BEIS - OpenDSR Phase 1 Report

Phase 1 Feasibility Study Report

1. Public Description of the Project

A partnership led by Carbon Co-op will deliver 'OpenDSR' a project assessing the feasibility and demonstrating the real-world potential for an open source, standards-based approach to demand side response (DSR) management services.

Our specification is flexible enough to map to a variety of anticipated DSR business models and contractual relationships, such as aggregator intermediary, DNO active network management, and ESCo (energy service company) and to integrate a variety of sizeable distributed domestic and flexible loads such as eclectic vehicles and direct electrical Heating.

Some market actors favour a 'walled garden' approach of proprietary systems and platforms to the management of DSR devices. Our experience and research suggests DSR business models will be based on small, tight margins and the need to integrate systems with a wide range of flexible assets. Attempting to monopolise value via intellectual property and market capture adds to these margins, reducing viability and interoperability.

The 'Open DSR' project seeks to unlock the value within the 'long tail' of flexibility of the existing electricity network in homes across the UK by promoting an open and standards-based approach to automated demand side response.

Successfully doing so will bring in to viability a number of proposed aggregator/ESCO business models as well as reducing capital cost outlays for DSR devices such as batteries, EVs and electrical heating systems, lower costs and will support new UK-based manufacturing, supply and retail supply chains as well as possible exports to North American markets.

2. Executive Summary

OpenDSR is an integrated system utilising OpenADR, which enables demand side response campaigns, integrating assets such as smart electric vehicle chargers and immersion heaters, delivered by a Community Energy Aggregator/ESCO intermediary.

The BEIS ‘Realising the Potential of Demand SIde Response to 2025’ Rapid Evidence Assessment report highlighted four areas in which action is required in order to develop a market for small scale and domestic DSR in the UK: policy interventions; business strategies, DSR products and services and user engagement and participation.

In stage 1, we proposed the OpenDSR project, and examined the feasibility for this project to work across all four of these areas. Open DSR comprises:

- A policy intervention mandating the adoption of a common open standard, OpenADR, following the example of California in bringing forward the conditions for a UK DSR market.
- The creation of an end-to-end system, OpenDSR, integrating market platforms, HEMS and DSR products and services
- A Community Energy-based Aggregator/ESCO business model, combining a novel business strategy and diverse income stacking with built in consumer engagement and participation.

The feasibility project took place between May and July 2018, was led by Carbon Co-op with the assistance of Community Energy Scotland, Megni (trading as OpenEnergyMonitor) and EV Parts Ltd and involved desk-based research, policy analysis, software systems architecture design and planning as well as real world research with two user groups: owner occupier, Community Energy members with electric vehicles and social housing tenants with immersion heaters.

This report details that work, examining the the policy, technical and business strategy elements of OpenDSR. The benefits of this approach are that:

- **Open Standards** such as OpenADR**,** create a **level playing field** and new market opportunities for all energy system actors.
- An integrated, Open Source system creates **more robust, inter-operable and cheaper systems for all**, enabling the tight margins necessary for a functioning DSR market, challenging existing energy system incumbents and opening the sector to disruptive new entrants.
- A Community Energy ESCO/Aggregator business delivery model creates a **trusted householder intermediary,** with lower customer acquisition costs and greater and quicker end user adoption.

In order to gather data and evaluate the potential of the OpenDSR approach, we propose 2.25 year, OpenDSR Demonstrator project.

The project will involve:

- The development and testing of the OpenDSR software system, integrating a series of existing Open Source software components in to an end-to-end DSR system.
- Two real world pilot sites:
    - 60 owner occupier, Carbon Co-op member homes will be installed with smart electric vehicle chargers

    - 40 social housing homes in Trafford, Greater Manchester will be installed with immersion heater controllers, solar panels and solar diverters.
- The performance of test DSR campaigns to demonstrate a series of business related use cases.
- The gathering of data in order to carry out a robust evaluation on the system performance against a range of KPIs (as outlined in the technical report).
- The creation of a Community Energy Aggregator/ESCO business model for the delivery of domestic DSR and other energy services.

The project will be led by Carbon Co-op who will oversee software integration and testing as well as the smart EV charger pilot site. Megni and EV Parts Ltd will be involved in software and hardware integration and installations. Great Places housing association will oversee engagement and installation at the social housing test site in Trafford. REGEN will assist with data collection and project evaluation as well as leading on business plan development.

This project demonstrates controllable, flexible demand in real domestic environments, with the potential to reproduce such an approach at significant scale, in particular via replication via the UK's widespread existing Community Energy sector.

3. Aims and Objectives

AIM: the aim of the demonstrator project is to show that deployment of an open standards approach can bring benefit to all actors within the energy system via the demonstration of an integrated DSR system, based on OpenADR using Open Source components, infrastructure as a service and a Community Energy Aggregator/ESCO business delivery model offering additional consumer involvement and engagement.

OBJECTIVES

- To carry out the **novel integration** and testing of existing open source components into the OpenDSR system within 12 months of project start.
- To use OpenDSR to demonstrate live **end-to-end DSR campaigns** using immersion heaters and solar PV diverters in social housing and smart EV chargers in Carbon Co-op members' homes between months 15 and months 24 of the project.
- To evaluate the **load shifting capabilities** of the OpenDSR approach and the ability of the assets tested to contribute to new DSR markets, after month 24 and before the end of the project.
- To carry out **market analysis and testing and the development** of a Community Energy Aggregator/ESCO co-operative intermediary business model (for owner occupiers and housing providers) throughout the project with a report delivered at project end.
- To collect data to support the evaluation of the **economic, social and environmental KPIs** for the OpenDSR system with a report delivered at project end.
- To **disseminate and document project learning** targeting policy makers, key energy system actors, throughout the project and with a report at project end.

4. Technical Solution and Expected Performance

The general technical concept of OpenDSR is that all the parts of a domestic demand side response system based on the OpenADR specification are either already available or at a pre-commercial stage of readiness. Furthermore, many of these parts have high-quality open source implementations which can be assembled together and integrated to form a complete system. The benefit of this is that the resulting system can act as both a publically available reference implementation for demand side response in the UK as well as being the basis of a competitive commercial system helping to reduce costs across the whole domestic DSR market.

OpenADR

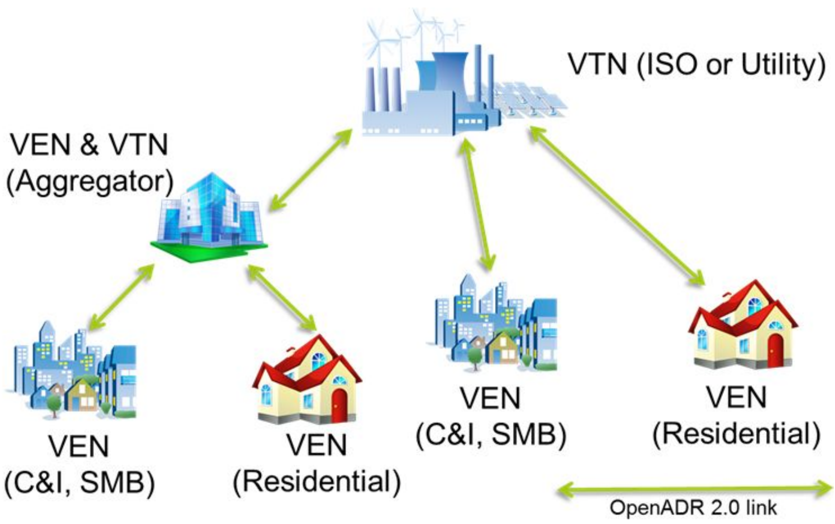
History and development

OpenADR[1] is a royalty free and open standard for automated demand side response. It was originally developed by the Lawrence Berkeley National Laboratory, partly in response to the California electricity crisis in 2000/2001, where a need for greater system flexibility was identified to improve grid resilience (amongst other measures). The standard has since been taken over by the OpenADR Alliance who have overseen the development of OpenADR 2. The OpenADR 2b standard is also now an IEC PAS with a view to it being developed into a full IEC standard in the near future. OpenADR 2 is also aligned with the Energy Interoperation and Energy Market Information Exchange OASIS standards which are likely to see wide adoption amongst US Energy utilities.

A significant recent development has seen OpenADR 2b mandated as the de-facto standard for automated demand response of HVAC and lighting appliances in statewide California Building Energy Efficiency Standards[2].

The standard has mainly been utilised by products and services in North American markets but has seen deployment in Europe in trials with some evidence of limited product support in the current UK/EU markets. It is notable that the USEF Foundation (which is developing a European energy market focussed standard for the description of flexibility markets) and OpenADR Alliance have formed a partnership to harmonise the two standards and standardise the use of OpenADR within USEF compliant markets. The EU and members states have currently not moved to develop a parallel standard to OpenADR.

General Features



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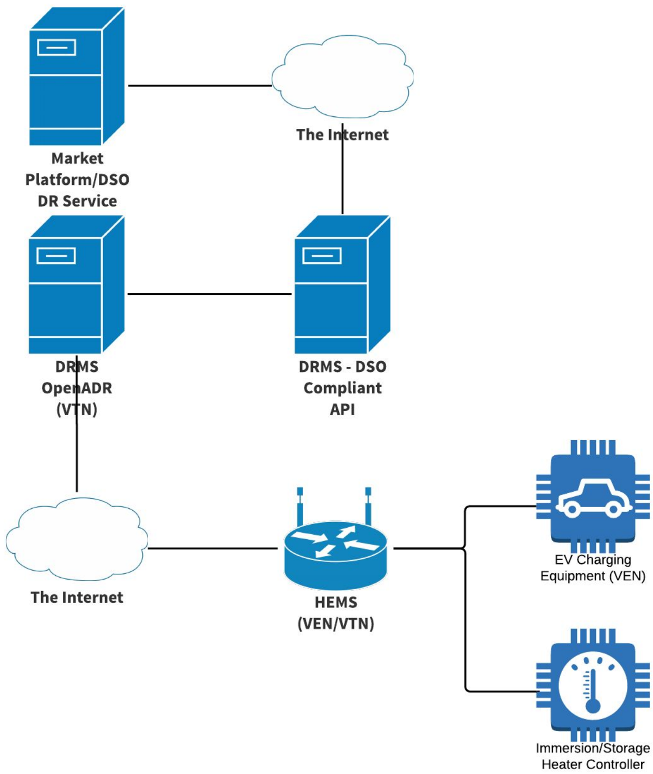
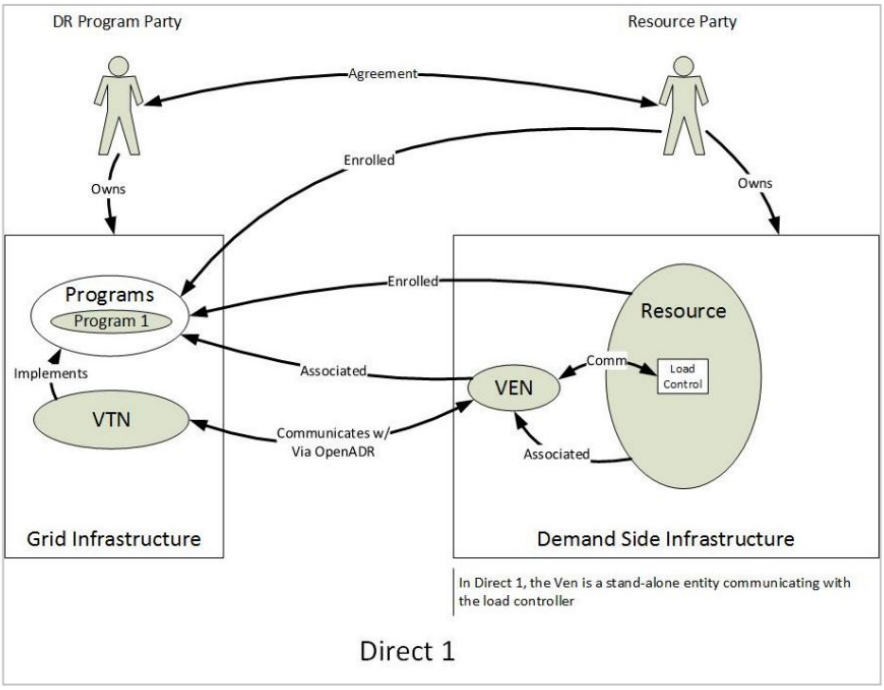
[1] "OpenADR Alliance." https://www.openadr.org/. Accessed 25 Jun. 2018.
[2] "Building Energy Efficiency Program ...." http://www.energy.ca.gov/title24/. Accessed 25 Jun. 2018.

OpenADR describes both the data model, control sequencing, and the method of data exchange for demand side response between different parties as interactions between actors within a service oriented architecture (SOA) as is typically found in modern internet connected systems. The primary actors are Virtual Top Nodes and Virtual End Nodes. There can be an arbitrary number of exchanges between VTN and VEN in sequence with a VTN also acting as a VEN (or vice versa). This is depicted in Figure X. Data is exchanged in an XML format over HTTPS (or XMPP). These core IP-based technologies benefit from almost universal support in internet-connected devices making it straightforward to implement OpenADR-based systems on a wide range of devices, including low-power microcontrollers and SoCs which are now increasingly found in domestic appliances.



The **primary** technological benefit of adopting an open standard like OpenADR is the use of an existing well developed data model and control flow and sequencing which supports a wide range of use cases and DER device types based on real-world use case experience. OpenADR 2 also has the concept of nested ‘profiles’ (currently ‘a’, ‘b’, and ‘c’) which contain an increasing sub-set of functionality. The ‘a’ profile is the simplest intended for low power/processing devices and implementing only a limited sub-set of the OpenADR command set (and is comparable to the demand side response functions found in Zigbee SE 1.x).



Security has also been a key consideration in the development of OpenADR, which has been targeting US NIST standards in its development. The primary method of encryption and authentication is using ‘mutual’ TLS authentication and encryption (X509 client/server certificate pairs). Partly by coincidence this has emerged as the industry standard for IoT message encryption and authentication. Message payloads can also be signed by both VTN and VEN devices for ‘high’ security. The specification also covers some aspects of authorisation although this is largely left as an implementation detail.

What OpenADR is not

OpenADR describes the data and sequencing of demand response control as well as prescribing the application layer protocols which are used and (to a lesser extent) how they are used. In this respect it differs from smart grid standards like SGAM and USEF, which are higher level and broader (and largely compatible pending current harmonisation efforts), and low-level hardware-based standards like Zigbee Smart Energy, which go further in specifying other network layers as well as the physical hardware on which applications run.

Description of high level use cases

The different intended use cases of the demand side response system will have some impact on it’s design. These reflect the business models of the likely route to market for such a system in the UK currently. OpenADR already accommodates all of the following use cases so it is largely a question of how the wider OpenDSR system will do so.

1. **Behind the meter optimisation**

In this scenario a half-hourly tariff schedule is produced daily by the customers electricity retailer and obtained by the aggregator by some means. This doesn’t require any relationship with the retailer only that this data is available by some means. An example of this would be the Agile tariff from UK supplier Octopus Energy[3] which provides a dynamic time of use tariff which follows the wholesale market spot price. Tariff schedules are published by Octopus daily and can be accessed by an API. Whatever the source, this is then used to generate an OpenADR demand response event for each user and their assets which is sent to the HEMS for control and attempts to operate the assets in a cost-optimal manner (for example, in the case of an EV this may result in deferring charging at peak times to cheaper times over night).

The relevant OpenADR 'program' (use case) is 'Critical Peak Pricing' or 'Residential EV TOU' depending on the technical characteristics of the loads (as described in the OpenADR 2.0 Demand Response Program Implementation Guide[4]).

2. Flexibility Market

In this use case, the aggregator receives requests for activation of flexibility assets under its control from other Market Actors (suppliers/DSO/SO). These requests may or may not be formatted according to the OpenADR specification (indeed they could be compliant with another standard, such as USEF, or a proprietary one). The aggregator estimates how best to utilise its portfolio of assets to maximise income generated and then activates assets accordingly by sending OpenADR events to the HEMS for direct control. No flexibility markets of this kind currently operate in the UK although a USEF market with these characteristics will be trialled in the FUSION project.

The relevant OpenADR 'program' (use case) is 'Capacity Bidding Programs' or 'Fast DR Dispatch' may be relevant depending on the operation of the flexibility market.

3. DSR Direct Load Control

In this use case a pre-existing agreement to provide capacity exists between the aggregator for the provision of flexibility from a portfolio of domestic assets in response to some predetermined signal from a DSO. We envision this occurring over the internet. For example, in the recent expression of interest by Western Power Distribution they describe a REST API which the DRMS must implement in order to exchange information with the DSO[5]. Ideally DSOs would implement an OpenADR interface but this is not required.

On receipt of the signal from the DSO the system identifies the appropriate assets (for example located in a specific geographical area) and initiates a demand side response event. This is done according to the control flow described by OpenADR, including the ability of asset owners to override the event (subject to some penalty or non-compensation).

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[3] "Agile Octopus | Octopus Energy." https://octopus.energy/agile/. Accessed 25 Jun. 2018.
[4] "OpenADR 2.0 Demand Response Program ... - OpenADR Alliance." http://www.openadr.org/assets/openadr_drprogramguide_v1.0.pdf. Accessed 3 Jul. 2018.
[5] "API documentation - Flexible Power Participant API." https://flexiblepowerwpd.co.uk/docs/verifying_signatures_1_0.html. Accessed 1 Jul. 2018.

In each case, once the event is over a report is generated containing information such as the number of participants, the proportion of assets responding (to all control signals), the estimated flexibility delivered (in kW/kWh). This is combined with data obtained from the smart metering system, such as the difference between measured load and historical average load in order to provide an estimate of the demand side response effect for reporting and auditing.

It is envisaged that in the case where multiple use cases were being pursued one would take priority over another and determine which event is communicated. In the case of (1) and (2), this can be determined by whichever is cost optimal. Use case (3) would likely take priority irregardless due to likely contractual penalties from not participating in an event.

This use cases can accommodate more traditional active network management scenarios and flexible connections as well as supporting more recent local flexibility tenders from e.g. UKPN and ENW. By supporting both forms of direct control as well as more dynamic market-based approaches to procuring flexibility OpenADR can help DNOs transition to future paradigms for DER control.

The ‘Capacity Bidding’,‘Thermostat Program’, or ‘Fast DR Dispatch’ may be relevant OpenADR programs depending on how the DSO scheme operates.

Summary of experience and evidence from previous studies and deployments

Network and communication issues

Recent DSR studies and demonstrators have been beset by communication issues which are not always fully documented or analysed (except insofar as their contribution to missing data)[6]. These issues appear to stem from both devices connected to home networks as well as proprietary data collection, communication, and control systems. Connectivity issues are usually attributed to a range of factors. These issues are not completely solvable and reflect the general engineering challenge posed by the provision of robust high-bandwidth and low-latency network connections. Any communication and networking solution inevitably involves a trade-off in various different areas but these can and should be optimised for the particular application.

Many DSR systems have relied on 3G/4G mobile data connections for both metering and control, the primary appeal of which is the universal nature of the connectivity offered. However signal strength has often been a problem (or a perceived problem by installers/suppliers/manufacturers at different times) and costs can be prohibitive depending on the application (both for the equipment and service).

[6] "Domestic demand-side response with heat pumps: controls and tariffs ...." 8 Mar. 2018, https://www.tandfonline.com/doi/full/10.1080/09613218.2018.1442775. Accessed 26 Jun. 2018.

Future solutions may be able to utilise long range low power radio networks which are being developed as a cost effective alternative to mobile networks for machine to machine applications. However these technologies are still in their infancy (commercially) and there is a question over how they will compete with new 4G and 5G mobile technology aimed at IoT (so-called 'Cellular IoT') going forward which provides many of the same benefits without having to build a redundant parallel communications infrastructure.

We have observed many issues caused by reliance on existing home wireless LAN (and then home internet) for connectivity. Whilst this solution is the cheapest it is difficult to develop a reliable and robust connectivity solution which will work well for the large range of wireless networking conditions. Many home routers provided by ISPs with a broadband subscription are also unable to support large amounts of devices (although this situation is improving slowly).

This all strongly suggests to us that either a wired network or a separate private wireless network are required for communication. Whilst a wired connection would always perform significantly better than a wireless one, installation of a wired ethernet link often adds too much to installation costs. In our experience it has even doubled installation costs in many cases due to the extra time required. In our experience homeowners also often report dissatisfaction with the installation of additional cabling around the home.

For these reasons we have concluded that we should use a dedicated private wireless network solution, either using a separate private Wifi access point or our own Zigbee HAN and gateway. This will ultimately be combined in a finished HEMS device but can be provided by off the shelf equipment during the demonstrator. This in turn is connected by wired ethernet to the home router. By providing our own wireless network we can have more control over performance and avoid security risks associated with re-using the existing home wireless LAN. Due to the use of ESP SoC-based devices (discussed further below) we can also take advantage of developments such as wifi meshing and bluetooth provisioning (for example using a smartphone app). Some ESP chip variants can also be provided with support for LPWAN networking which could be cost-effective in some local energy scheme contexts.

Interoperability

Significant effort has been expended in local energy trials on making legacy AMI systems and newer analytics systems interface. These barriers need to be reduced through the use of standard defined interfaces between systems. The UK smart metering system promises to greatly reduce some of these barriers and is one of the main reasons we are so keen to exploit it in our proposed demonstrator. Other interoperability issues exist between DER assets and HEMS or DRMS systems, many of which are currently closed systems. We circumvent these issues here by utilising open hardware based DER assets where we can provide our own interface (OpenADR), but we think imposing standards on certain classes of asset (as has been done in California) will be necessary in order to unlock the full potential for domestic DSR.

Metering issues

Metering of electricity use, at least at the level of grid imports, but also potentially per-circuit connected to DER assets, is a current requirement of most if not all demand response schemes. Up to now this has required the installation of additional metering equipment, typically advanced meters which can be used for half-hourly settlement and sometimes additional MIDS class sub-meters on the circuit connected to the DER asset.

Current metering requirements are an obstacle to domestic DSR on cost grounds running into £100s additional per installation (depending on the scheme requirements). An example of a recent local flexibility scheme being proposed by WPD requires half-hourly metering and additional minute by minute metering[7]. Whilst a range of advanced meters provide half-hourly metering, the minute by minute metering would pose various challenges for typical advanced metering systems overcoming which is likely to result in too costly a system for domestic DSR. The only viable way forward would seem to be use of UK SMETS smart meters as they are deployed and become available for half-hourly settlement and integration into other systems, including the availability of real-time data obtained directly from the smart metering HAN using a CAD (for minute by minute metering for example).

Previous trials have also had extensive issues with meter communications[8]. Many advanced meter deployments for local energy schemes have involved the construction of dedicated communications infrastructure (for example Zigbee mesh networks which then did not work[9] or a LoraWAN network with a redundant 3G solution with attendant higher costs[10]) which will be too costly to deploy outside of the context of funded trials. We believe the only real cost efficient solution to this going forward will be the UK smart metering communication infrastructure combined with use of the home internet connection and in a small number of cases a 3G/4G fallback.

Any requirement for additional circuit level sub-metering is also likely to add too much in terms of cost for domestic installations. For certain classes of DER assets (including all those considered here) where the load profiles can be easily dis-aggregated from the overall household demand this should be unnecessary. However, given that there is currently a general expectation that DER assets will be separately metered based on existing commercial schemes some disruption of industry norms may be required to make this work. In the below described system we assume that the data obtained from the UK smart metering system (in conjunction with other telemetry and monitoring data) is sufficient for the purposes of whatever domestic DSR scheme is pursued.

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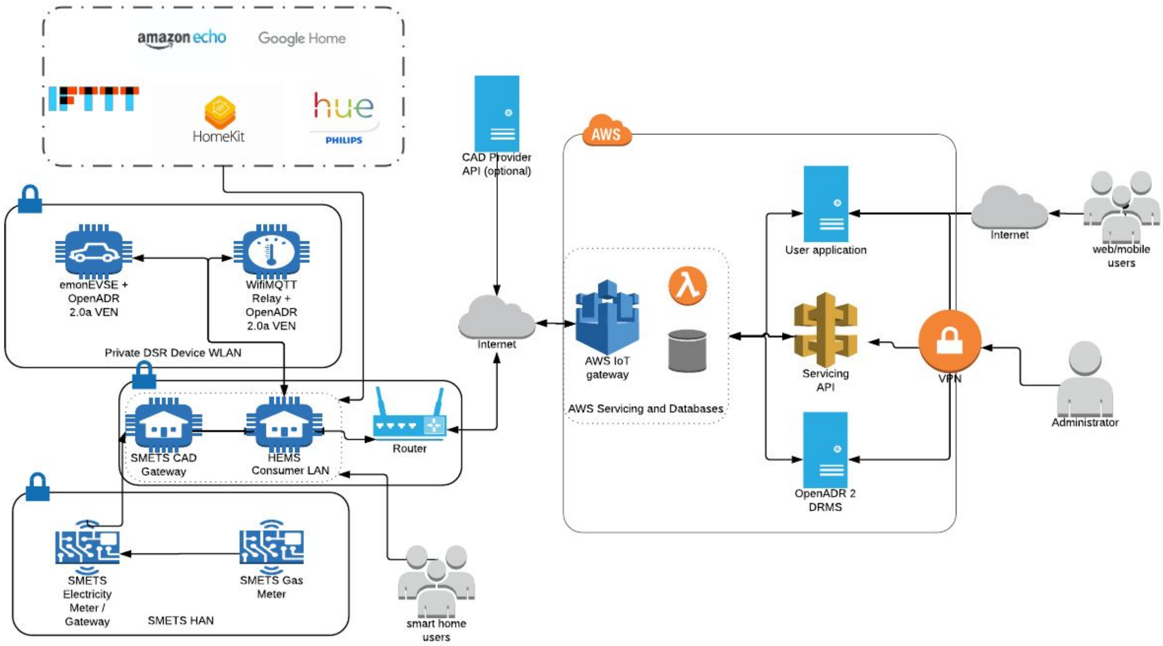
[7] "Services for Winter 2018 and Summer 2019 V2.0 - Flexible Power." http://www.flexiblepower.co.uk/FlexiblePower/media/Documents/Winter-2018-Summer-2019-EOI-Document.pdf. Accessed 26 Jun. 2018.
[8] "Regen | Sunshine Tariff." 30 Aug. 2016, https://www.regensw.co.uk/sunshine-tariff. Accessed 25 Jun. 2018.
[9] "Smart Fintry Innovation Report." 12 Apr. 2018, http://smartfintry.org.uk/wp-content/uploads/2018/04/Smart-Fintry-Innovation-Report-final.pdf. Accessed 26 Jun. 2018.
[10] "Energy Local." 9 Dec. 2014, http://www.energylocal.co.uk/. Accessed 26 Jun. 2018.

Example OpenDSR implementation

In this section we describe an example OpenDSR implementation. In each section we provide an indication of the costs and TRL of each part (and where relevant the work required to increase the TRL). Costs are based on a 100 user demonstrator.

High Level Architecture



System and Network Topology

The choice of topology can have a large impact on other design choices and overall performance. OpenADR is quite flexible in supporting a range of system topologies through the VEN/VTN concepts as well as not requiring that it is implemented throughout the whole system. This system design uses a 'Home Energy Management System' as a hub on premises which acts as an intermediary with the demand response management system (and telemetry and device management services). This is depicted in Figure X. The additional complexity introduced by the addition of the HEMS is offset by several advantages of this approach:

- Interoperation; the HEMS can be used as a software/hardware interfacer to many types of DERs which means they do not need to implement OpenADR themselves (however in the proposed demonstration we aim for the DER assets to be OpenADR 2a compatible for maximum future potential).
- Local control and unified operation; by integrating with a HEMS the DER products can be accessed and controlled using a single interface.

Sub-systems

We outline below the key subsystems. Further technical data is provided in the technical feasibility study.

DER asset - emonEVSE

The EmonEVSE is an existing commercially available EVSE product manufactured and distributed by Megni (trading as OpenEnergyMonitor). It integrates an ESP8266 SoC which is used for communication and providing an on-device API. It is capable of supplying 32A single-phase (7kW) or three-phase (22kW).

In the demonstrator an OpenADR 2 VEN client will be implemented on the device which will communicate with the HEMS (acting as a VTN) to facilitate demand response using the equipment.

DER asset - Immersion heater controller/diverter

The immersion heater controller is a WifiMQTT[11] which uses a 16A relay to switch the load and is supplied by Megni (trading as OpenEnergyMonitor) and manufactured by ProSmart[12]. Similar to the WmonEVSE, this is powered by an ESP8266 SoC and we will implement the same OpenADR 2a client as on the emonEVSE above (with different operating parameters).

The relay will be installed in parallel with any existing manual switch in order to not disrupt the normal/expected operation of the system.

The immersion heater control will be installed in two configurations depending on whether any on-site generation is present:

1. No on-site generation: the WifiMQTT is directly connected to the supply of the immersion heater and controls its operation.
2. On-site generation: the WifiMQTT is installed on the boost relay input of an immersun [13] diverter or similar.

DER asset - Storage heater

The storage heater controllers would be Sonoff Pow TH[14] or other third-party controller which provides a single channel relay switching up to 16A and temperature/humidity sensors. Unlike the above, the storage heater controllers would be directly coordinated by the HEMS over the private wireless network (effectively the HEMS acts as the VEN). The reasons for not implementing an OpenADR client for the storage heater controller are that OpenADR 2 does not incorporate the required control logic for a group of storage heaters which requires the use of a thermal model of the house as well as processing of input from various environmental sensors. This will be implemented in the HEMS instead and then presented to the upstream OpenADR system as a single asset as per the specification. However, this does add development costs and lower the TRL of this part of the system.

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[11] "WiFi MQTT Control Relay Thermostat - Guide | OpenEnergyMonitor." http://guide.openenergymonitor.org/integrations/mqtt-relay/. Accessed 26 Jun. 2018.

[12] "proSmart - Спестете и управлявайте Вашия дом през смартфон!." https://prosmartsystem.com/. Accessed 2 Jul. 2018.

[13] "immerSUN." https://www.immersun.co.uk/. Accessed 2 Jul. 2018.

[14] "Sonoff Pow R2- WiFi Switch for Energy Usage Power Monitoring - Itead." https://www.itead.cc/sonoff-pow-r2.html. Accessed 26 Jun. 2018.

The compatible types of storage heaters are those with manual or thermostatic controls. This is typically not found on newer ‘automatic’ or ‘quantum’ types (which integrate a digital thermostat and do not provide a suitable input). New EU legislation (‘Lot 20’) also requires that storage heaters have these features, typically making them incompatible with the control scheme here. This may make finding enough trial participants difficult depending on the population of storage heaters available and will reduce the number of compatible heaters going forward.

Smart metering HAN and Consumer Access Device

To gain access to smart metering data at high resolution for metering/auditing purposes we propose to use a third-party consumer access device (CAD) of which there are currently several available which advertise compatibility with a range of SMETS-based metering systems. In any future commercial product these functions will be combined in a single HEMS device. These products require the use of their own APIs to access the smart metering data and a software agent would be run on the HEMS to integrate this with the rest of the system. In any future commercial implementation this data would be obtained directly locally from the smart meter HAN.

There is some question currently over the ability/capacity/willingness of suppliers to support the required pairing procedure for CADs[15]. Consumers attempting to independently go through this procedure have had mixed results[16] and there seems to be a low level of awareness amongst suppliers and consumers about CADs as well as the supplier license obligations around supporting them. Hopefully this situation will improve rapidly over the next years of the rollout. It is likely that during the demonstrator a partnership will need to be established with one or more suppliers/device manufacturers to facilitate this activity. This will contribute valuable evidence on consumer/supplier interaction with CADs which will support the ongoing rollout.

There is some precedent for the creation of an open source CAD from California (where Zigbee SEP based smart meters have been used for sometime)[17]. Whilst this would be one of our ultimate goals, it will not be feasible on the time scale of the demonstrator project and we will opt to use a commercially available solution such as the Hildebrand Glow[18] or Prescience Mira[19].

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[15] "BEAMA CAD guide." 8 May. 2018, http://www.beama.org.uk/asset/32BD967E-9475-4362-83B553251A84C1F4/. Accessed 1 Jul. 2018.
[16] "Can I connect a CAD to my smart meters if OVO open the Home Area ...." 15 Dec. 2017, https://forum.ovoenergy.com/smart-meter-compatibility-67/can-i-connect-a-cad-to-my-smart-meters-if-ovo-open-the-home-area-network-han-1102. Accessed 28 Jun. 2018.
[17] "Design of an Open Smart Energy Gateway for Smart Meter Data ...." https://drrc.lbl.gov/sites/default/files/lbnl_-_182358_design_of_an_open_smart_energy_gateway_for_smart_meter_data_management_final.pdf. Accessed 28 Jun. 2018.
[18] "Glow hub (wired CAD) - Hildebrand." http://www.hildebrand.co.uk/our-products/hub/. Accessed 28 Jun. 2018.
[19] "Presciense: Shaping a Smarter World." https://presciense.com/. Accessed 28 Jun. 2018.

Home Energy Management System

In this example system the Home Energy Management System is provided by an inexpensive single board computer (SBC) running HASS.io. HASS.io[20] is a specialized Linux operating system providing a HEMS application which can be easily extended and integrated with other products. HASS.io adds Home Assistant (an open source Smart Home and Home Energy Management application) to resin.io[21] (an open source Linux OS for IoT), which integrates a range of device and software management features which simplify the process of firmware and software lifecycle management using technology such as Docker. This will support rapid iteration and continuous deployment on the HEMS and mitigate issues presented by having to manage a large fleet of devices.

Home Assistant also supports a wide range of integrations with existing smart home products such as Philips Hue Lights and Nest Smart Thermostat as well as popular services like Amazon Alexa[22]. This integration is important in communicating the value of the system to consumers.

Additional functionality of the HEMS will include optimisation of self-consumption where micro-generation exists on premises.

A prototype of such a HEMS device already exists based on work for another project (Nobel Grid) as well as the open hardware emonPi (developed by Megni/Open Energy Monitor project).

In the demonstrator a third-party Consumer Access Device (CAD) will be used to integrate with the smart metering data and provide this data to the HEMS and the backend. A final commercial product would integrate the functionality of the HEMS and CAD in a single device.

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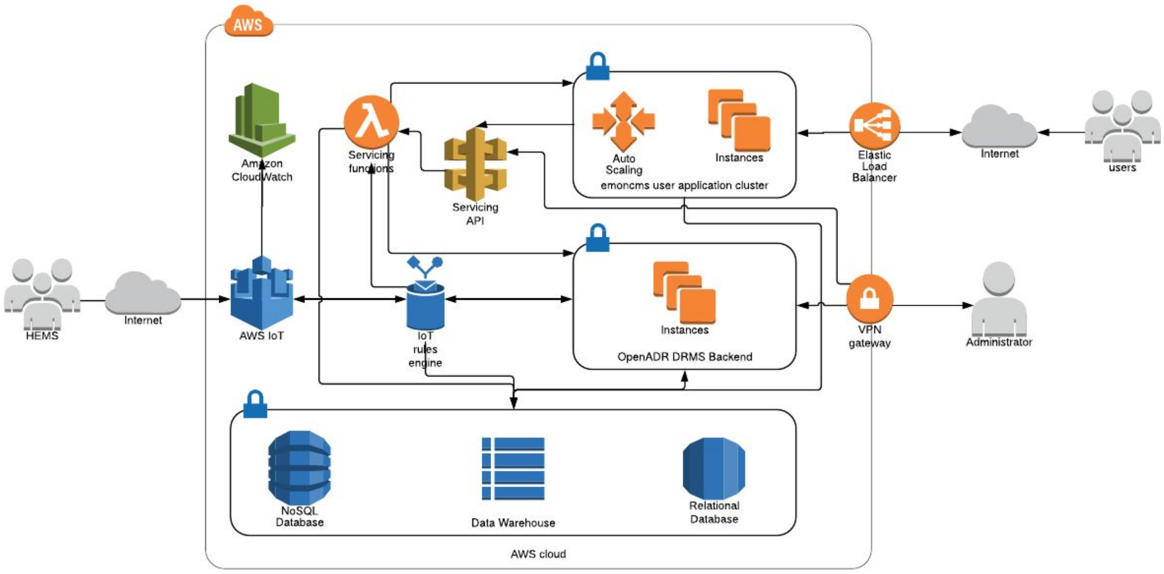
[20] "Home-Assistant.io." http://hass.io/. Accessed 2 Jul. 2018.
[21] "Resin.io." https://resin.io/. Accessed 2 Jul. 2018.
[22] "Components - Home Assistant." https://www.home-assistant.io/components/. Accessed 2 Jul. 2018.

Use of AWS



The AWS IaaS service is used for a range of functionality to reduce operational and development costs and accelerate deployment. The envisioned use of AWS for OpenDSR is depicted in Figure X. This includes:

- Device monitoring and management with AWS IoT. AWS IoT simplifies the device management workflow from provisioning through to monitoring. A software agent (based on reference implementation provided by AWS) on the HEMS implements the required middleware. This service also will integrate with HASS.io functionality such as network control and over the air update mechanisms. The HASS.io state will be mapped directly to the AWS IoT Device Shadow.
- Message transport and brokering: OpenADR message payloads from DER assets are proxied over AWS IoT MQTT. The semantics of the OpenADR XMPP PUSH transport can be mapped directly to those used in AWS IoT MQTT with some small modification. XMPP is in reality never used as the DRMS system connects directly to AWS IoT, however DER assets communicate with the HEMS using OpenADR 2a HTTPS over the local network ensuring wider compatibility. The DRMS is also capable of providing HTTPS/XMPP interfaces and implements HTTPS for administrative clients. This greatly reduces the time and cost of deploying a scalable solution for connected devices.[23]
- Stream processing: AWS IoT Rules Engine facilitates rule based processing of messages arriving at the broker. This greatly simplifies and reduces the costs of many common data processing tasks (e.g. filtering of messages based on type and re-formatting for storage).

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[23] "Samsung Selects AWS IoT for Cloud Print with Help from ClearScale ...." 30 Jun. 2017, https://aws.amazon.com/blogs/iot/samsung-selects-aws-iot-for-cloud-print-with-help-from-clearscale/. Accessed 26 Jun. 2018.

- A rigorous and well documented 'shared security' model, where the platform provides an extensive suite of services and tools to support encryption, authentication, authorisation, monitoring, audit (some at no extra cost) but relying on the system architects to deploy these effectively. This significantly reduces the cost and time associated with auditing and compliance whilst ensuring the system can adapt quickly to new requirements.
- Authorisation: application level authorisation (in addition to transport level authentication provided by mutual TLS) can be enforced at the broker or through AWS IAM policy.
- Audit and compliance: AWS platform provides a wide range of tools for audit and compliance built in to the platform.

The primary benefits of AWS are reducing initial development and capital costs and time to market. AWS also implements a rigorous 'shared security' model which promotes the principle of least privilege and security by design philosophies we have committed too.

A schedule of indicative costs is provided below for a year long demonstrator involving 100 devices based on an existing demonstrator for 200 devices on AWS.
Additional phase 2 costs:

Data Warehouse

Telemetry and logging data will be stored in a real time database on AWS to support monitoring, operations, billing, and compliance. Any user data will be further pseudo-anonymised using a second identifier. Only data required for the operation of the system in stored (pursuant to principle of data minimisation).

Detailed energy usage data will be stored separately in the user application database at an optional level of resolution set by the user.

All data will be encrypted at rest (using platform provided master keys stored in a key management system) and in transit using TLS.

DRMS

The Demand Response Management System (DRMS) which interacts with DER assets via the HEMS is an open source OpenADR-compliant VTN produced by EPRI[24].

This product will be further developed for the purpose of the demonstrator to alter its branding and add new functionality, such as the MQTT transport bridge. Any changes which are deemed useful for the original software will be submitted as pull requests upstream. The forked code will be open sourced. Indicative costs for these developments are provided below.

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[24] "GitHub - epri-dev/OpenADR-Virtual-Top-Node: This application is an ...." https://github.com/epri-dev/OpenADR-Virtual-Top-Node. Accessed 28 Jun. 2018.

User Application

For the user application we will use a modified version of emoncms[25], an open source environmental and energy data processing, visualisation, and storage system. Megni oversee this project and Carbon Co-op also have extensive experience with the software and have contributed widely to its development. The software has a modular structure and we would likely develop a new module to support interaction with the DRMS and wider system as well as modifying several existing modules (groups, devices) to support the operation of the system. All changes will be contributed back to the open source community.

Servicing API

It is likely that there will be additional business logic required in the system which will not be provided (or will be difficult to add) to the user application or the DRMS. An example might be the provision of an API which can respond to DR requests from a DSO system (as has been proposed in the recent WPD EOI on local flexibility). Where required we will provide this using a serverless appliance running on AWS which provides a servicing API through an API gateway. This greatly enhances the extensibility, modularity, and flexibility of the system whilst reducing the time needed to iterate and deploy additional features which is a normal but often overlooked occurrence during implementation.

Data privacy and cybersecurity

Data privacy and cybersecurity are key concerns in domestic demand side systems. As with any IoT system an attacker has the potential to gain access to user data as well as access to private networks, but in the case of DSR systems there is also the potential for disrupting the operation or even damaging expensive assets. Where a large enough number of assets are under control in a specific area there is even the potential for disruption of the electricity grid.

Our data privacy approach is rooted in the new data protection regulations (DPR) introduced by the EU GDPR and the UK implementing legislation the Data Protection Act 2018. In particular, anonymization and encryption of personal information and energy monitoring data (which can itself constitute personal information under the new regulations). We also have extended compliance monitoring to all parts of the system supported by AWS tools.

Our approach to cyber security is a layered security model where we utilise multiple layers of encryption, authorisation, and authentication. For example, the DRMS (through which DSR events are scheduled) is protected by multiple layers of encryption: TLS for transport and encryption at rest using platform keys; multiple layers of authentication: VPN admin network, user authentication provide by AWS Cognito with two factor authentication; multiple layers of authorisation: in-app role-based authorisation, AWS Cognito.

In addition we also take advantage of the extensive audit and compliance capabilities built-in to AWS and will use these to do real-time monitoring for unusual/suspicious access patterns.

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[25] "Emoncms." https://emoncms.org/. Accessed 28 Jun. 2018.

We also aim to follow the software design principles of 'least privilege' and 'security by design' (as required under the new DPR) in architecting the system and have already pursued these in our development of new features for emoncms.

How OpenDSR improves energy system performance

Cost

Savings from time of use optimisation/price arbitrage
With the introduction of dynamic time-of-use tariffs enabled by the smart meter rollout there is an opportunity for customers and their DER assets to save money by responding to changes in price. This can be facilitated by an aggregator system like OpenDSR by producing an optimal schedule for operation of DER assets to minimise costs for customers (and taking into account other costs/benefits from other services and loss of utility etc). Peak pricing differentials on these tariffs is often in the region of 20p-30p and over the course of the year and with sufficient amounts of flexibility behind the meter there is the potential for a customer to avoid using electricity in these time periods with savings of £50 - £100 (in the case of high electricity users). On a wider system level the ability of customers to respond dynamically to changes in market price has the potential to improve market efficiency and reduce costs for all consumers.

Reduction in distribution costs
DNOs are beginning to procure local flexibility services, including potentially from domestic customers. These have the potential to generate income for customers with flexibility as well as saving money through e.g. deferring the need for more costly reinforcement, potentially saving all distribution customers money. OpenDSR supports all current proposed local flexibility use cases.

Savings from demand charge reduction
The targeted charging review has proposed the introduction of demand charges as part of electricity tariffs. By being more cost-reflective these can help to reduce costs for all network customers. The OpenDSR system can help high demand users optimise their usage to reduce these costs.

Impact on wholesale and other market prices
It can be argued that the eventual inclusion of demand side response in the wholesale, balancing, and other markets will help to lower market prices by providing increased competition to generators and other participants. OpenDSR can be used to aggregate demand and flexibility for these markets.

Energy Efficiency

Optimal control of appliances
In the case of certain electric heating systems, the addition of a home energy management system, as provided in OpenDSR, can improve the operation of the heating system to provide better thermal comfort (as well as potentially generating income/saving money).

Indirect impacts on home energy use
User engagement with demand side response can be argued to entail an increased awareness of other electricity usage in the home. In a similar way that installation of solar PV can promote energy efficiency, users may seek to reduce energy use at specific times to support DSR events. OpenDSR can help facilitate this activity by providing prompt notifications to users about events as well as historical summary about energy use and DSR performance.

Carbon Savings

Increase in renewable penetration
The deployment of demand side response at a system level supports a higher penetration of renewables in various ways. In areas of constraints both demand and capacity can be managed dynamically to allow more renewable generators to connect. At a higher level, DSR can help prevent curtailment of large wind farms by incentivising demand turn-up in the market. OpenDSR supports both these use cases.

Supporting electrification of transport
By enabling EV owners to make money from smart charging this adds to the value proposition of EV ownership as well as helping to reduce the need and cost of infrastructure upgrades. We hope to demonstrate this using OpenDSR.

Supporting electrification of heat
Smart control of heat pumps maybe crucial in convincing consumers to switch from gas central heating systems. This is not part of our demonstrator but the comprehensive standard behind OpenDSR and its extensible nature will make it easy to add this at a later stage.

Supporting battery storage deployment
Batteries are the best (and most expensive) form of flexibility. Enabling consumers to make money from allowing their batteries to be used for demand side response contributes to changing the economics of battery storage installation and increasing the rate of adoption. Batteries have not been proposed as part of our demonstrator but, similar to heat pumps, would be easy to add at a later stage.

Table 1 – Performance information

Performance parameters for the proposed Phase 2 DSR demonstration system *(Please complete for all the performance parameters which are relevant for your demand response system.)*	**Expected performance of the proposed demand-side response demonstration system – assuming the proposed system is successfully developed & deployed.**

Peak power to be controlled (kW)	Electric Vehicle Charger 7kW (single-phase) / 21kW (three-phase) Immersion Heater <3.2kW (diverter+relay) / <3.68kW (non-diverter relay-only) For the diverter version there is also the possibility of slaving up to 2 additional diverters for larger amounts of power although the market for this is quite limited (it may be more appropriate for SME/agricultural customers). Storage Heater <3.68kW (Control relays are rated 16A – depends on max power of storage heater). We assume in the below that the storage heater has a max power of 2.5kW.
Range of power that can be controlled (kW) (If the power is controlled in discrete levels, please provide details too)	Electric Vehicle Charger 1.38kW – 7.36kW (in increments of ~0.23kW). Immersion Heater Max power of immersion heater or Off. Storage Heater Max power of storage heater or Off. For example, in the case of a 2.5kW heater it would be 0 or 2.5kW (assuming the charging control has been manually set to the maximum).
Duration of demand control: for what period of time can the demand be controlled. Please provide a full description – for example, if different durations are possible for different levels of power.	Electric Vehicle Charging Assuming car is fully charged every night, efficiency is 25 kWh/100 miles (based on Nissan LEAF), and average daily mileage is 25 miles this means that there will be 10kWh drawdown. Therefore car will charge fully in approximately 1.5 hours. To determine a demand turn-down figure we assume that the car must charge to 100% within a 12 hour *Demand turn-up* 1.5 hours @ 7kW 7 hours @ 1.38 kW *Demand turn-down* 10.5 hours @ 7kW 5 hours @ 1.38kW Immersion Heater ~10kWh is required to take a 180 l of water in a tank from 20C to 60C. We assume the tank is well mixed and 75% of this capacity is available (to account for any drawdown/losses in this time) . This means the tank can be ‘charged’ in ~2 hours (maybe longer depending on losses). For demand turn-down

	we assume 'charging' has been optimised so sufficient heat stored is available during peak usage hours (through pre-charging or otherwise). *Demand turn-up* 2 hours *Demand turn-down* 10 hours This is consistent with results from more sophisticated thermal demand models[26]. <u>Storage Heater</u> *Demand turn-up* 2 hours *Demand turn-down* 2 hours
Please describe the total energy (in kWh) which could typically be controlled: **a) each day;** **b) each week; and** **c) each year.**	Based on above numbers and additional assumptions stated below. <u>Electric Vehicle Charging</u> (a) 10 kWh (b) 60 kWh (c) 2900 kWh Assume 1 day of week not available. Assume 75 days per year not available. <u>Immersion Heater</u> (a) 7.5 kWh (b) 45 kWh (c) 2175 kWh Assume 1 day of week not available. Assume 75 days per year not available. <u>Storage Heater</u> (a) 12kWh (b) 72 kWh (c) 1440 kWh Assume 1 day of week not available. Assume 120 days of operation per year.

[26] "Unlocking the demand response potential from domestic hot water tanks." https://www.reading.ac.uk/web/files/tsbe/Saker_TSBE_Conference_Paper_2013.pdf.

Please describe how the demand will be controlled (e.g. is it fully dispatchable or does it respond to pre-agreed thresholds or at set times).	Electric Vehicle Charging ● Not fully dispatchable. ● The EV must be at base and connected to the charger. ● It is envisioned that the EV will not be dispatchable if the EV battery is below a certain threshold (e.g. 30% for demand turn-down) or full (in the case of demand turn-up). Immersion Heater ● Not fully dispatchable. ● The availability of the immersion heater for DSR is dependent on the available thermal capacity in the water tank. With sufficient notice the tank could be preheated to ensure there is sufficient hot water which may be drawn down during any demand turn-down event or, conversely, the charging of the tank could be deferred so that it falls within a demand turn-up event. Storage Heater ● Not fully dispatchable. For reasons discussed above, the storage heater is only available for DSR where it is 'charging' (demand turn-down) or has available thermal capacity for that day which can be utilised without causing discomfort (demand turn-up). ● The amount of flex available is dependent on a number of factors, primarily the thermal comfort of householders, which is sensitive to the operation of the storage heater. Given a large enough population of storage heaters under control it should become possible to predict an amount of effective dispatchable power at a given time. ● This makes the performance and value proposition of storage heater more complex compared to electric vehicles/immersion heaters.
Response time (time taken to respond to control signal)	Due to the communication overheads incurred between the multiple services/devices (DNO/SO <-> aggregator, aggregator <-> HEMS, HEMS <-> DSR assets) and any requirement for manual intervention the response times can vary depending on the use case. Home internet connection latencies are typically 30ms or lower and will not be the main limiting factor. In our experience <10s is consistently achievable in an automated system using similar topologies and software stacks. In other scenarios the latencies could be lower e.g. if the system is used directly by a DNO in an active network management scenario the latencies could be much lower (<2s) as the DSR event does not have to be negotiated between the parties first and the signal from the DNO could be received over a signaling network.

Power consumption (specify the peak and average power required to operate the proposed DSR system) (kW)	The self-consumption of power by DER asset controllers and the CAD/HEMS is limited. For 10,000 devices average power consumption (indicative): ● Utility/SO server – 1000W ● Aggregator servers – 1000W ● HEMS – 10W x 10,000 = 100,000W ● Storage Heater Controls – 5W x 5,000 = 25,000W ● EV Charging Control (OpenEVSE) – 20W x 5,000 = 100,000W So peak power consumption ~0.025kW.
Scaling: can the power and capacity of the proposed DSR system be increased? Describe how the system can be scaled if relevant.	Scaled easily by adding more providers with DSR assets (many per household) and HEMS (one per household). Backend service designed to scale to ~10,000 HEMS initially.
Geographical or proximity constraints?	Electric Vehicle Charging The EV charging point typically would be mounted on an exterior wall of a property or inside a garage and then be connected to the main consumer board on a separate circuit. For cost reasons the length of this cable run can be quite limited. Immersion Heater The controller (and diverter if relevant) needs to be installed on the heating circuit between the distribution board and immersion heater. Storage Heater Relay controllers will need to be located between the storage heater and consumer board, preferably next to the storage heater so their intended purpose is clear. The wireless thermostat can be located anywhere inside home. Signal issues can be mitigated using mesh repeaters.
Infrastructure requirements? (e.g. does the DSR system have to be in a climate-controlled environment?)	N/A

Size & weight of system (for a specified level of controlled demand)?	<u>Electric Vehicle Charger</u> Dimensions = 300mm x 230mm x 100 mm Weight = 3kg <u>Immersion Heater</u> *Controller* 87mm x 50mm 0.162kg *Diverter* 235mm x 152mm x 72mm 2kg <u>Storage Heater</u> 80mm x 87mm x 50mm 0.162kg <u>HEMS/CAD</u> 90mm x 95mm x 30mm 0.12kg
Environmental impact?	No direct emissions. Indirect emissions from manufacture, supply, distribution, installation, and 'end of life' of the hardware. No harmful radiation. No toxic materials above regulated levels. All components suitable for disposal in normal waste or e-waste streams.
Cyber security risks and proposed mitigations against these cyber security risks?	The main risks are the ● Loss of user data: This could happen either by gaining privileged access to the DSR controllers, the HEMS, the user application, or the aggregator server. ● An attacker takes control of the operation of demand response assets or disrupts their operation. This would require control of the DRMS and other subsystems. In our threat modelling attackers in each case may be motivated by different goals and pursue different strategies (e.g. brute force attacks versus social engineering) to achieve their goals and our mitigations try to reflect this. Our response to this is a security model which can be described as a layered model, with multiple enclosing layers of authentication, authorisation, and encryption ensuring that the data and control of DSR assets is protected. We outline some of the primary

	mitigations below: ● User data stored on remote servers is pseudo-anonymised and encrypted at rest with the encryption keys stored in a key management system. ● We will use IaaS (e.g. AWS) which promotes security best practices and can be systematically and continuously monitored and audited. ● Authorisation and authentication across all services is provided by a single identity provider (AWS Incognito). ● Access to web services is over HTTPS. For the DRMS, access is by virtual private network only and is not internet accessible. ● HEMS will be provisioned with unique TLS X509 certificates during commissioning and installation which can also be revoked later (for example if it is suspected the DSR system in a particular property has been compromised or is breaching conditions). ● The network connecting the DSR assets to the HEMS uses a private wireless LAN. The wireless LAN is secured by WPA2. DSR controller applications connect to the HEMS application using mutual TLS authentication using X509 certificates which are provisioned during installation. ● Both DSR controllers and the HEMS can be updated remotely over the air.

Table 2 – System costs and cycle life

Cost element *(Please complete for all the performance parameters which are relevant for your proposed DSR solution.)*	**Expected cost of the proposed demand-side response system – assuming the proposed system is successfully developed & deployed**	**Notes - please provide a brief explanation of the status of this cost data, e.g. known price for off-the-shelf equipment; initial estimate based on estimates of man-days (more detailed evidence can be provided in an Annex or in supporting documents if necessary).**
<u>Capex</u> (including all major components, balance of plant, associated structures/enclosures, IT / software)		
Capital costs (in £/kW of controllable demand)	<u>EV Charging</u> 111.43 <u>Immersion Heater</u> 72.01 <u>Storage Heater</u> 103.75	Based on actual supplied costs and specification as detailed in technical description of system. kW controllable detailed above. Spreadsheet used for these calculations is included with this report.

Capital costs (in £/kWh of controllable)	EV Charging 0.24 Immersion Heater 0.11 Storage Heater 0.26	Based on estimate of annual kWh controllable detailed above.
Other capital costs – (in £ - please list items in Notes column)		
Opex & Maintenance Costs		
Annual operating costs (in £/kW of controllable demand)	EV Charging 6.43 Immersion Heater 12.24 Storage Heater 11.26	Based on estimates of operating costs for 10,000 installations extrapolated from real costs for 100 installation system. Includes staffing, IT, and overheads.
Annual operating costs (in £/kWh of controllable demand)	EV Charging 0.01 Immersion Heater 0.02 Storage Heater 0.03	Based on estimate of annual kWh controllable detailed above.
Other annual operating costs (in £ - please list items in Notes column)		
Annual maintenance costs – (please specific items in Notes column)	EV Charging 59850.00 Immersion Heater 13500.00 Storage Heater 27000.00	Taken as 1% of capex. This is assumed to cover maintenance and replacement of equipment. It should be subsumed into above operating costs.
Cycle Life		

Typical operating life (in cycles – please outline typical operating pattern in Notes to secure this cycle life)	10 years/3000 cycles	Relays are main point of failure correlated with cycling for all DER assets considered and are their rating for this is used as the basis of the figure here.

5. Innovation and Technology Readiness

In this section we outline the key innovative approaches, describe the current state of the art, and compared the proposed solution to existing DSR solutions.

Innovative Approaches

Our approach is characterised by several innovative approaches to the establishment of a market-ready domestic DSR system:

- Use of an open royalty-free standard for defining the interface between DER assets and control systems: this helps to create a market for domestic DSR by promoting a common standard for interoperability between DER assets and control systems as well as reducing the time to market by incorporating an existing mature data model and control flow for DSR. The adoption of DSR standards by California utilities has accelerated the provision of domestic DSR there. Many schemes which have been proposed to date have used proprietary non-standard technology at many levels in the system whether it be control hardware, firmware, middleware, or client software. This inevitably leads to higher-costs for end-users from vendor lock-in, duplication of functionality, lower quality implementations, and planned or unplanned obsolescence of technology (such as when legacy systems are shutdown).
- This is also important in meeting higher standards of security which may be expected from systems which control DSR assets. Demonstrated compliance with standards helps consumers have confidence in the integrity of a given system and reduces the development time and costs required for a verifiably secure system. Standardisation can also help to create product synthesis, which boosts the value and desirability of a system to consumers.
- Use of a mixture of existing open-source implementations and off-the-shelf components: many of the components required for a domestic DSR system already exist and can be easily and quickly assembled using cloud computing/IaaS services.
- Use of SMETS CAD: Adding demand response capability onto a CAD drives cost reduction and creates a HEMS solution based on convergence of technologies and standards. Use of the SMETS meters avoids the need for installation of expensive additional metering equipment which is typical in many smart energy trials and ultimately undermines the scalability and commercial viability of such schemes.
- Use of cloud computing / IaaS services to drive down operating and start-up costs: recent developments in IaaS services for IoT, data storage, analytics, and identity

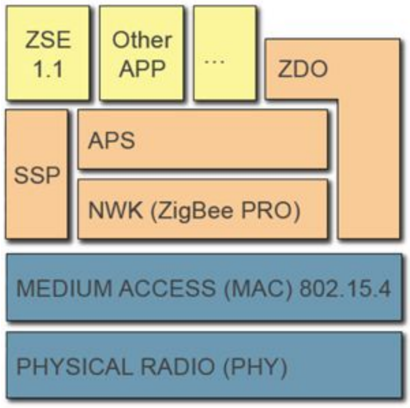
and access management support rapid and low-cost deployment of scalable systems supporting large numbers of DER assets. This has the potential to dramatically reduce costs and time to market. Many existing solutions prioritise or require the use of unproven and expensive middleware whose functionality could be provided by combining existing services offered by cloud providers at lower or no cost.

- Synthesis with a community-led business model which supports the development of local flexibility markets. Existing alternative domestic DSR solutions

Existing technical alternatives to OpenADR

We have restricted our consideration here to open standards which describe demand side response data models and exchange. There is a larger number of proprietary implementations which provide a subset or superset of the functionality desired by OpenDSR.

Zigbee Smart Energy 1.x



Zigbee Smart Energy 1.x, which is the standard used at the core of the UK smart metering system, provides for limited control of DER assets where these have integrated a Zigbee Smart Energy module and implemented a suitable application profile. The main difference with OpenADR is that it is more low-level in terms of providing a definition of the hardware and communication/networking and would likely require additional development to support specific applications which may be included ‘out-the-box’ by OpenADR (which exists only within the application layer). It also does not specify the operation of a control plane or topology for the wider system. Some work has been undertaken to harmonise Zigbee SE operation with OpenADR (the use of at least one of these is mandated by the California Energy Commission in the 2016 Building Energy Efficiency Standards[27] for demand response with HVAC and lighting systems). The use of one would also not preclude the use of the other. For example, Zigbee SE could be used for device control between the DER asset and a HEMS and then OpenADR could be deployed between the HEMS and the DRMS system (and a third different interface could then exist between the aggregator DRMS and a market or DSO system).

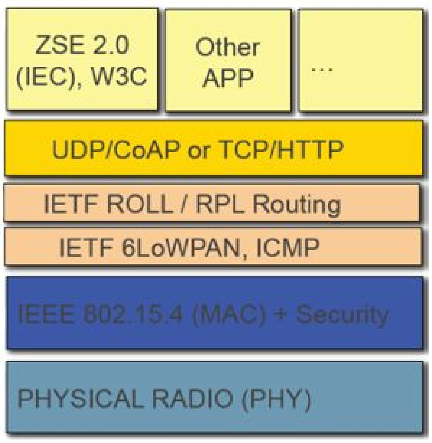
[27] "2016 Building Energy Efficiency Standards - California Energy ...." http://www.energy.ca.gov/title24/2016standards/. Accessed 1 Jul. 2018.

The primary advantage of using Zigbee SE 1.x would be technological synthesis with the UK smart metering system, however in practice it would be unlikely it could use exactly the same hardware/software stacks for both functions as a separate HAN (and attendant hardware) would be required, limiting the benefit of using the same underlying technology. For Zigbee 1.x there are additional benefits in terms of security (compared to OpenADR and internet-connected systems in general) as deployments are normally segregated from the internet and only support a limited set of commands and restricted data formats as inputs (making arbitrary code execution more difficult) as well as having the potential for multiple layers of encryption and authentication which can exceed those found in TCP/IP based devices (although these are not always used). However, where security issues are identified (and this has happened already with Zigbee based hardware[28]) the more inflexible hardware/firmware basis of Zigbee devices can make them harder to fix (although being software based and internet-connected is no guarantee of good software lifecycle management either as the large number of reported IoT security issues have shown).

SMETS HAN Connected Auxiliary Load Controller (HCALCS)

Within SMETS (which builds on Zigbee Smart Energy 1.x) standards[29] there is a concept of a 'HAN Connected Auxiliary Load Controller'[30] which would be a device within the SMETS Zigbee HAN containing the smart meters which can control the operation of DER for demand side response. It is not clear to what extent such a device could be also controlled by an aggregator via a Consumer Access Device paired into the same HAN or if this is even desirable. OpenADR 2a has largely the same functionality.

Zigbee Smart Energy 2



Zigbee Smart Energy 2 (based on Zigbee 2) contains more support than 1.x for demand side response. However, Zigbee 2 hardware is quite different to Zigbee 1.x in that it implements the application layer on top of an Internet Protocol v6 (IPv6) stack. Only the lowest network

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[28] "Researchers exploit ZigBee security flaws that compromise security of ...." 11 Aug. 2015, https://www.csoonline.com/article/2969402/microsoft-subnet/researchers-exploit-zigbee-security-flaws-that-compromise-security-of-smart-homes.html. Accessed 25 Jun. 2018.

[29] "The Smart Energy Code - SEC." https://smartenergycodecompany.co.uk/the-smart-energy-code-2/. Accessed 25 Jun. 2018.

[30] "Smart meters and demand side response - GOV.UK." 22 Dec. 2016, https://www.gov.uk/government/publications/smart-meters-and-demand-side-response. Accessed 1 Jul. 2018.

layers of the stack are the same as those found in Zigbee Smart Energy 1.x. As such Zigbee 1.x hardware is generally not compatible with Zigbee 2 (and vice versa) and typically requires separate hardware. It is more feasible for a device to implement Zigbee 2 alongside the Thread (used by Nest Smart Thermostats) and 6LowPan due to more overlap in the protocols. The ability to support a number of newer developing standards could be seen as an advantage.

Apart from utilising Zigbee SE 2, OpenADR could use a Zigbee 2-based network for transport as it is IP-based. The benefits of utilising it instead of another conventional IP-based solution are more marginal when weighing them against the additional costs of development for Zigbee. However, there would be some benefit in developing a device using both Zigbee SE 1.x (for SMETS meter interaction) and Zigbee 1.x/2 (for transport) due to efficiencies and overlap in development required and this is something we may explore in future.

Current and expected TRL

The proposed system is a mixture of off-the-shelf components and new components which need to be developed albeit primarily for the purpose of integrating existing components. The control hardware for EV charging and immersion heating control already exist as commercially available products but their firmware needs to be adapted to incorporate an OpenADR client. The requirements of this are well understood.

A much larger amount of development work is anticipated for incorporating storage heaters (on both the controllers and in the HEMS software agent) and for this reason we are minded to suggest excluding this from the demonstrator and focussing on EV chargers and immersion heaters.

The CAD and HEMS will be based on existing products (depending on procurement) and maybe even can be combined in the same device. The software that would need to be developed for the CAD/HEMS is an OpenADR VTN/VEN client and a device management software agent, although in both cases these already exist in some form (in the first case there are several existing tested open source implementations and in the second the functionality is largely implemented in the AWS IoT Software Development Kit and accompanying examples).

An existing open source demand response management system (DRMS) will be used requiring only some limited development to rebase the code against more recent software dependencies and to integrate it with AWS (primarily to enable it to use the MQTT broker provided by AWS IoT as a transport mechanism).

For the user application we will focus on the development of an existing platform called emoncms created by the partners. This is primarily a web-based application although also has several Android/iOS clients developed separately. We will focus on providing a web/email/text message-based user interface as this has been identified as the most important in user requirements testing. However, due to the way the user application software is constructed an API will also be created which can be used for any future mobile application.

AWS IaaS services will be used to integrate the different software components, providing data warehousing, identity and access management, a message bus and data processing pipeline, a servicing API, and auditing and compliance capabilities.

Generally speaking, at the conclusion of the demonstrator we anticipate most parts of the system will be either ready for inclusion in a commercial product/service or will only need limited further development. The exception would be the storage heater controller software/hardware which we believe would require a further testing and piloting, however we have chosen to exclude this here and therefore have assessed the expected TRL of the demonstrated system to be **TRL 7**.

The current and expected TRL for each sub-system is summarised in the below table.

Subsystem	Current TRL	Expected TRL
emonEVSE	6	8
immersion	6	8
storage heater	3	6
CAD	7	8
HEMS	5	7
AWS integration	5	7
Data Warehouse	7	8
DRMS	7	8
User Application	7	8
Servicing API	4	7
Whole System	*5*	*7*

6. Market Potential and Exploitation Plans

Market research

Our market research looked at two distinct user groups: Carbon Co-op and other Community Energy group members (generally owner occupier householders living in Greater Manchester) who have or are considering obtaining an electric vehicle and social housing tenants living in Bara and Orkney who have storage/immersion heaters.

Using online and postcard surveys, one-to-one interviews, door knocking and focus groups, the feasibility study examined consumer attitudes within these groups to the installation and adoption of the respective DSR technologies.

Our key findings were:

- Social housing tenants are wary of such interventions and require assurances around financial benefits, disruption and other potential risks
- Community Energy group members are very positive about the potential for EV smart charging and DSR, identifying themselves the financial and environmental benefits of such an approach

An area to highlight is the great enthusiasm identified within Community Energy group and Carbon Co-op members for participation within a Smart EV charger DSR service. In particular, a number of innovative business delivery models were suggested in focus group discussions, including mechanisms for income sharing and incentive redistribution. This echoes existing research suggesting consumers can be mobilised in innovative environmental projects via collective action with face-to-face and online feedback.

For more detail see in depth write ups in the appropriate Appendix.

Potential UK market size and job creation potential

We present here a cursory analysis of the potential market for OpenDSR.

Overall market size

By 2025 the National Grid 'Community Energy' Future Energy Scenario predicts a 0.83GW reduction in peak load due to domestic DSR, rising to 1.5GW in 2030[31]. For balancing this would be valued at around £60 m per year (using prices from the current balancing market[32]) in 2025, rising to £110m in 2030. The full market value of this DSR would be potentially much higher in future energy markets (although we should also expect a large penetration of DSR to suppress the prices in wholesale, balancing, and other markets). For example, the recent capacity market auction cleared at £6,000/MW with only a very small proportion taken by DSR. This potential is more than sufficient going forward to support a wide range of DSR activity.

Aggregator energy services

We anticipate aggregation to be a low margin business activity (similar to electricity supply) which will rely on stacking value from multiple revenue streams and synthesis with other business activities (such as energy efficiency and energy services). We believe (based on business modelling and market research) that the level of DSR revenue at which aggregators will become viable is when a typical home receives an average of £100 from

[31] "Future Energy Scenarios: Home | National Grid." http://fes.nationalgrid.com/. Accessed 3 Aug. 2018.

[32] "System Sell & System Buy Prices - BMRS - BM Reports." https://test.bmreports.com/bmrs/?q=balancing/systemsellbuyprices/historic. Accessed 3 Aug. 2018.

DSR activity, which should be possible from a combination of different forms of DSR (time of use, EV charging, electric heating control, and batteries).

We assume an aggregator would initially take a 30%-40% share of any revenue generated through DSR activity (with this amount reducing over time). In our business modelling (included in the attached spreadsheet), this amount is sufficient to achieve profitability on a five year timescale and initially supports 10 new jobs for each 10,000 customers added.

Under the National Grid ‘Community Renewables’ Future Energy Scenario, by 2025 an estimated 15m homes will be engaged in some form of smart EV charging (and a larger number in other forms of DSR). Valued at £100 per household this translates to a £150m market for DSR services.

Under the same scenario, this would result in the creation of 15,000 new jobs in energy services by 2025.

If we assume 20% of the 2.5m owners of immersion heaters also engage with DSR this would add a further 500 jobs nationally. Batteries and heat pumps have the potential to add to this further as their deployment continues (although we anticipate the potential to be lower initially).

Market case for an open source and open standards based system

Open Standards

Open standards (as promoted by OpenDSR) have the main effect of accelerating the growth of the UK DSR market as a whole. In California, the mandated use of OpenADR has arguably helped to accelerate the deployment of domestic DSR procurement (see case study) to its current commercially active status. Consumers benefit from industry agreeing and providing a common interface for the use of their products which enables them to be seamlessly integrated with other products and systems. This may reduce the amount of value that any manufacturer/supplier can extract from a given product, but due to lower costs for integration it creates a larger potential market.

OpenADR

As outlined in the BEIS DSR Rapid Evidence Assessment (2017), "the consensus across several reports is that policy and regulation are essential to overcome barriers to DSR, and that without them, DSR amongst smaller users will remain low.”

The benefit of the OpenADR standard is that it enables whole system integration to take place, ie linking DSOs market platforms, Aggregators platforms, home energy management systems, smart meters and smart appliances, with the involvement of multiple energy system actors.

As can be seen by the case study in California, mandating open standards has a quantifiable and immediate impact on the viability of DSR services, releasing the value of DSR, assisting the emergence of new viable business models and providing essential energy system services.

Open Source

The use of open source components within OpenDSR has the potential to reduce capital and operating costs and can be utilised to control a variety of smart devices under a wide range of incentive schemes, markets and tariff regimes.

Case Study: California and OpenADR

OpenADR 1.0 was developed by the Lawrence Berkeley National Laboratory in response to the California electricity crisis. Californian IOUs have been making use of OpenADR in California since 2007 to improve reliability and performance of their electricity networks and reduce costs. The system has allowed Californian DSR providers and operators to automatically communicate demand response signals with each other as well as their customer base via the internet.

The California Energy Commission in 2010 predicted that a 5% drop in peak demand would provide enough savings in generation, transmission and distribution costs to remove the need for 625 emergency peaking power plants. This represented a financial saving of US$300 million for California every year. These savings trickle down in terms of wholesale cost reductions for utilities and retail prices for end-users.

California's top three utilities, Pacific Gas and Electric Co. (PG&E), San Diego Gas & Electric Co. and Southern California Edison were already managing 260MW of demand through OpenADR 1.0. by the end of 2012. By 2013, they were insisting on OpenADR 2.0 certified products and platforms from their partners (eg, those who may assist localised dispatch of emergency and price demand response resources).

Due to the success of OpenADR deployments in the state the California Energy Commission has now mandated the use of OpenADR 2 for HVAC systems in the 2019 Building Energy Efficiency Standards.

Summary of benefits to different actors

Energy system actor	Benefits of Open Standards	Benefits of Open Source
Regulators	Creates a level playing field, encourages new entrants, promotes innovation, discourages monopoly and lock-in reducing costs to consumers.	Discourages monopoly reducing costs, benefits consumers.
DSOs	Creates viable market for DSR,	Enables greater choice of

	lower distribution costs.	Aggregator
Technology providers	Opens market to many more suppliers, lowers entry barriers	Promotes innovation for start-ups, encourages MVP development, community support, quicker development, low development costs, lower barriers to entry, greater longevity of software
Aggregator	Creates viable DSR market, creates value margin, creates viable business model	Lowers entry barriers for new entrants, increased interoperability for novel technologies and services.
Customers	More consumer choice, breaking manufacturer monopolies, reduced prices, decreased obsolescence and device churn, no need for multiple HEMS for each asset.	Lower consumer costs and/or higher incentives, more secure.

The case for Open Source

Open Source software is a form of software whereby source code is released under a license which copyright holders grant users the rights to study, change, and distribute the software to anyone and for any purpose. Open Source software is often developed in a collaborative, distributed and public manner. Such software creates a strong value proposition and competitive advantage as compared to proprietary formats, of particular interest as deployed in an energy system context:

- More secure software, more robust and less prone to attack,
- Cheaper software with reduced development and operation costs
- More open and transparent systems - important in public infrastructure context
- Increased interoperability benefiting from integration with multiple other systems

Additionally, a focus on low cost and minimum viable products tends towards the participation of innovative, agile and investive start-ups and SMEs as well as 'disruptive' new entrants, challenging incumbents and sector monopolies.

Open source business models tend to focus less on protection of Intellectual Property and instead on development expertise, consultancy services and consumer service provision.

There are multiple examples of open source software and open source systems gaining a competitive advantage within a technology sector and in time displacing proprietary incumbents.

Such examples exist within:

- Internet browsers - the displacement of Microsoft's Internet Explorer by Mozilla, Opera etc
- Phone operating systems - eg Android
- Cloud based computing - eg Linux based servers

The sector is not limited to software and examples of Open Source hardware include Raspberry Pi computers. Project partners Megni deploy both Open Source hardware and software in their OpenEnergyMonitor and EmonCMS products.

Market case for Community Energy Aggregator/ESCO intermediary

The importance of trusted intermediaries to enabling DSR and launching other energy services has been repeatedly posited. This is reflected in the National Grid Energy Scenarios, which conceive of a distinction between the widespread development of 'Community Energy' and more conservative scenarios such as 'Two Degrees' (which instead involve more state/centralised intervention). Between these scenarios the difference in peak reduction potential is 0.3GW, equating to £21m in balancing market value. The difference in energy services equals £75 m in market value. This hints at the huge difference that trusted intermediaries, community groups, co-operatives, and non-profits could make it achieving the potential of DSR.

A Community Energy intermediary combines a novel and replicable business model with a user engagement methodology. Community Energy organisations are not-for-profit, often incorporated as co-operatives, locally based and involved in one or more activities including renewable generation, energy efficiency and demand reduction and delivery of grid services.

The model in development by Carbon Co-op sees these intermediaries acting as ESCOs and Aggregators, value stacking income streams to develop a viable business model. Aggregator/ESCOs oversee domestic energy system improvements such as energy efficiency measures, alongside the fitting of Demand Side Response ready consumer energy devices such as smart electric vehicle chargers, solar diverters etc. Though many groups are small scale and reliant on volunteers, others such as Carbon Co-op have paid staff teams and have delivered very large construction and engineering projects.

This delivery model helps overcome a variety of business model and end-user barriers to the successful deployment of DSR in the UK.

Trust is repeatedly cited by end users as a requirement for DSR, in particular in relation to automated demand loads. As not-for-profit, member owned organisations, Community Energy groups have been shown to have very high levels of consumer trust.

Research demonstrates that the environmental benefits of DSR can be a strong motivating factor to involvement. Community Energy groups are typically environmentally and routinely carry out climate change advocacy work and Carbon Co-op's research in the Feasibility stage demonstrates very high levels of consumer interest in participating on the basis of the activity's environmental impact.

Research demonstrates the relatively high costs of securing participation and notes high marketing costs may make business models less cost effective. But, with large consumer memberships and marketing channels based on ‘community champions’ and word of mouth, Community Energy groups can reduce such costs. In Spain, the Som Energia energy supplier has built up a customer base of 60,000 householders without spending any marketing budget. And the very high levels of interest in the feasibility project - with householders as far away as Exeter expressing an interest in attending focus group sessions in Manchester, this pattern is likely to be replicated in the UK.

Finally, it has been shown that energy system actor unbundling means the benefits of DSR may be stretched thinly across multiple actors reducing its overall viability. However, the latest European Commission Clean Energy Package (2018) incorporates an energy system role known as Local Energy Communities, an entity likely to be incorporated in to UK law before 2019. This would see elements of generation, supply, distribution and energy efficiency being delivered at a geographically specific local level, facilitated by a not-for-profit intermediary such as a Community Energy group. With the National Grid Future Energy Scenarios (2018) envisaging more localised DSR aggregators, these policy proposals would help concentrate DSR incomes within a single energy system actor.

Potential for implementing elements of the innovation separately

Our approach breaks into three areas:

- Open standards approach
- Integrated, end-to-end OpenDSR system for controlling smart devices
- Householder intermediary delivery model

Each of these innovations fits together, but if required, each can be implemented separately.

Potential for advantage in overseas markets and export potential

OpenADR has been mandated for use in California and projects have been delivered around the United States of America. Projects have also been delivered or are active in Canada, China, Japan, South Korea and India. As a result, the integrated OpenDSR system has the potential to replicated and implemented in many different countries and energy system contexts. Additionally, should OpenADR become mandated in the UK, technology providers and product manufacturers can begin to export to these overseas markets

Competition and the OpenDSR USP

There are a limited number of alternative products and services available in the UK which provide a domestic DSR service.

Ovo VCharge/Home Energy Storage/V2G

Ovo Energy (a UK supplier) are developing a range of domestic demand side response products and services. Their storage heater controller service VCharge[33] has been active for a number of years. Participating in the service requires switching to Ovo as the supplier, using their provided SMETS1 smart meter, and is only compatible with supplied equipment.

[33] "VCharge Dynamo for your storage heater | OVO Energy." https://www.ovoenergy.com/vcharge. Accessed 2 Jul. 2018.

This is similar to the forthcoming Home Energy Storage[34] and Vehicle to Grid[35] products and accompanying demand response services. The Ovo system has the main advantage of being first to market and integrating the supply of electricity with the supply of equipment and associated energy services.

The main difference between our proposed system and the Ovo system is interoperability and extensibility. Our system does not require the involvement of a specific supplier (except maybe to pair a CAD) or the use of specific makes of HEMS or DER asset, only that they implement a compliant OpenADR client. Different parts of our proposed system are interchangeable.

Moixa Smart Battery and GridShare

Moixa offer customers taking its Smart Battery[36] participation in its GridShare service where customers are paid £50 per year to allow the battery to be controlled remotely. The Moixa batteries main advantage is that it is an integrated product and service which consumers purchase as a package.

The main disadvantage of the Moixa system would seem to be vendor lock-in: based on our understanding it cannot be switched to another flexibility provider and there is a risk of obsolescence if the company changes its future product/service or stops trading.

The capacity of the standard Moixa Smart Battery is quite small (at 430W - 750W) and so it is not clear how it can provide the level of compensation based on current typical market prices for capacity/utilisation of DER and we assume this is a loss leading activity. This could lead to the offer changing in future.

The GridShare service is only compatible with Moixa products currently although GridShare is being marketed as a commercial aggregator platform so presumably is capable of interacting with DER assets from other manufacturers.

OpenDSR USP

We would summarise the main advantages of OpenDSR compared to the competition as:

- Interoperability: with other systems, platforms, products and components and an ability to integrate broader range of consumer products i.e. new technologies, features and capabilities
- Flexibility: our proposed system can control a wide range of DER assets and different parts of the system can be exchanged for existing or alternative parts.
- Non-exclusivity of supplier and no vendor lock-in.
- Designed for smart meter integration: unlike other solutions we are focussed on integration with the smart meter rollout.

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[34] "Home Energy Storage | OVO Energy." https://www.ovoenergy.com/home-energy-storage. Accessed 2 Jul. 2018.
[35] "OVO Vehicle-to-Grid Charger | OVO Energy." https://www.ovoenergy.com/electric-cars/vehicle-to-grid-charger. Accessed 2 Jul. 2018.
[36] "Moixa." http://www.moixa.com/. Accessed 2 Jul. 2018.

Opportunities for future development

OpenADR can also support a range of other DER asset types including:

- Heat Pumps.
- Batteries.
- Vehicle to Grid.
- SMEs/Commercial DSR.

All of these can be simply added to the system by implementing an appropriate OpenADR client on the device or in a connected controller (of which the immersion heater controller is a prototype for on/off operation).

Heat pumps have the most near-future potential with the National Grid Future Energy Scenario ‘Community Power’ predicting that there will be 1m heat pumps by 2025, increasing to 3m in 2030. Most of these systems could be used for demand side response in the right conditions, particularly if a standard for DSR were mandated. There are some additional complexities involved in DSR for space heating systems but

Batteries are beginning to see deployment in domestic settings but are currently not cost-effective. Falling battery prices and other factors such as changes to charging will at some point make batteries economical for domestic solar PV owners although growth in storage deployment is likely to be driven by large commercial and industrial installations.

7. Conclusions

We have outlined in this report how a domestic demand side response system can be deployed based on open standards, open source software, and off-the-shelf hardware. This has many advantages over current commercial offerings, primarily around reducing costs and waste, promoting competition and innovation through lowering barriers to entry, and synthesis with other services and products.

Existing domestic DSR solutions are too costly and have suffered many issues relating to interoperability, metering, and communications. An open source and open standards based DSR system can address these challenges using existing components and through taking advantage of the new smart metering infrastructure and cloud computing services.

OpenDSR is an innovative approach to the problems posed by domestic DSR characterised by its use of open source and open standards, integration with smart meters, synthesis with community energy business models, and better interoperability.

Our market research into user requirements established that there is a great interest in DSR amongst current and prospective EV owners, contrasted with a reluctance to engage and wariness around costs for social housing tenants. This shows the complexities inherent in deploying domestic DSR but also shows how the correlation of specific classes of DER asset with specific demographics/types of consumer can help in targeting marketing and recruitment efforts.

We have identified large growing potential markets for OpenDSR, particularly on a 5-10 year timeline as new technologies are widely deployed. We have outlined a 5 year business plan which can achieve profitability by expanding with the market.

A Community Energy Aggregator/ESCO intermediary can secure high levels of customer involvement and trust, reduce acquisition/conversion costs, and deliver cost-effective services to end users.

The OpenDSR demonstrator in Greater Manchester has the ability to test and evaluate the potential of a DSR system which may show how to overcome key barriers to the creation of a viable domestic DSR market in the UK.

Recommendations

- That the mandating of an open standard for domestic demand side response (such as OpenADR) for specific or all prospective DER asset classes be investigated by BEIS as a means to accelerate the deployment of domestic DSR.
- BEIS should ensure that reforms currently in progress in the areas of charging, consolidation and simplification of ancillary service markets, capacity markets, local flexibility markets, and increasing access to wholesale and balancing mechanism support domestic DSR. Specifically, ensuring that aggregated DER assets are not unfairly discriminated against, that smart meters are suitable for meeting the requirements of these markets, and lowering the minimum capacity so that smaller assets and portfolios can participate.