestic profiles"

223 However, there was no statistically significant reduction in consumption during the single peak half-hour of demand over the whole year.

224 CER (2011), "Electricity Smart Metering Customer Behaviour Trials (CBT) Findings Report"

225 This is the overall participation rate. It should be noted that consumers did receive a financial incentive for participating in the trial.

226 Customer-Led Network Revolution, (2015), "Developing the smarter grid: The role of domestic and small and medium enterprise customers"

227 One-third of participants engaged the energy control function at least once. However, on average, only 10% of trial participants did so for any given peak period. The trial also observed a spike in washing machine usage after the peak period for consumers not engaging the function, suggesting some may have manually deferred consumption.

228 By definition, any customer that "engaged" in this trial shifted 100% of demand.

Domestic demand-led DSR

Table 12. Summary of evidence on engagement and availability of domestic DSR

Tariff type	Evidence type	Source	Take-up	% of participants that changed behaviour	% of demand shifted, for participants	Appliance
Dynamic time of use	Trial	**Low Carbon London**[229]	24%		9%	Total household load
Static time of use	Consumer survey	**Smart Energy GB survey**	30% (28% if automated)[230]			Total household load
Dynamic time of use	Consumer survey	**Smart Energy GB survey**	25% (29% if automated)			Total household load
Static time of use	Consumer survey	**Consumer Focus**[231]		50%[232]		Cold and wet appliances
Static Time of use	Consumer survey	**EPRG (2010)**[233]	>50%[234]			Wet appliances

229 Low Carbon London, (2014), "Residential Demand Side Response for outage management and as an alternative to network reinforcement, Report A1" p24

230 Smart Energy GB (2015), *Is It Time? Consumers and Time of Use Tariffs* p20

231 Consumer Focus (2012) *From devotees to the disengaged – Economy 7*

232 This refers to the proportion of customers already on Economy 7 and Economy 10 tariffs that deliberately run appliances, other than water and space heating systems, at off peak times to save money.

233 Platchov, Pollitt, Reiner, and Shaorzhadze (2010), *2010 EPRG Public Opinion Survey: Policy Preferences and Energy Saving Measures,* EPRG Working Paper 112 Cambridge Working Paper in Economics 1149

Table 12. Summary of evidence on engagement and availability of domestic DSR

Tariff type	Evidence type	Source	Take-up	% of participants that changed behaviour	% of demand shifted, for participants	Appliance
Static time of use	Modelled scenarios	**Redpoint Energy and Element Energy (2012)** [235]	Up to 100%[236]		10% (now) to 40% (2030)	Smart appliances, heat pumps and EV
Static time of use	Modelled scenarios	**Redpoint Energy and Element Energy (2012)**	8% (2015), to 31-64% (2030)[237]		5% (now) to 20% (2030)	Other appliances
Direct control	Trial	**CLNR Smart Washing Machine Direct Control Trial**[238]		30%[239]		Wet goods

234 Willingness to shift usage to after 9pm if electricity were cheaper after that time. However, only a 25% and 18% of respondents used washing machines and dishwashers respectively during these times. See also Sustainability First, (2012), "Paper 3: What demand side services could household customers offer?" p39

235 Redpoint Energy and Element Energy, (2012), "Electricity System Analysis – future system benefits from selected DSR scenarios"

236 P15 states that it is assumed that all hosueholds with a smart meter and a smart technology (smart appliance, HP or EV) take up either a STOU tariff or direct control

237 Some of these may be on more advanced forms of DSR, including direct load control

238 Customer-Led Network Revolution, (2015), "Insight Report: Domestic Direct Control"

239 Of the times when a user interacted with a washing machine that had received an event, they delayed the cycle on 30% of occasions. Events were also associated with an average reduction in power usage during the peak half-hour of 26W, compared to days when load control events were not sent – a very significant proportion of average washing machine load.

Domestic demand-led DSR

Table 12. Summary of evidence on engagement and availability of domestic DSR

Tariff type	Evidence type	Source	Take-up	% of participants that changed behaviour	% of demand shifted, for participants	Appliance
Direct Control	Trial	**CLNR Air Source Heat Pump Direct Control Trial**		67%	100%[240]	Heat pumps
Dynamic time of use	Consumer survey	**Smart Energy GB survey**	37%			Heating
Direct control	Consumer survey	**Spence et al (2015)** [241]	50%			Wet goods
Direct control	Consumer survey	**Spence et al (2015)**	30%			Cold goods
Direct control	Consumer survey	**Spence et al (2015)**	30%			Water heating
Direct control	Consumer survey	**Mert et al (2008)**[242]	77%[243]	-	-	Wet goods

240 Customer-Led Network Revolution, (2015), *Developing the smarter grid: The role of domestic and small and medium enterprise customers* p49 – consumers cancelled the events 33% of the time (this may have been accidental, since adjusting the thermostat would cancel the event), and electricity consumption among those that did not cancel it fell close to zero during events.

241 Spence, Demski, Butler, Parkhill and Pidgeon (2015), *Public Perceptions of Demand-Side Management and a Smarter Energy Future*, Nature Climate Change

Table 12. Summary of evidence on engagement and availability of domestic DSR

Tariff type	Evidence type	Source	Take-up	% of participants that changed behaviour	% of demand shifted, for participants	Appliance
Direct control	Consumer survey	**EPRG (2010)**	60%[244]	-	-	Wet goods
Direct control	Consumer survey	**EPRG (2010)**	60%[245]	-	-	Cold goods
Direct control	Modelled scenarios	**Redpoint Energy and Element Energy (2012)**	At least 4-12% by 2030[246]	100%	-	Smart appliances, heat pumps and EV

Source: Various

242 Mert et al, 2008, Consumer acceptance of smart appliances , referred to in Frontier Economics and Sustainability First for DECC (2012), *Demand Side Response in the domestic sector – a literature review of major trials* p28. This survey covered Austria, Germany, Italy, Slovenia and the UK.

243 Proportion of customers that would accept a shift of three hours

244 Proportion that would allow pre-set off-peak running of wet appliances in return for a 5% decrease in bills.

245 Proportion that would allow interruption of cold appliances in return for a 5% decrease in bills.

246 This is the figure across all households. However, it is assumed that all households with one of these smart technologies take up at least one form of DSR. Additionally, the modelling assumes some households (9%-19%) take up critical peak pricing.

Domestic demand-led DSR

7.3 Costs

We have considered three types of costs that may be associated with domestic demand-led DSR:

- **Capital costs** – i.e. costs incurred in order to bring a unit of DSR capacity on to the system. The two types of capital cost considered below are relevant to an aggregator seeking to enable a site for dynamic DSR.
- **Fixed O&M costs** – costs incurred each year for a given amount of capacity.
- **Running costs** – costs incurred for each kWh of demand that is reduced or shifted.

The costs involved will vary significantly depending on the asset being used to provide DSR, and the specific arrangement being used to call it. We have therefore provided a general description of the forms of cost that may be incurred rather than specific quantitative estimates.

7.3.1 Capital costs

Other than electrical energy storage (some indicative costs of which are included above) the appliances we have considered in section 7.1 are likely to be purchased independently of the existence of any DSR scheme.[247] The relevant capital cost to use in modelling is therefore the *incremental* cost of enabling an appliance for DSR.

As discussed in section 3.2, there are a wide vary of ways in which domestic demand-led DSR could be called, and these will be associated with different capital costs – some examples of the types of cost are listed below.

- Many forms of DSR will use the smart metering infrastructure for dispatching or metering events, and would require a consumer to have a smart meter. However, it is planned for all domestic consumers to have a smart meter installed by the end of 2020, so these are not incremental costs for the provision of DSR.
- If the smart meter is to be used to directly control appliances such as storage heaters, an additional cost may be incurred in installing a "variant" meter with built-in auxiliary load control switches, or an auxiliary load control

247 This is not entirely a clear-cut distinction, and the decision to take up some more discretionary appliances (particularly heat pumps and electric vehicles) will depend at least in part on the savings available from any time-of-use tariffs.

switch connected via the Home Area Network. However, existing Economy 7 customers will receive a variant meter at no additional cost to them.

- Forms of DSR facilitated through gateway (and potentially a home energy management system) will require investment at the household level to purchase and install this hardware. The SmartThings Hub is a Zigbee gateway currently available in the US for $99 (excluding installation).[248] The Nest and Hive home energy management systems can be purchased and installed by UK consumers for £249[249] and £199[250] respectively.[251] However, some consumers may install these types of device independently of DSR (for example, installing a HEMS to optimise heating or, in the future, purchasing a device such as a router or smart TV with built-in gateway functionality). In such cases, the cost of the hardware will not be incremental to DSR.

- There may be incremental costs associated with purchasing "smart" appliances over regular ones, or smart plugs to enable the remote dispatch of appliances.

For I&C demand-led DSR, a key cost cited by aggregators was the marketing and sales incurred to expand their portfolio. This might also be a relevant cost for domestic installations.

7.3.2 Fixed O&M costs

Some of the technologies described above will also be associated with ongoing costs. For example, firms that wish to access DCC services will either need to become a DCC user or enter into a commercial contract with one. The cost to access data via the DCC has yet to be confirmed, although the DCC currently estimates the variable cost of service requests will be very low.[252]

As with I&C demand-led DSR, it is also possible that consumers may require a regular payment (or reduction in bills) to accept forms of DSR which impose inconvenience upon them. For example, the Customer-Led Network Revolution

248 https://shop.smartthings.com/#!/products/smartthings-hub, accessed on 27/05/2015

249 https://store.nest.com/uk/product/thermostat/, accessed on 25/06/2015

250 https://www.hivehome.com/?gclid=CKrCv-3RqsYCFeLItAodLb8L8A&gclsrc=aw.ds, accessed on 25/05/2015

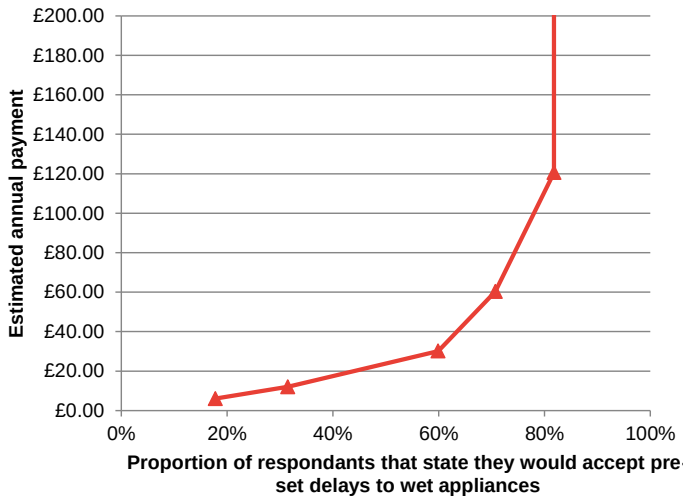
251 These types of device are not currently used for DSR in the UK, although Nest's "Rush Hour Rewards" system has been used for air conditioning DSR in the US.

252 DECC (2015), *Forward Look: Smart Metering-enabled Innovation in energy management in the non-domestic sector* p17

project offered domestic participants an incentive of £50 to join trials including those for domestic DSR.[253]

Consumers will vary in the compensation required for DSR events - i.e. there will be an upward-sloping supply curve for domestic DSR. **Figure 45** demonstrates an illustrative supply curve for direct control, drawing on a 2010 survey conducted for the EPRG (the survey presented bill savings in percentage terms, and we have multiplied by an average bill to give a rough sense of scale).[254] On the basis of this single survey, one might expect a material level of engagement for a yearly payment of just £10. However, the typical peak-time diversified consumption wet goods is only around 100W (see **Figure 40**). Even a low payment of £10 would therefore translate to a yearly availability payment of £100/kW, far in excess of the amounts currently paid by aggregators to I&C DSR providers (see section 5.3).

Figure 45. Illustrative supply curve for domestic DSR based on survey evidence



Source: Frontier analysis of Platchov, Pollitt, Reiner, and Shaorzhadze (2010), *2010 EPRG Public Opinion Survey: Policy Preferences and Energy Saving Measures,* EPRG Working Paper 112 Cambridge Working Paper in Economics 1149. Percentage bill saving figures have been multiplied by the latest (April 2015) Ofgem SMI figure for an average bill (£603) to place the figures in context.

253 Customer-Led Network Revolution (2015), *The role of domestic and small and medium enterprise customers*, p22

254 As with all survey evidence, there is a risk that respondents' stated behaviour may not match what they would do in practice.

7.3.3 Running costs

As with I&C demand-led DSR, a key variable cost for most of these appliances is the extent to which a "payback" of higher electricity consumption occurs after the DSR event. The cost of this will depend on the price of electricity, as well as the extent of any storage losses that may need to be covered. **Table 13** summarises the main drivers of running costs across the different types of domestic DSR we have considered.

Where the operation of DSR is not transparent to customers (for example, for wet appliance postponement), it is possible that customers may also incur inconvenience which they need to be compensated for (this could be through an availability payment, as discussed above).

Table 13. Drivers of running costs for domestic DSR

Form of DSR	Drivers of running costs
Heat pumps (air source, with thermal storage)	In principle, "payback" energy consumption would be required to replenish the storage, which could be higher than the original load reduction due to storage losses. However, there is evidence that this effect may not be significant.[255] Within the CLNR direct load control trial, a 1kW reduction in demand for an hour of load reduction appeared to be associated with a 0.5kW increase in demand for the following hour.[256]
Heat pumps (all types, gas hybrid)	There is no "payback" of electricity usage. Instead, there is a cost of gas burned in a boiler during the period for which load is reduced.[257]
Electric vehicles	If charging is simply postponed to later in the night, there may be no additional costs.[258] Additional charge/discharge cycles may involve storage losses, and could also decrease the life of the battery.
Wet appliances	There are no storage losses when postponing a washing cycle. The cost will therefore depend on the price of electricity during the time that the cycle has been postponed to.
Cold appliances	In principle, fridges will need to increase power consumption after a DSR event to maintain temperatures.
Electrical energy storage	Charge/discharge cycles may involve storage losses, and could also decrease the life of the battery. The round-trip efficiency of the Tesla Powerwall has been estimated at 87%.[259]

Source: Frontier Economics

255 Clearly, a 50% increase in *power* after the DSR event may be extremely significant to DNOs. However, this suggests that there may be no overall increase in *energy* use over the day as a result of load-shifting.

256 Customer-Led Network Revolution (2015), *Insight Report: Domestic Direct Control* p38

257 As an illustrative example, consider a hybrid system consisting of an ASHP with a coefficient of performance of 3.5, and a gas boiler with an efficiency of 85%. For every 1kWh of electricity not consumed by the heat pump, the gas boiler will require (3.5/85%) = just over 4kWh of gas

258 Indeed, postponing of charging could reduce losses through self discharge, although this seems highly unlikely to be material, given Li-Ion batteries have a self-discharge rate of around 2% to 3% per *month* (http://www.mpoweruk.com/performance.htm, accessed 09/06/2015)

259 http://www.engineering.com/ElectronicsDesign/ElectronicsDesignArticles/ArticleID/10057/Teslas-Powerwall-by-the-Numbers.aspx accessed 24/06/2015

7.3.4 Greenhouse gas and local emissions

The effect of domestic DSR on emissions depends on the technical characteristics of the underlying DSR resources.

Many forms of DSR consist of a shift in demand. As with I&C load-shifting, the consequence for emissions will depend on:

- the "payback" of energy consumption required after the DSR event (this will be zero for technologies that involve curtailment of load rather than shifting); and
- the relative carbon intensity of grid electricity during the period of demand reduction, compared to an increase in demand.

In many instances (for example, DSR to reduce wholesale electricity costs), the carbon intensity will likely be lower during the period where demand is shifted to. Providing the "payback" energy is not significantly greater than the original reduction in energy, these forms of DSR will be associated with a decrease in carbon emissions. The updated version of the DDM can calculate the carbon emissions increase or decrease associated with DSR.

If changes in emissions are internalised, then they will affect the costs of these forms of DSR, potentially altering the volume that is utilised. Carbon is priced via the EU ETS, and the vast majority of electricity is generated by larger generators which face these costs. Carbon costs and benefits for demand-led DSR are therefore priced in to the cost of electricity.

Hybrid heat pump systems will produce both carbon and other local emissions when the gas boiler substitutes for the heat pump.[260] As explained in footnote 257, avoiding the use of 1kWh of electricity might require around 4kWh of gas to be consumed. This would result in carbon emissions of around 0.8kgCO_2e[261] (this is broadly similar to using an OCGT to generate 1kWh of electricity)[262] and local air quality costs valued at roughly 0.44p.[263]

260 Compared to a counterfactual where only the heat pump is used.

261 Based on an emissions factor of 0.2kgCO_2e/kWh (from DECC's October 2014 appraisal guidelines).

262 National Grid (2015), *Short Term Operating Reserve Carbon Intensity Report*

263 Based on air quality damage figures in DECC's October 2014 appraisal guidelines.

8 DNO smart grid technologies

This section looks at the potential for flexibility from two DNO smart grid[264] technologies: electrical energy storage systems and voltage control technologies.

In recent years, considerable developments have been made in a variety of innovative technologies which could be deployed by DNOs to manage demand and generation on their networks. A full survey of the scope of smart grid technologies is outside the scope of this report. Instead, we focus here on two important examples:

- **Grid-level electrical energy storage systems** that are connected to the distribution networks fall under the definition of DSR used in this report. We focus here on storage units connected to DNO substations (storage units connected within domestic consumer premises are discussed in section 7). Transmission-connected storage (such as the large existing pumped storage plants)[265] is outside the scope of this report.

- **Enhanced automatic voltage control** technologies provide a way for DNOs to reduce the power demand on their networks by adjusting the voltage. We briefly consider the evidence around these techniques, drawing on Electricity North West's CLASS project.

We consider these in turn below.

264 A smart grid is defined by the Electricity Networks Strategy Group as follows: "*A Smart Grid as part of an electricity power system can intelligently integrate the actions of all users connected to it - generators, consumers and those that do both - in order to efficiently deliver sustainable, economic and secure electricity supplies.*" ENSG (2009), *A Smart Grid Vision*

265 We note that smaller pumped storage plant, such as the 50MW "quarry battery" proposed for Glyn Rhonwy in North Wales, could be connected to the distribution networks.

8.1 Grid-level electrical energy storage

Summary of the evidence base

The table below summarises the main types of sources that have been used in this section, and indicates where some of the greatest uncertainties lie.

Area	Main sources of evidence and robustness
Potential capacity of grid-level EES	There are a very wide variety of scenarios for future EES rollout, demonstrating uncertainties in areas such as technological process, policy, and the extent to which revenues can be aggregated across multiple DSR uses. However, as discussed in section 3.1.2, storage investment could be modelled endogenously within the DDM, in which case forecasts would not need to be entered into the model.
DSR capabilities of grid-level EES	The broad capabilities (in terms of response time and duration) for existing forms of electrical energy storage are well defined. There are greater uncertainties regarding the technologies that may be developed in the future.
Current capital costs for grid-level EES	Estimates are available for storage technologies such as Lithium-Ion batteries. UK trials such as Northern Powergrid's Customer-Led Network Revolution and UKPN's Smarter Network Storage have provided data on the total costs of installing such systems. However, as "first-of-a-kind" projects, these are likely to overstate the costs of a DNO installing such a system in the light of the learning from these trials.
Future capital costs for grid-level EES	Various forecasts exist for how the costs of technologies such as Lithium-Ion batteries will decrease over time. These extrapolate past trends and are clearly open to greater levels of uncertainty
Fixed O&M costs for grid-level EES	A generic estimate of fixed O&M costs is available from a US study; more UK-specific evidence may be available from trial data.
Variable costs for grid-level EES	Battery efficiency has been recorded as part of trials such as Northern Powergrid's Customer-Led Network Revolution.

DNO smart grid technologies

8.1.1 Sources of potentially shiftable load

A variety of technologies for storage are currently under development. Technologies that have been demonstrated (or are being actively developed commercially) include:

- batteries (including lead acid, zinc air, li-ion,[266] sodium-nickel-chloride,[267] and sodium-Suphur (NaS)[268] chemistries);
- compressed air storage;
- thermal storage, including pumped heat[269] technologies; and
- smaller pumped storage schemes.

Capacity

Currently, grid-level storage on the distribution networks is limited to a small number of demonstration schemes, such as those installed as part of UK Power Networks' Smarter Network Storage project, Northern Powergrid's Customer Led Network Revolution project, and Western Power Distribution's Falcon project. To date, UK energy storage operators have committed to commissioning storage with a capacity exceeding 16.5MW.[270]

A wide variety of projections for future storage capacity have been made. For example, DECC's 2050 calculator (which aggregates storage at all levels of the grid) has scenarios that range from no further storage capacity by 2050 (level 1) to a scenario with a total of 20GW of storage (level 4). These are illustrated in **Figure 46**.

266 Li-ion batteries have been trialled a number of times within the UK, including the large batteries used for the Customer-Led Network Revolution, a 6MW unit installed by UKPN in Leighton Buzzard, a 200kW UKPN battery at Hemsby, as well as 25kW units installed as part of SSEPD's Low Voltage Connected Energy Storage trial

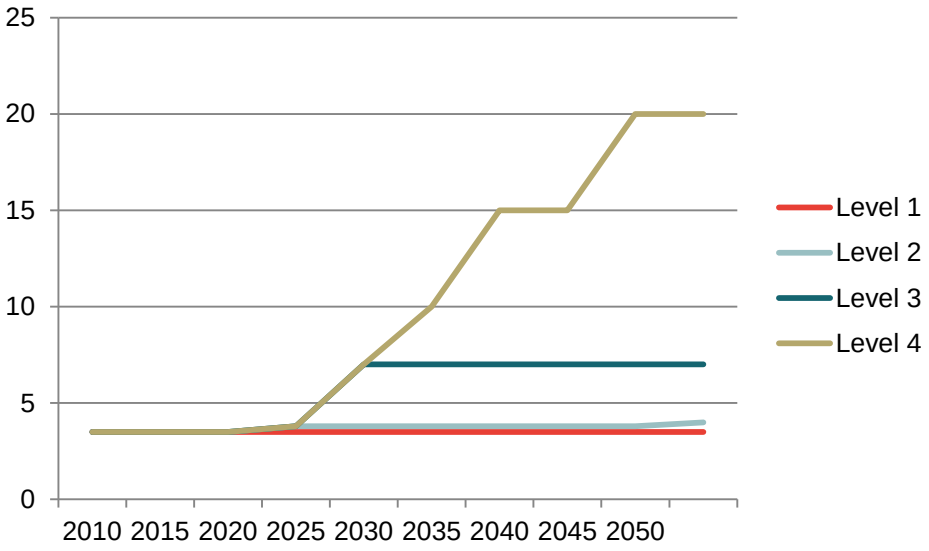
267 Western Power Distribution's FALCON LCNF project has installed 5 50kW, 100kWh batteries of this type.

268 SSEPD installed a 1 MW NaS battery in Shetland in 2011. Following a fire at a similar unit in Japan, this was replaced with a 1MW Lead-Acid Battery. See SSEPD (2013), *LCNF Tier 1 Interim Close-Down Report: 1MW Battery, Shetland*

269 For example, Isentropic have developed a pumped heat electricity storage technology using gravel storage vessels - http://www.eti.co.uk/project/distribution-scale-energy-storage/

270 Energy Storage Operators Forum (2014), *A Good Practice Guide on Electrical Energy Storage* p1. This document provides a detailed summary of many UK storage projects (as well as details on business models, costs, and other relevant factors).

Figure 46. DECC 2050 calculator scenarios for storage



Source: DECC (2010), *2050 Pathways Analysis*

A commonly cited ambition, based on both the benefits and production pipelines for storage, is for 2 GW of additional storage by 2020, of which **1 GW** might be at the distribution network level. Averaging over a number of scenarios (which are generally more optimistic than DECC's pathways), a 2014 Pöyry report for ELEXON comes to a total storage figure of 20GW by 2050, which might imply around **7GW**[271] of distribution network storage by 2035.

These figures are only intended to provide an indication of the potential scale for distributed storage. The actual uptake will depend heavily on the revenues that can be obtained through DSR, which will in turn depend on the rest of the energy system (for example, volumes of intermittent distributed generation).

Flexibility

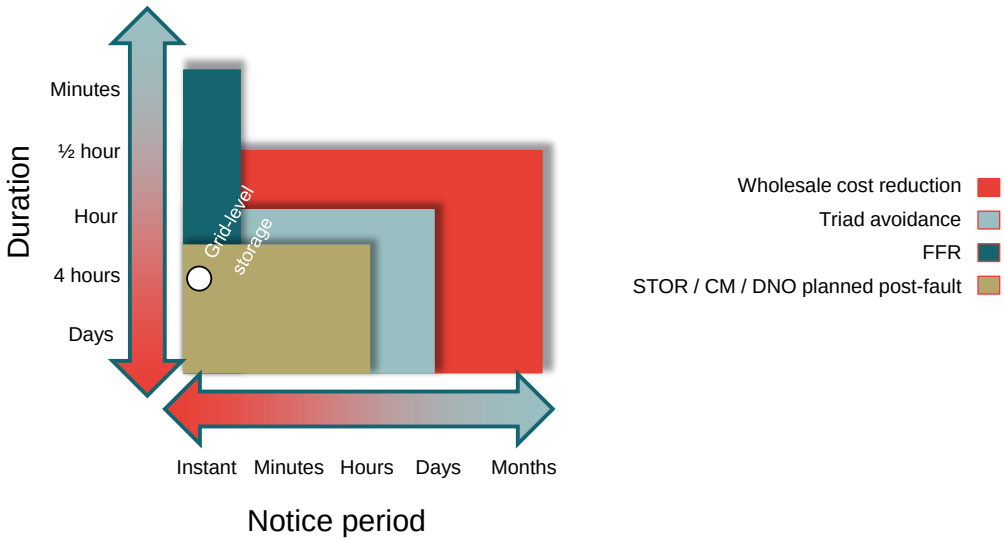
In general, battery technologies will be capable of extremely rapid response (as an example, the li-ion batteries installed by Northern PowerGrid for the CLNR project provided response times of under a minute).[272] **Table 14** and **Table 15** show how power output can typically be sustained for several hours. The high degree of flexibility implied by these technological characteristics mean that they would be suitable for providing a wide variety of DSR services (**Figure 47**). For

271 Going from 5GW of storage in 2020 to 20GW in 2050 implies an average increase of 500MW per year. If half of this were on the distribution network, that would imply 6.25GW of extra distributed storage by 2035, in addition to the 1GW by 2020.

272 Customer Led Network Revolution (2014), *Lessons Learned Report: Electrical Energy Storage*

example, UK Power Networks' Smarter Energy Storage site at Leighton Buzzard is scheduled to participate in both FFR and STOR.[273]

Figure 47. Illustrative DSR capabilities of grid-level storage



Source: Frontier Economics

273 UK Power Networks (2015), *Smarter Network Storage Low Carbon Network Fund – SNS 1.12 Energy Storage as an Asset* p36

Table 14. Costs and technical data for different grid-level storage technologies

	Power (MW)	Discharge time (hours)	Energy output (MWh)	Efficiency	Lifespan (years)	Cost	Cost (£/kW)	Cost (£/kWh)
Compressed air	441	8	3,528	70%	40	£185.2m	£420	£52
FeCr battery	100	8	800	75%	15	£116.5m	£1,165	£146
Lead acid battery	100	4.8	480	90%	15	£153.9m	£1,539	£321
Zinc air battery	50	6	300	80%	15	£45.7m	£914	£152
Li-Ion battery	10	3	30	94%	15	£33.7m	£3,370	£1,123
NaS battery	1	7.2	7.2	75%	15	£2.2m	£2,200	£306
Isentropic storage	1.4	4	5.6	75%	25	No cost data		

Sources: National Grid's Electricity Ten Year Statement 2014, and are ultimately based on the DOE/EPRI Storage Handbook 2013; Isentropic storage figures from http://www.westernpower.co.uk/docs/general/WPD-IFI-Rpt-2011_12.aspx p41 and http://www.eti.co.uk/project/distribution-scale-energy-storage/

DNO smart grid technologies

Table 15. Costs and technical data for Li-Ion batteries used within SNS and CLNR projects

	Power (MW)	Discharge time (hours)	Energy output (MWh)	Efficiency	Lifespan (years)	Cost	Cost (£/kW)	Cost (£/kWh)
Smarter Network Storage battery	6	1.67	10	See note below	10 - 15	£11.2m	£1,867	£1,120
CLNR 2.5 MVA	2.5	2	5.292	83.2% (69.0% after parasitic load)	18-20 (manufacturer estimate) 10 (CLNR assumption)	£4.62m	£1,849	£874
CLNR 100 kVA	0.1	2	0.2003	86.4% (56.3% after parasitic load)		£0.49m	£4,899	£2,446
CLNR 50 kVA	0.05	2	0.1059	83.6% (41.2% after parasitic load)		£0.41m	£8,211	£3,877

Sources: Customer Led Network Revolution (2014), *Lessons Learned Report: Electrical Energy Storage* and Customer Led Network Revolution (2014) *Electrical Energy Storage Cost Analysis*; UKPN (2014), *Smarter Network Storage learning event* slides (for cost and capacity – p16); UKPN and Baringa (2013), *Smarter Network Storage – business model consultation* (for typical lifetime – p46); UKPN (2013) *SN4.11 Investment Model Template* (for discharge time; note that the template is populated with representative values for illustration only – it also includes assumed battery and system discharge efficiency at 97.9% for the first year of operation however we have not reported this since it may be inconsistent with the measured CLNR values).

8.1.2 Arrangements for calling DSR

We now consider how the flexibility provided by the storage could be accessed.

In principle, owners of storage could respond to **price-based incentives**, such as:[274]

- The varying wholesale price of electricity (either at an intraday or forward stage); and
- avoidance of network charges (TNUoS and DNoS).

Using price-based incentives to dynamically call DSR when it is required for a DNO is perhaps possible, but could add significant complexity to DUoS tariffs, and would not provide a guarantee to DNOs that the storage asset would be available to provide the security required.[275]

For providing network services, some form of **direct control** from the DNO may therefore be required to dispatch storage on demand. For example, the CLNR batteries were under the control of an active network management system run by Northern Powergrid. Alternatively, if the storage asset were controlled by another party, a DNO could send an instruction to that party to dispatch storage capacity.

A possible complication arises for storage operated by the DNO as a distribution network asset. Trading of energy by DNOs is not practical within the current regulatory arrangements,[276] given restrictions on DNOs operating generation assets, or distorting competition in generation and supply activities. However, given the additional revenue streams that could be unlocked from other uses of DSR, it seems likely that a business model would be adopted which permitted the owner of the storage to take advantage of these opportunities. For example, a third party could trade energy on behalf of a DNO entity, even if the owner of the storage asset is a DNO. A full discussion of the potential business models for storage is outside the scope of this paper, although a number of recent studies exist in this area including the Pöyry and UKPN/Baringa reports cited above, as well as work carried out by the Storage and DG subgroup of Workstream 6 of the DECC/Ofgem Smart Grid Forum.

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274 In general, the arrangements for calling DSR for distributed generation (set out in **Table 6** on page 41) should be equally applicable to grid-level storage

275 UKPN and Baringa (2013), *Smarter Network Storage – Business Model Consultation* p41

276 Pöyry for ELEXON (2014), *Storage Business Models in the GB Market* p29; Electricity Storage Network (2014), *The Role of Storage in the Smart Grid*, prepared for Smart Grid Forum Work Stream 6

8.1.3 Costs

Capital costs

Up-front setup costs for electrical energy storage technologies are currently high relative to flexible generation technologies. As shown in **Table 14**, the US Department of Energy produced estimates of storage technology costs in 2013 that ranged from £420/kW (for compressed air storage) to £3,370/kW (for Li-Ion battery storage). These costs relate to storage units capable of providing many hours of output, and we would expect costs to be lower for batteries sized to deliver a shorter period of output.

For a real-life UK example, the Customer Led Network Revolution project installed six Li-Ion batteries (one 2.5MVA battery, two 100kVA batteries, and three 50kVA batteries). The total cost ranged from £8,211/kVA for the smallest unit to £1,849/kVA for the largest. These costs are shown in **Table 15**. The costs of UKPN's Smarter Network Storage battery (currently in trial) are broadly consistent with this.

The costs of electrical energy storage have decreased rapidly in recent years: Industry-wide cost estimates for Li-Ion batteries are estimated to have declined by approximately 14% annually between around 2007 and 2014.[277]

Fixed O&M costs

The 2013 US Department of Energy / EPRI handbook includes fixed O&M cost estimates for a variety of storage technologies. For Li-Ion batteries used for transmission/distribution grid support (the same application as the CLNR and SNS batteries), these are approximately £5/kW/year for 1MW-10MW batteries.

The CLNR project did not identify specific operational expenditure, which was carried out as part of a tendered contract with the storage technology supplier. However, the project did identify significant parasitic losses caused by the running of ancillary load (such as air conditioning) required to maintain the sites in a ready state. These were particularly significant for the smaller sites: One of the 50kVA sites experienced an average parasitic load of 1.77kW, reducing round-trip efficiency from 83.6% to 41.2% (assuming one charge-discharge cycle per day).[278]

The SNS project has produced a template to demonstrate EES business models (the inputs to this template are intended to be representative, but are only illustrative, and are not based on empirical real case values).[279] This template

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277 Nykvist, B. and Nilsson, M (2015), *Rapidly falling costs of battery packs for electric vehicles*, Nature Climate Change Vol 5 April 2015

278 Customer Led Network Revolution (2014) *Electrical Energy Storage Cost Analysis*

279 UKPN and Baringa (2013), *Smarter Network Storage – business model consultation* p17

includes a total of £85,018 of opex per annum for a 6MW/10MWh battery, divided into the following categories:

- £10,000 for inspection and maintenance;
- £5,000 for spare parts;
- £40,000 for facilities cost;
- £5,000 for insurances;
- £15,000 for management and administration;
- £18 for self discharge losses; and
- £10,000 for energy trading and risk management.

These illustrative values would imply a total opex of around £14/kW/year.

Variable costs

The variable costs of a storage system will depend on both its efficiency, and the price differential between when the unit is being charged and discharged. **Table 14** shows that efficiencies might range from 70% (for compressed air storage) to 94% (for Li-Ion batteries) – although the latter figure does not appear to include the effect of parasitic loads.

Greenhouse gas and local emissions

As with load-shifting, the consequence of the use of storage upon emissions will depend on:

- the efficiency of the storage device; and
- the relative carbon intensity of grid electricity during the period of demand reduction, compared to an increase in demand.

In many instances (for example, DSR to reduce wholesale electricity costs), the carbon intensity will be lower during the period where demand is shifted to. The updated version of the DDM can calculate the carbon emissions increase or decrease associated with DSR.

8.2 Enhanced Automatic Voltage control

DNOs have trialled "smart" techniques that enable them to better control the voltage of their networks,[280] typically to mitigate voltage issues that may occur

[280] Some examples of projects that have trialled enhanced approaches to voltage control include Northern Powergrid's Customer-Led Network Revolution, UKPN's Flexible Plug and Play and WPD's Low Carbon Hub.

due to the increasing connection of distributed generation. However, these types of technique may also be suitable for producing targeted load reductions needed for DSR uses. In this section, we briefly summarise some information that has been obtained from Electricity North West's CLASS project, which is currently trialling technologies that enable the automated and remote dispatch of voltage control.

It should be noted that voltage control can also be installed at the level of individual premises.[281] The Voltage Optimisation Industry Council for Excellence states that power reductions of between 5% and 13% can be achieved.[282] We understand that in principle some of these in-premises units could be enhanced to provide DSR services such as frequency response – and potentially controlled by an aggregator for the purposes of supplying longer-duration DSR services such as STOR. For the purpose of modelling, it will be important to not double-count reductions in power usage that could occur from both grid-level and within-premises voltage optimisation.[283] This section focusses on the potential for grid-level voltage control. However, in-premises voltage control does have significant potential to unlock greater levels of I&C DSR, and further research in this area could be of benefit.

8.2.1 Sources of potentially shiftable load

The power demand for certain loads can change with voltage. Actions taken by the DNO to lower the voltage on their network are therefore a potential source of DSR.

Voltage control is already used by DNOs to provide demand reduction to National Grid in response to events leading to a supply shortfall, as a substitute or complement to consumer disconnection. It is expected that DNOs can carry out voltage control within 10 minutes of receiving instructions from National Grid, and may typically be able to reduce demand by 1.5% with a 2% voltage reduction, and reduce demand by a further 1.5% with a 4% voltage reduction.[284]

Electricity North West's CLASS project has trialled techniques for controlling the voltage on the network. These techniques can provide a rapid response time: Disconnecting one of a paired arrangement of primary transformers could result

281 For example, the website of powerPerfector (http://www.powerperfector.com) notes a wide range of both industrial and commercial customers

282 VOICE *Buyer's Guide for Voltage Management & Optimisation* p5

283 The extent of any double-counting will depend on how much voltage reduction DNOs can carry out without detailed knowledge of the load connected to each substation, which will affect the potential for further gains using in-premises solutions.

284 Operating Code No. 6 (OC6) Demand Control

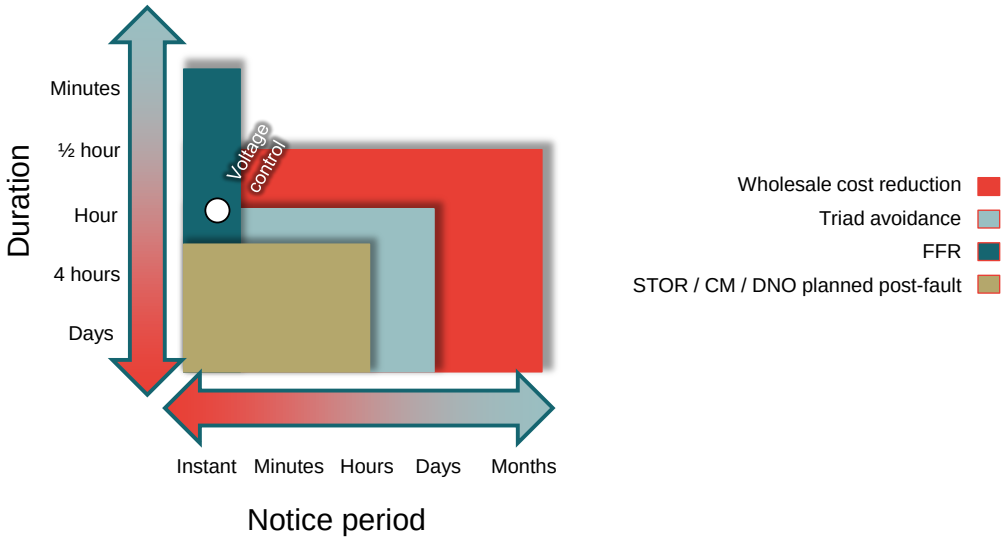
in a demand reduction within two seconds, while changing the voltage by adjusting the transformer tap position might take 30 seconds.[285]

These techniques should be capable of providing a response duration of at least an hour.[286] Indeed, during testing of an automated system for calling voltage reduction when power increased above a threshold, voltage control was in operation for over six hours.[287]

Data produced from the trial so far shows that these techniques were able to reduce demand by 6% at a substation.[288]

If applied widely, these types of techniques could potentially provide a significant DSR capacity. However, care should be taken not to double-count the voltage control services that DNOs already provide National Grid during times of system stress.

Figure 48. Illustrative DSR capabilities of voltage control



Source: Frontier Economics

8.2.2 Arrangements for calling DSR

The technologies trialled in the CLASS project were installed and directly controlled by the DNO. It is possible that other entities could interface with the DNO to also directly control DSR. The project has included the installation of

285 Electricity North West (2014) *Design approach to CLASS trials and associated test schedules* p15

286 Electricity North West (2014) *Design approach to CLASS trials and associated test schedules* p11

287 Electricity North West (2014) *CLASS Capability Report for Trial Scenarios* p14

288 Electricity North West (2014) *CLASS Capability Report for Trial Scenarios* p5

an interface to National Grid's network management system, allowing National Grid to view and initiate voltage regulation.[289]

As explained in the previous section on storage, DNOs themselves are currently not permitted to trade electricity on the wholesale market.

8.2.3 Costs

We have not carried out an analysis of the costs of these technologies (the CLASS project is still ongoing).

Survey evidence collected by the CLASS project suggests that customers do not observe impacts on power quality as a result of the trialled techniques.[290] This is consistent with research carried out for DECC and Ofgem, which suggests that voltage reductions of 6% are unlikely to have much impact on the lifetime or continuing operation of most household equipment.[291]

Capital costs may vary depending on the required functionality at a site (whether the facility to disconnect one of a paired arrangement of transformers, resulting in a very rapid voltage change, is required). [292] In addition, costs can vary significantly from site to site. For example, substations that already had the appropriate relay only required a controller to be fitted to enable voltage changes to be dispatched remotely, while substations with an older relay needed this replacing.

Greenhouse gas and local emissions

If these technologies are able to successfully reduce load, then the reduction in carbon emissions (and other pollutants emitted by generating plants) will depend on the marginal generators at the time when load is reduced.

As discussed above for I&C and domestic demand-led DSR, the EU ETS ensures that these costs are priced into the wholesale cost of electricity. If operators of storage and voltage control face these costs (this will depend on the business and regulatory model), then they will affect the attractiveness of these forms of DSR.

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289 Electricity North West (2012), *Low Carbon Networks Fund Full Submission Pro-forma: Customer Load Active System Services* p7

290 Electricity North West (2015), Customer Load Active System Services Customer Survey Initial Summary Report

291 London Economics for OFGEM and DECC (2013), *The Value of Lost Load (VoLL) for Electricity in Great Britain* p51

292 Electricity North West (2014), *CLASS Commissioning Report*

DNO smart grid technologies

9 Implications for modelling

In parallel with the research undertaken for this report, Lane Clark & Peacock (LCP) were commissioned by DECC to add additional DSR functionality to the investment and dispatch model used by DECC.

In this section, we first provide a basic description of the model used by DECC, and then set out how the different types of DSR considered in this report can be modelled.

9.1 Modelling background

DECC currently utilise the Dynamic Dispatch Model (DDM) for forecasting the future of the GB electricity market.

The DDM is a comprehensive fully integrated power market dispatch model covering the GB power markets over the medium to long term. The scope of the model is to report metrics of electricity dispatch from GB power generators and investment decisions in generating capacity in GB. The full lifecycle of power generation plant is modelled, from planning through to decommissioning.

The DDM currently allows for a simplified representation of DSR that attempts to capture the effect that DSR may have on the wholesale markets in an aggregated way.

The research provided in the rest of this report demonstrates the wider contribution that DSR can make to the energy market including through participating in the Capacity Market, providing ancillary services, and affecting demand profiles.

An important aim of this project has been to develop in-house capability to understand how DSR[293] may interact with Capacity Market auctions and improve the representation of the unique characteristics of different types of DSR in the DDM. Many forms of DSR can be represented by existing DDM functionality but some have required enhancements to better reflect the findings of this report.

The developments will allow DECC to represent the following key characteristics of different categories of DSR.

- The interaction with the **wholesale market** – this may be through direct participation or indirectly through reducing or shifting load.
- The contribution to the **Capacity Market** – either through direct participation for contracts or indirectly in the form of a reduced requirement for conventional generation capacity.

293 This paper does not offer model inputs regarding permanent demand reduction.

- The investment **decisions / uptake of DSR** – the model now has the additional capability to capture the drivers that will determine the level of potential DSR that is realised.
- **Wider system impacts** – to maintain consistency with ongoing work to model "whole system impacts", the contribution of DSR to ancillary service markets (such as STOR, frequency response and the balancing market) has been allowed for.

The modifications to the DDM mean that it can now select investment in DSR technologies in a way similar to that described in the 2014 report for DECC by the Centre for Sustainable Energy, *An analysis of D3 in DECC's energy system models*. It should be noted that while our report (and the associated modelling) consider demand response and distributed energy, demand reduction (the other "D" of "D3") is outside the scope of this work.

The remainder of this section provides an overview of how the different types of DSR covered in this report can be modelled using existing and new functionality.

9.2 Distributed generation

Distributed generation technologies are similar in nature to conventional power plant technologies modelled in the DDM. This means the DDM is capable of simulating these technologies in detail including all the areas of interest: wholesale market interaction, Capacity Market interaction, investment decisions and, upon completion of ongoing work, wider system impacts.

In particular the DDM has extensive capability to model CHP generation and policy incentives in a high level of detail.[294]

Currently DECC models the investment decisions of a number of technologies that could be considered distributed generation outside of the DDM. For example, DECC inserts scenarios into the DDM for investment in small distributed OCGTs that have been developed elsewhere. The DDM then captures the effects of these technologies on the wholesale, capacity and ancillary service markets in a consistent way.

However, the DDM can alternatively be used to model the investment in these technologies directly.

294 See LCP (2014), *Modelling the impacts of additional Gas CHP capacity in the GB electricity market* for further details – available at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/389070/LCP_Modelling.pdf

Implications for modelling

9.3 I&C back-up generation

The research finds that back-up generation could represent a significant source of DSR and potentially contribute materially to meeting security of supply targets. The detail on potential I&C back-up generation capacity and costs presented in this report has been incorporated into the DDM to improve the modelling of this form of DSR and its interaction with the Capacity Market and contribution to ancillary markets such as STOR.

The DDM has been modified to allow back-up generators to be modelled in a manner similar to conventional power plant. This approach allows for back-up generators to directly participate in the Capacity Market with other conventional technologies and allows the uptake of this form of DSR to depend on the Capacity Market outcomes.

The investment costs for adding an additional diesel back-up generator to an aggregator's portfolio may be relatively independent of the size of the generator. This leads to the sharply increasing cost curve illustrated in **Figure 15**. To take account of this in the modelling, diesel generators have been split into a number of size tranches.

9.4 I&C demand led DSR

As discussed in this report I&C demand led DSR incorporates a number of widely different technologies each with individual costs and characteristics.

The technologies will need to be modelled differently depending on their fundamental operation in the wholesale market. Broadly we classify the technologies into three categories:

- load reduction;
- load shifting; and
- no wholesale market interaction.

9.4.1 Load reduction technologies

Load reduction technologies will reduce load in response to a high wholesale prices. This might be the case for temporary reductions in I&C lighting load (if this form of DSR is possible at all), or industrial processes which are cancelled rather than postponed.

The DDM has been modified to allow DSR technologies that fall into this category to be modelled in a way similar to conventional power plants. The investment or uptake of these technologies can then be determined within the DDM depending on the savings they are able to make by reducing load in the

wholesale market or contributing to security of supply in the Capacity Market (if allowed to compete in this market).

Modification has been made to the DDM to allow for the fact that these technologies may have very specific availability profiles (for example, if lighting DSR through temporary dimming was modelled, winter availability may be greater than in the summer).

Technologies that reduce load by shifting it to another time of the day can also be approximated in this way. This will likely also be the preferred approach where load shifting actions are only taken in extreme circumstances, due to high costs of actually shifting load, as opposed to on a regular basis.

Ideally, the availability of demand for load-reduction should be consistent with the overall demand profiles used within the DDM, to prevent load being reduced where it was not forecast in the first place. This issue is more important for load-shifting, and is discussed in greater detail in the following section.

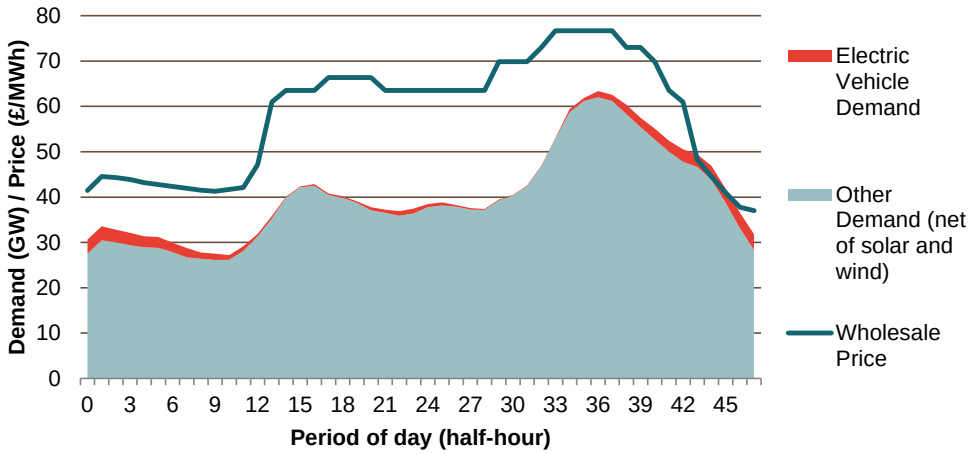
9.4.2 Load shifting technologies

A number of DSR technologies have the potential to shift the occurrence of load within a given day. This is likely to be the case for hot water, water pumping, and industrial processes which can be postponed, as well as HVAC and refrigeration (if these are able to participate in the wholesale market).

This method of interacting with the wholesale market is fundamentally different from a modelling perspective to the operation of conventional power plant and could not be adequately captured with the existing modelling capability. Development has been undertaken to allow the DDM to capture this behaviour.

An illustrative example of this new functionality is included in **Figure 49** below (this considers Electric Vehicles (EVs) which also use the new load-shifting functionality and are discussed in the domestic section, below). This chart depicts a possible profile of electric vehicle charging alongside residual demand (non-EV demand net of intermittent renewables) and wholesale prices for a typical future weekday. Without any load shifting the typical EV user is expected to charge their vehicle after returning from work. This timing for load coincides with the typical peak demand periods of the evening.

Figure 49. Load profile for electric vehicles, residual demand and wholesale price

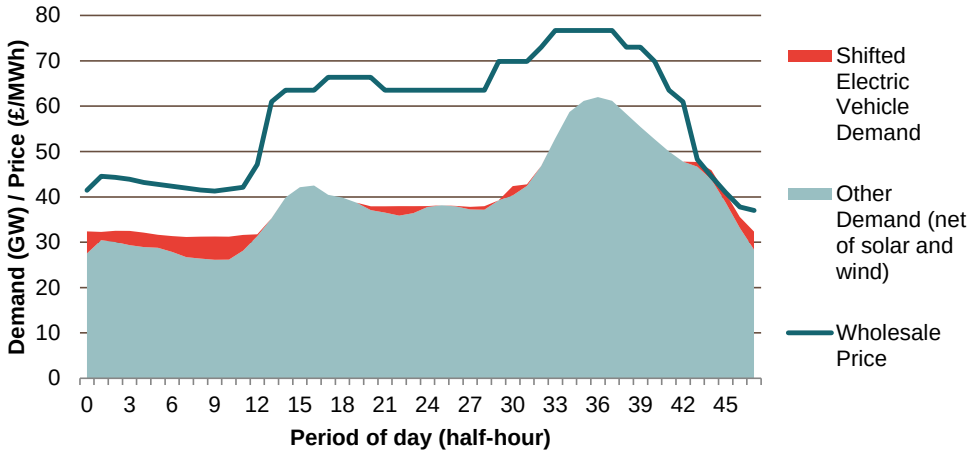


Source: Illustrative example

Figure 50 then demonstrates the modelled demand after the load shifting functionality has been enabled in the DDM. EV load has been shifted, up to a maximum of six hours, to time periods where residual demand is lowest. As shown load has been shifted away from the peak after work hours to time periods in the early morning (later in the night) where residual demand is lowest. With the wholesale price shown this shift achieves a 12.5% reduction in energy costs for electric vehicles.

This functionality is then capable of both determining the potential revenue stream for DSR that will contribute to the investment decisions as well as creating the 'shifted' demand profile that the wholesale market will operate according to.

Figure 50. Shifted load profile for electric vehicles, residual demand and wholesale price



Source: Illustrative example

However, it is important to understand the implications and prerequisites for this approach to modelling. A prerequisite for modelling this form of DSR is that it requires the overall demand profile in the DDM to be consistent with the profile for the specific form of load which is being shifted. For example, consider modelling a scenario where significant amounts of DSR can be obtained from shifting EV load. For this to be done correctly the overall load profile within the DDM would need to already include the EV load profile by half hour in every given year, otherwise it would be reducing more load at peak than is possible.

Currently the DDM only uses a static daily load shape, which changes with different day types and seasons, but not through time. The demand forecasts and load profiles are additionally only split into domestic / non-domestic sources and not disaggregated to the level of different end use.

Functionality has been added to allow the DDM to incorporate different load profiles, and demand forecasts, by end use of electricity. The aggregate level of demand and importantly the future demand profile can then be determined in the model consistent with forecasts of changes in use of energy (such as increasing EV uptake).

The data requirements for this level of detailed modelling remain a challenge for the demand forecasting team. For example, DECC's demand models currently do not split out future I&C demand by end-use, which limits the extent to which I&C load-shifting can be modelled in a consistent way. However, important sources of potential load shifting DSR such as electric vehicles and heat pumps can potentially be readily included with the level of data found in this project.

Implications for modelling

9.4.3 No wholesale market interaction

A number of technologies might not interact with the wholesale market directly (potentially due to short duration of dispatch), but may still be expected to participate in the capacity or ancillary services markets. For example, DECC may wish to run a scenario that considers that forms of I&C DSR such as HVAC and refrigeration are used for services such as FFR but not in the wholesale market itself.

Such technologies can be modelled with the newly developed DSR representation within the DDM. These technologies can be considered 'load reduction' DSR technologies with a cost to reduce load set sufficiently high so as to never be applied.

9.5 Domestic demand led DSR

Domestic demand led DSR can be represented with the newly implemented DDM functionality as with I&C demand led DSR. Again the most important classification for each technology will be in into three categories of wholesale market participation: load shifting, load reduction, and no wholesale market interaction.

- Most of the forms of domestic demand-led DSR we have considered shift load (although it is possible that cold appliances in particular may have too short a dispatch time to operate in the wholesale market).
- However, hybrid air-source heat pumps would operate as load reduction.

As with I&C demand-led DSR, a difficulty arises given DECC's underlying demand profiles do not break out the different end-uses, and so it is possible that the model may shift or reduce demand that is not there in the first place. This is somewhat less of an issue with forms of DSR based on technologies that are not currently widespread (EVs and heat pumps),[295] as these can be added to a pre-existing load profile that does not already include them. We have therefore populated the DDM with inputs for electric vehicles and air-source heat pumps. However, to use this modelling functionality in a robust way, it will still be necessary for DECC to identify the proportion of forecast energy demand from heat pumps.[296]

295 Domestic electrical energy storage can also be modelled, since this does not have an "original" load profile and can be dispatched at will (subject to technical constraints on battery power and capacity ratings).

296 DECC's forecasts already break out electric vehicle energy usage.

9.6 DNO smart grid technologies

A degree of grid-level storage could be approximated using the new load-shifting functionality. However, the functionality is designed specifically for shifting the incidence of load and certain features specific to the use of batteries may not be appropriately captured, especially at high levels of penetration.

Demand reduction through the use of enhanced automatic voltage control could be modelled using the new demand-reduction functionality.

9.7 Summary of DSR modelling within the DDM

Table 16 below summarises, for each type of DSR considered in this report:

- the DDM functionality that can be used to represent it; and
- whether the updated DDM contains inputs relating to this type of DSR.

Table 16. Summary of DDM DSR modelling

DSR type	DDM functionality	DDM populated with data
Distributed generation		
Thermal generation technologies	Existing functionality for dispatch of generators	✔**Yes** DDM already includes inputs for these types of technology.
Renewable generation technologies	Existing functionality for dispatch of generators	
CHP generation technologies	Existing functionality for dispatch of CHP	
I&C back-up generation		
I&C back-up generators	Existing functionality for dispatch of generators	✔**Yes** The DDM has been populated with new data.
I&C demand-led DSR		
HVAC	Load-shifting (might also be modelled as not participate in wholesale market)	✘**No** We have provided some tentative inputs in section 6. However, these load profiles by end usage will not be consistent with the overall DDM I&C load profile, and if modelled could lead to load being shifted from where it does not already exist.
Hot water	Load shifting	
Refrigeration	Load-shifting (might also be modelled as not participate in wholesale market)	
Lighting	Load reduction	
Water pumping	Load shifting	
Other industrial processes	Load shifting or load reduction	✘**No** In addition the issue noted above, this is an extremely heterogeneous category without adequate data.

Table 16. Summary of DDM DSR modelling

DSR type	DDM functionality	DDM populated with data
Domestic demand-led DSR		
Electric resistive storage heating	Load shifting	✘ **No** We have provided some tentative inputs in section 7. However, these load profiles by end usage will not be consistent with the overall DDM I&C load profile, and if modelled could lead to load being shifted from where it does not already exist.
Heat pumps with storage	Load shifting	✔ **Yes** We have provided an illustrative scenario to use in the DDM. However, as the DDM demand profile does not split out heat pump load, results may be inconsistent.
Gas hybrid heat pump systems	Load reduction	✔ **Yes** We have provided an illustrative scenario to use in the DDM (this will require choosing how many heat pumps are part of hybrid systems). However, as the DDM demand profile does not split out heat pump load, results may be inconsistent.

Implications for modelling

Table 16. Summary of DDM DSR modelling

DSR type	DDM functionality	DDM populated with data
Electric vehicles	Load shifting	✔**Yes** We have provided an illustrative scenario to use in the DDM. Electric vehicle demand can be broken out from the overall load profile used within the DDM.
Wet appliances	Load shifting	✘**No** We have provided some tentative inputs in section 7. However, these load profiles by end usage will not be consistent with the overall DDM I&C load profile, and if modelled could lead to load being shifted from where it does not already exist.
Cold appliances	Load shifting (might also be modelled as not participate in wholesale market)	
Domestic electrical energy storage	Load shifting	✔**Partial** An approximation of domestic EES can be captured, however, this is an area for future improvement. We have provided some illustrative inputs.
DNO smart grid technologies		
Grid-level electrical energy storage	Load shifting	✔**Partial** An approximation of grid level storage can be captured, however, this is an area for future improvement. We have provided some illustrative inputs.

Table 16. Summary of DDM DSR modelling

DSR type	DDM functionality	DDM populated with data
Enhanced automatic voltage control	Load reduction	✘ **No** This report has not quantified the costs of these systems.

Source: Frontier Economics and LCP

Implications for modelling

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