CrowdFlex: Discovery

Final report

Strategic Innovation Fund

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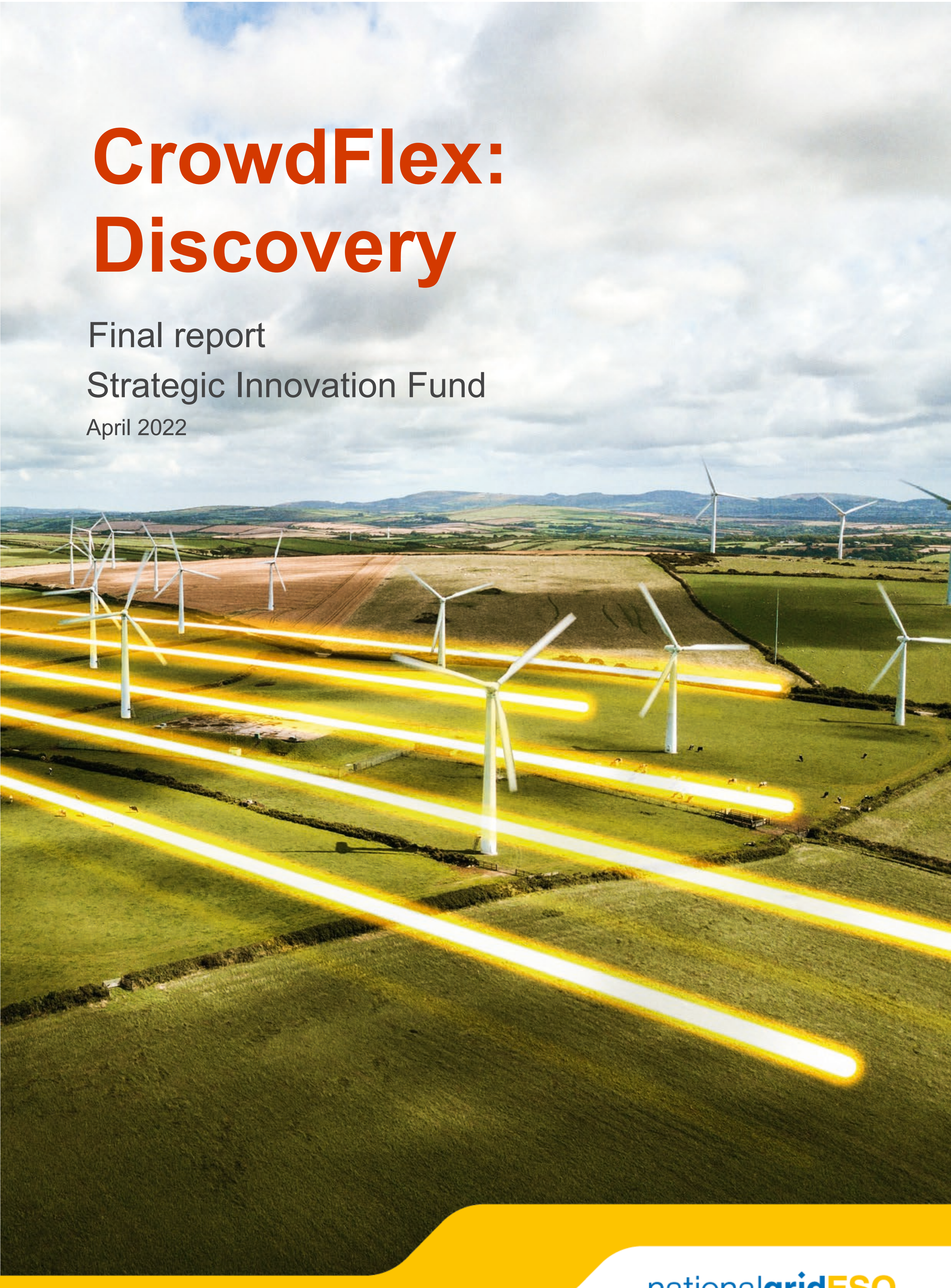

nationalgridESO

Executive summary

Today, flexibility on the electricity system is mostly provided by adjusting generation in response to changing demand. With more variable renewable energy (VRE) generation coming online, as the system decarbonises, the responsibility of flexibility must include more of the demand side. The domestic sector plays a large role in shaping the total demand of the system. The rollout of low carbon technologies (LCT) in the home, including electric vehicle (EV) chargers, heat pumps, etc. has the potential to rapidly increase domestic demand, creating new peaks. This poses a transformational challenge to the whole energy system, with the system peak set to increase from 58GW to 69GW (+19%) between 2020-2030 (Consumer Transformation, FES 2021). Under the current business-as-usual (BAU) approach, this would require new generation capacity and significant network reinforcement, which may be expensive and inefficient. This would inevitably raise customers' electricity bills and be carbon intensive. However, the introduction of LCTs into the home present an unprecedented nascent source of flexibility. If domestic consumers were able to reprofile their demand, as part of a coordination of the whole system, an innovative resource of domestic flexibility service could offer a reliable and cost effective alternative.

CrowdFlex: Discovery builds upon a previous study undertaken by National Grid ESO, SSEN, Octopus Energy, and Ohme, CrowdFlex: NIA [1]. This investigation into the technical potential of domestic flexibility has shown that price signals to homeowners can reduce evening peak domestic consumption by >50%, and could provide a GB flexibility resource of 7GW turn-down, and >10GW turn-up: a resource of national significance.

CrowdFlex: Discovery is the first of three phases of a planned CrowdFlex innovation project. It aims to establish domestic flexibility as a reliable and cost effective energy and grid management resource, providing it alongside BAU solutions such as network reinforcement or new thermal capacity, by participating in energy markets and flexibility services. CrowdFlex: Discovery has three key objectives:

1. To understand and align ESO and DSO requirements for domestic flexibility services and develop commercial frameworks suitable for the statistical nature of flexibility.
2. To identify the technology capability and consumer behaviour parameters to explore in a future large scale consumer trial.
3. To understand how the statistical nature of flexibility can be developed into reliable modelling of domestic demand and flexibility.

CrowdFlex: Discovery engaged with stakeholders within ESO, SSEN, and WPD to understand the challenges that face the whole system, both currently and looking towards the future as VRE generation increases and more LCTs come online. Currently the ESO/DSOs solve these challenges through energy markets and flexibility services. Within these stakeholders, Discovery has confirmed that there is strong appetite for domestic flexibility to play an active role in energy markets and services. The introduction of such a large resource of flexibility could greatly reduce the operational costs of the ESO (namely constraints, reserve and energy balancing, which amounted to £2 billion in 2021 [2], £72 per household) and the capacity and network reinforcement investment of both ESO and DSOs.

Flexibility services are procured by the ESO/DSOs to enable flexible assets to balance energy, ensure a security of supply, and avoid constraints on the network. CrowdFlex identified key distinctions for how assets must behave when participating in different energy markets and flexibility services, which relates closely to the specification for flexibility service classification laid out in PAS 1878 [3]:

- **Energy markets** encourage a **PAS-Routine** change in behaviour from consumers, by leveraging flexible assets. This may be either through voluntary behaviour change or through the automation of assets. PAS-Routine draws on incentives (financial or other) to influence energy demand, encouraging either demand turn up or demand turn down. Aggregators must forecast consumer demand and position themselves on the market accordingly. If the aggregator declares their position incorrectly, they will be subject to imbalance charges, but the final responsibility of energy balancing will pass to real-time flexibility services.

- **Contracted services** require assets to guarantee availability to provide a demand turn-up/down response if called upon and could be delivered as **PAS-Response** type services. The service provided

[1] CrowdFlex consortium, CrowdFlex: NIA, Energy Networks Association, 2022
[2] National Grid ESO, Monthly BSUoS Summary, ESO Portal, 2021.
[3] British Standards Institution, PAS 1878 Energy smart appliances - System functionality and architecture – Specification, 2021

may be critical to the operation of the power system, and may be called during system stress events. These PAS-Response type services are therefore usually more essential to system operation, i.e. if the service fails then it may disrupt the system, for example cause an outage. An aggregator must react to dispatch instructions or grid conditions, issuing a PAS-Response request to domestic assets. Therefore, failure to deliver PAS-Response type services is often met with steep non-delivery penalties.

With this in mind, CrowdFlex: Discovery lays out what a large-scale trial of domestic flexibility should aim to achieve, and the trial parameters required to succeed in this. For PAS-Routine type flexibility, in addition to a timewise vector of baseline demand, a CrowdFlex trial should generate a timewise vector of projected flexible capacity, for each time interval, through the year. PAS-Response type flexibility has two different "flavours". PAS-Response flexibility for system operational events (e.g. Frequency Response and Reserve) must provide a firm response that is pre-declared, but the firm capacity of the response can be declared many times throughout the year. As the firm response for these types of service may vary throughout the year, response should be tested multiple times under a variety of conditions (season, weather, time of day, concurrent PAS-Routine incentives). Given the speed of response generally required, it would most likely be procured via an automated response. The second "flavour" is PAS-Response type flexibility for system stress events (e.g. Capacity Market and NOA agreements). These services demand the firm response is declared up to years in advance and be available throughout the year. Therefore, there would likely be a number of tests run during system stress events (typically cold weather periods for demand led peaks, but also potentially summertime for supply led stress) to ensure that any response is reliable and can contribute to system critical functions. These services may be called via an automated response or in a manner similar to the "Big Turn up/Down" experiments conducted in the NIA study.

The forecasting of domestic demand and flexibility was identified as an invaluable resource for both National Grid ESO and DSOs. Improving the forecasting of baseline domestic demand will reduce the associated uncertainty, while increasing ESO and DSO demand-side visibility, greatly improving their understanding of how households consume energy at any given moment and understand how this affects system operation. This would in turn reduce the associated cost of energy balancing by shifting the balancing responsibility away from balancing services and reduce the required operational reserves procured, further reducing the operational costs of ESO. This is illustrated in Figure 1 below.

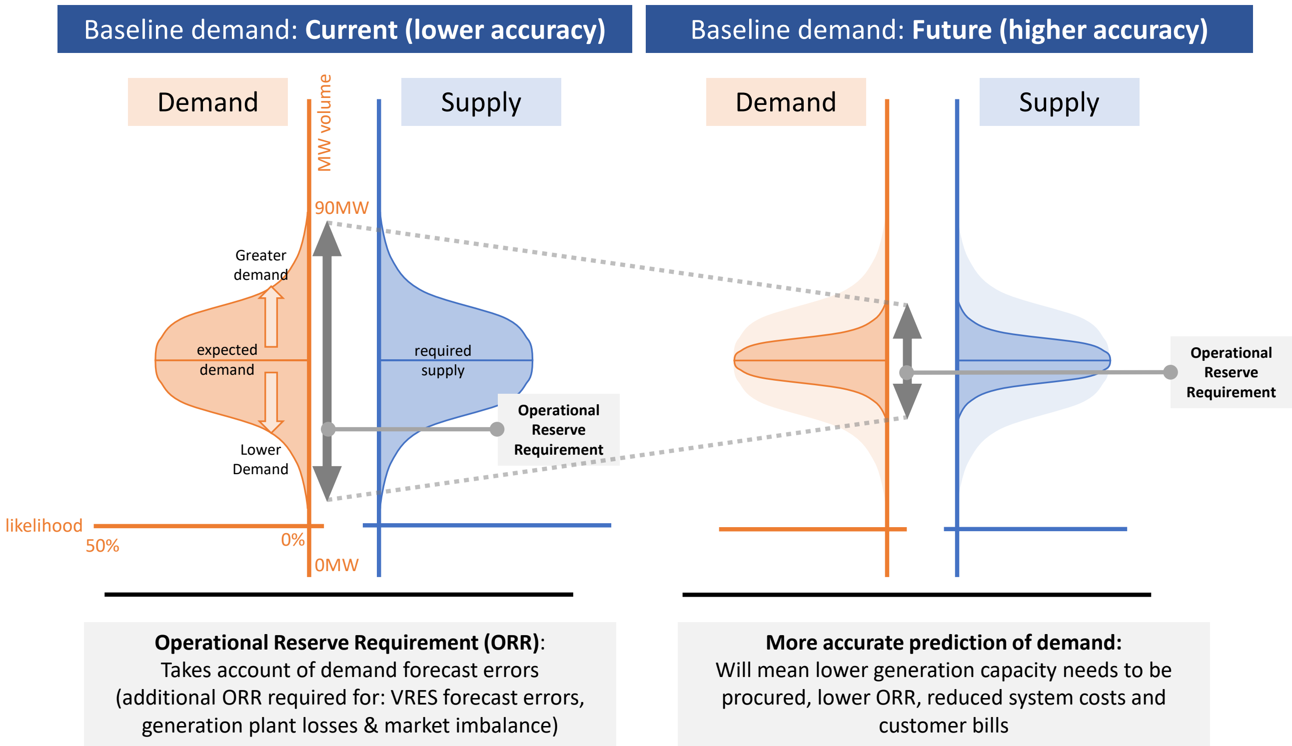

Figure 1: Improving demand forecasting, reduces the associated uncertainty, reducing the need for Operational Reserve Requirements.

A key output of CrowdFlex will be a methodology to forecast this domestic demand baseline and flexibility. CrowdFlex: Discovery has outlined a high-level modelling approach:

1. Demand forecast (baseline/counterfactual) – forecast demand per household per half hour
2. Flexibility potential (i.e. max up and down shift) forecast – forecast max shift possible per house for each flexibility delivery period based on historical & known loads
3. Expected flexibility outturn forecast – forecast expected deliverable flexibility over a single period based on participation and depth estimates applied to the flexibility potential forecast.

The intention is that stages 1 and 3 should be probabilistic, but stage 2 will be deterministic as it consists of the maximum and minimum bounds on potential outturn. A core output of this modelling will be the ability to describe flexibility as a probability distribution function (PDF), giving the probability of delivering a flexible response, with respect to the baseline, at any given time. This will inform the VirtualES and will become a key pillar of the digital twin ecosystem.

As described above, flexibility capacity data is inherently stochastic, and even across very large populations the capacity is best described by statistical, rather than deterministic methods. Nevertheless, the ESO and DSOs indicated that, at least in the near-term, they would continue to procure flexibility via a declaration of firm capacity, an approach introduced for large-scale generating assets whose flexibility is deterministic. This requires stochastic assets, such as domestic flexibility, to derate their flexible capacity to ensure they can deliver the response they are contracted for. However, procuring flexibility stochastically via a PDF, would eliminate the need to derate capacity, reducing over procurement on the ESO/DSO side, which could provide system savings for all stakeholders. This is described below in Figure 2.

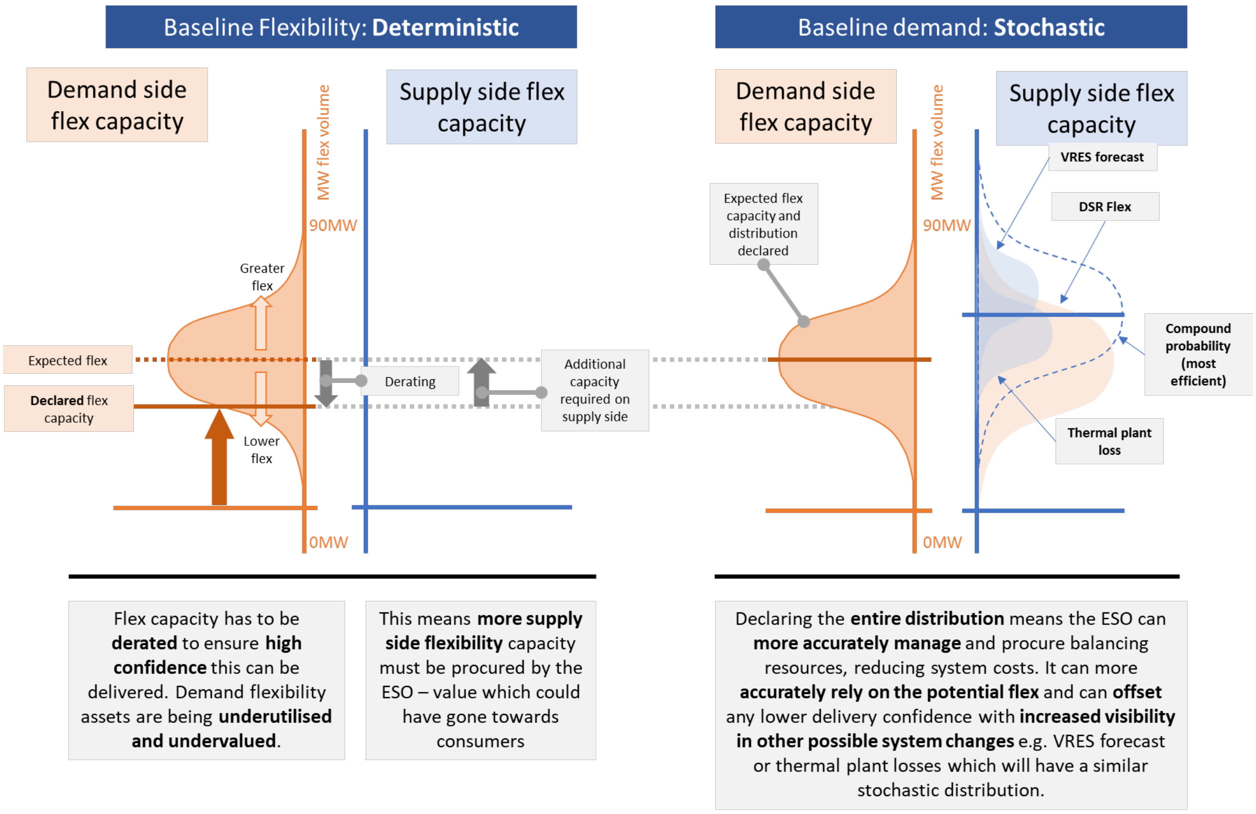

Figure 2: Declaring flexible capacity for stochastic assets, such as domestic flexibility, stochastically rather than via a derated firm capacity can reduce the need for over procurement, reducing system costs.

To explore this further, going forward into CrowdFlex: Alpha and CrowdFlex: Beta, we will pursue a two-pronged approach reflected in Figure 2. The first will explore the value and commercial viability of domestic flexibility procured via deterministic markets and services, requiring it to be derated to ensure it delivers its contracted response. The second will lay out a long-term pathway to introduce a stochastic approach to flexibility via a PDF approach. This approach will improve confidence in the services and revenues available to domestic flexibility in the near term, ensuring it can be rolled out rapidly, while laying out a long-term pathway to introduce a stochastic approach to flexibility, which would provide system savings for all stakeholders. Both prongs are essential for the decarbonisation of GB's energy system, leveraging the much needed resource that is domestic flexibility in the near term to accelerate the uptake of LCTs and deployment of VRE generation, while ensuring an effective and efficient system for the future, operating at least cost for the consumer.

Contents

Glossary

ADMD – After Diversity Maximum Demand

API – Application Programming Interface

BAU – Business As Usual

BEIS – Department for Business, Energy and Industrial Strategy

BEVs – Battery Electric Vehicles

BM – Balancing Mechanism

BMU – Balancing Mechanism Unit

BSUOS – Balancing Service Use Of System charge

BTM – Behind the Meter

CfD – Contract for Difference

CIM – Common Information Model

CLNR – Customer Led Network Revolution

CO2 – Carbon Dioxide

CSR – Corporate Social Responsibility

CVEI – Consumers, Vehicles and Energy Integration

DBSCAN – Density-Based Spatial Clustering of Applications

DC – Dynamic Containment

DER – Distributed Energy Response

DERMS – Distributed Energy Management System

DFES – Distribution Future Energy Scenarios

DM – Dynamic Moderation

DN – Distribution Network

DSO – Distribution Network Operator

DR – Dynamic Regulation

DRS – Domestic Reserve Scarcity

DSO – Distribution System Operator

DSR – Demand Side Response

DSRSP – Demand Side Response Service Provider

dToU – dynamic Time of Use

EAC – Estimated Annual Consumption

ENA – Energy Networks Association

EV – Electric Vehicles

EFA – Electricity Forward Agreement

FES – Future Energy Scenarios

FFR – Firm Frequency Response

FR – Fast Response

GB – Great Britain

GDPR – General Data Protection Regulation

GSP – Grid Supply Point

GW – Giga Watt

HEMS – Home Energy Management System

HEUS – Home Energy Usage Survey

HH – Half Hourly

HP – Heat Pump

HV – High Voltage

Hz - Hertz

ICE – Internal Combustion Engine

IMF – Information Management Framework

ITE – Independent Technical Expert

kW – Kilowatt

kWh – Kilowhatt-hour

LCT – Low Carbon Technologies

LV – Low Voltage

MEDA – Modern Energy Data Access

MID – Measuring Instruments Directive

ML – Machine Learning

MPAN – Meter Point Administration Number

NGESO / ESO – National Grid Electricity System Operator

NIA – Network Innovation Allowance

NOA – Networks Options Assessment

OEM – Original Equipment Manufacturer

OPTICS – Ordering Points To Identify the Clustering Structure

PAS – Publicly Available Specification

PCA – Principal Component Analysis

PDF – Probability Density Function

PN – Physical Notification

PSDM – Power System Dispatch Model

PV – Photovoltaic

SIF – Strategic Innovation Fund

SLES – Smart Local Energy Systems

SMETS – Smart Metering Equipment Technical Specification

SO – System Operator

SPD – Satisfactory Performance Day

SSEN – Scottish and Southern Energy Networks

STOR – Short Term Operating Response

sToU – static Time of Use

ToU – Time of Use

TRL – Transport Research Laboratory

t-SNE – t-Distributed Stochastic Neighbour Embedding

UKPN – United Kingdom Power Networks

V2G – Vehicle to Grid

V2GB – Vehicle to Grid Britain

VES – Virtual Energy System

VRE – Variable renewable energy

VRES – Variability of Renewable Supplies

WPD – Western Power Distribution

1 Capture requirements of the System Operator & the Distribution System Operators

Section 1 captures and summarises the responses to interviews conducted by the CrowdFlex consortium with experts within the System Operator (ESO) , National Grid ESO, and the Distribution Network Operators (DSOs) Scottish and Southern Electricity Networks (SSEN) and Western Power Distribution (WPD). The objectives of these interviews were to:

1. Identify the challenges that face the SO and DSOs both currently and in the future, particularly as more low carbon technologies (LCTs), such as electric vehicles (EVs) and electric heating appliances connect to the network;

2. Identify the energy services and markets that are currently in place to help solve these challenges; and

3. Gain a high-level understanding of how operators within the ESO and DSOs view domestic flexibility as a resource to help solve these challenges in the future.

CrowdFlex conducted 14 interviews with National Grid ESO and 3 interviews with the DSOs.

Section 1.1 and 1.2 summarise the SO's and DSOs' operational challenges and the current energy markets and flexibility services to solve such challenges. Section 1.3 and 1.4 capture the ESO and DSOs' technical requirements and scenarios for domestic flexibility. Section 1.5 highlights where the needs of the ESO and DSOs are aligned and where there is a need for CrowdFlex to investigate how conflicting requirements can be aligned when providing domestic flexibility in the next stage of the project.

1.1 Identifying the current and future operational challenges facing the transmission and distribution systems/networks

As the energy system decarbonises and generation shifts away from large thermal generation towards variable renewable energy (VRE) generation, energy system flexibility must increasingly shift from the generation side (i.e. peaking plants) to the demand side of the system (i.e. demand side response). This is because while thermal generation could be turned up/down to match the needs of the demand side, VRE is reliant on the natural resources it draws upon (e.g. wind and solar). Therefore, the demand side must become more flexible to maintain the flexibility on the system. Flexibility is an essential resource for the ESO and the DSOs to effectively manage their network and overcome the operational challenges that the ESO and DSOs face.

Domestic flexibility is just one tranche of demand side flexibility available to the ESO and DSOs, but if fully utilised could prove to be a large and valuable source of flexibility as more LCTs are integrated into the system. In order to understand how domestic flexibility could be utilised, we first need to understand operational challenges that domestic flexibility could assist in solving. The challenges can be broadly split into two groups: current challenges that as more VRE and LCT come online will only become more prevalent, and future challenges that will begin to emerge as more VRE and LCT come online. National Grid ESO and the DSOs, through the ENA Open Networks Project, have already outlined a range of flexibility services and responses that they utilise, or plan to develop, to help solve these challenges.

These challenges and their respective services/responses were confirmed in interviews with the SO and DSOs along with discussing the suitability of domestic flexibility assets to provide the services. This is summarised in Table 1.

Table 1: The current and future operational challenges facing the ESO and DSOs, the respective services/responses to overcome them, and the suitability of domestic flexibility assets to provide the services[4][5][6][7][8].

System/network challenges	Current & future services/responses	Key features of service	Suitability of domestic flexibility assets
Current challenges			
Demand caused constraints (transmission & distribution)	Demand turn-down, Thermal – Balancing Mechanism (ESO) Sustain, Secure, distributed generation (DSO)	Time: Seasonal, diurnal (evening peak) Duration: ~1-3h Predictability: Day ahead	
Generation caused constraints from VRE generation (transmission & distribution)	Demand turn-up, Thermal – Balancing Mechanism (ESO) Sustain, Secure (DSO)	Time: Year round Duration: Hours Predictability: Day ahead	
Maintaining network frequency (transmission)	Frequency response (ESO)	Time: Year round Duration: 4 hour periods Predictability: Seconds Ramp up/down: Required	
Energy balancing (transmission)	Energy markets Reserve, Balancing Mechanism (ESO)	Time: Year round Duration: all day Predictability: Hour ahead	
Restoration of outages (transmission & distribution)	Restoration (ESO) Restore (DSO)	Time: Year round Duration: anytime Predictability: Seconds Ramp up/down: Required	
Future challenges			
Stabilising system with reduced inertia (transmission)	Frequency response, Stability (ESO)	Time: Year round Duration: 4 hour periods Predictability: Seconds Ramp up/down: Required	
Maintaining voltage across network (transmission & distribution)	Reactive power (ESO) Dynamic (DSO)	Time: Year round Duration: All day Predictability: Seconds Ramp up/down: Required Voltage control: Required	
Periods of sustained low VRE generation (transmission)	Capacity market (ESO) Sustain (DSO)	Time: Year round Duration: Hours – several days Predictability: Day ahead	
Passive EV charging increasing peak demand (transmission & distribution)	Demand turn-down (ESO) Sustain, Secure (DSO)	Time: Seasonal, diurnal (evening peak) Duration: ~1-3h Predictability: Day ahead	
Sustained heat pump loads increasing peak demand (transmission & distribution)	Demand turn-down (ESO) Sustain, Secure (DSO)	Time: Seasonal, diurnal (morning & evening peak) Duration: ~4h Predictability: Day ahead	

[4]National Grid ESO, Operability Strategy Report, 2021
[5]National Grid ESO, Markets Roadmap to 2025, 2021
[6]ENA, Open Networks Project – Active Power Services Implementation Plan, 2020
[7]UKPN & LCL Learning Lab, DNO Guide to Future Smart Management of Distribution Networks Summary Report, 2019
[8]National Grid ESO, Bridging the Gap to Net Zero, 2021

A central aim of the CrowdFlex project is to align the provision of the services in Table 1 to key domestic assets in order to solve the operational challenges facing the ESO and DSOs generating value across the energy system, from generators and system operators all the way down to energy suppliers and consumers. High-level features of domestic assets, technical capabilities are established in Table 2. Together these form the suitability ratings assigned in Table 1. CrowdFlex: Alpha will investigate the technical capabilities of domestic assets in more detail to confirm specifically which services domestic assets may participate in and therefore should be taken through to the trial phase.

Table 2: High level features of the technical capabilities of domestic assets.

Domestic asset	Key features technical capabilities of asset
Domestic appliances	**Baseline:** Typical electricity profile **Flex availability:** Year round, all day (limited response)
EVs	**Baseline:** ~2h demand, evening peak **Flex availability:** Year round, ~14h overnight
Electrified heat (heat pumps, storage heaters, etc.)	**Baseline:** 2x ~4h demand, morning & evening peak **Flex availability:** Seasonal, ~1h without storage, ~2-4h with additional thermal storage

1.2 Existing ESO & DSO energy markets and services

Currently, both the ESO and the DSO offer a range of active power flexibility services in conjunction with energy markets. Energy markets are operated independently from the SO/DSOs (excluding the Balancing Mechanism), they are a marketplace for suppliers and generators to trade energy, ensuring the quantity of energy generated matches that required by the supplier at a given time. Flexibility services are procured by the ESO/DSOs[9] to enable flexible assets to balance energy, ensure a security of supply, and avoid constraints on the network. How assets must behave in energy markets is distinctly different to how they must behave when providing contracted services - offering two distinct opportunities for providing domestic flexibility that CrowdFlex: Discovery considered. This distinction relates closely to the specification for flexibility service classification laid out in PAS 1878[10]:

- **Energy markets** encourage a **PAS-Routine** change in behaviour from consumers, by leveraging flexible assets. This may be either through voluntary behaviour change or through the automation of assets. PAS-Routine draws on incentives (financial or other) to influence energy demand, encouraging either demand turn up or demand turn down. Aggregators must forecast consumer demand and position themselves on the market accordingly. If the aggregator declares their position incorrectly, they will be subject to imbalance charges, but the final responsibility of energy balancing will pass to real-time flexibility services.
- **Contracted services** (and real-time markets, e.g. Balancing Mechanism) require a **PAS-Response** request in close to real-time. Often a contracted service requires assets to guarantee availability to provide a demand turn-up/down response if called upon. Therefore, an aggregator must react to dispatch instructions/grid conditions, issuing a PAS-Response request to domestic assets. PAS-Response type services are usually more essential to system operation, i.e. if the service fails then it may disrupt the system (e.g. cause an outage). Therefore, failure to deliver PAS-Response type services is often met with steep non-delivery penalties.

The ESO and DSO services available to flexible assets are depicted in Figure 3 along with the response times required and timescales of imbalances that are addressed by each service. It also highlights that markets can provide energy balancing in the intraday/day ahead period through PAS-Routine operations (in yellow) of energy markets). Pre-agreed periods of demand turn-up/down contracts (such as those contracted in the Sustain DSO service) can also be achieved with PAS-Routine operations. PAS-Response signals (in red) for contracted services are likely to be required for real-time balancing, constraint, and capacity management services contracted by the ESO and DSOs. Please note that all services are described in detail in section 1.3.

[9] Most commonly through procurement markets where flexible assets may bid to provide the service.
[10] British Standards Institution, PAS 1878 Energy smart appliances - System functionality and architecture – Specification, 2021

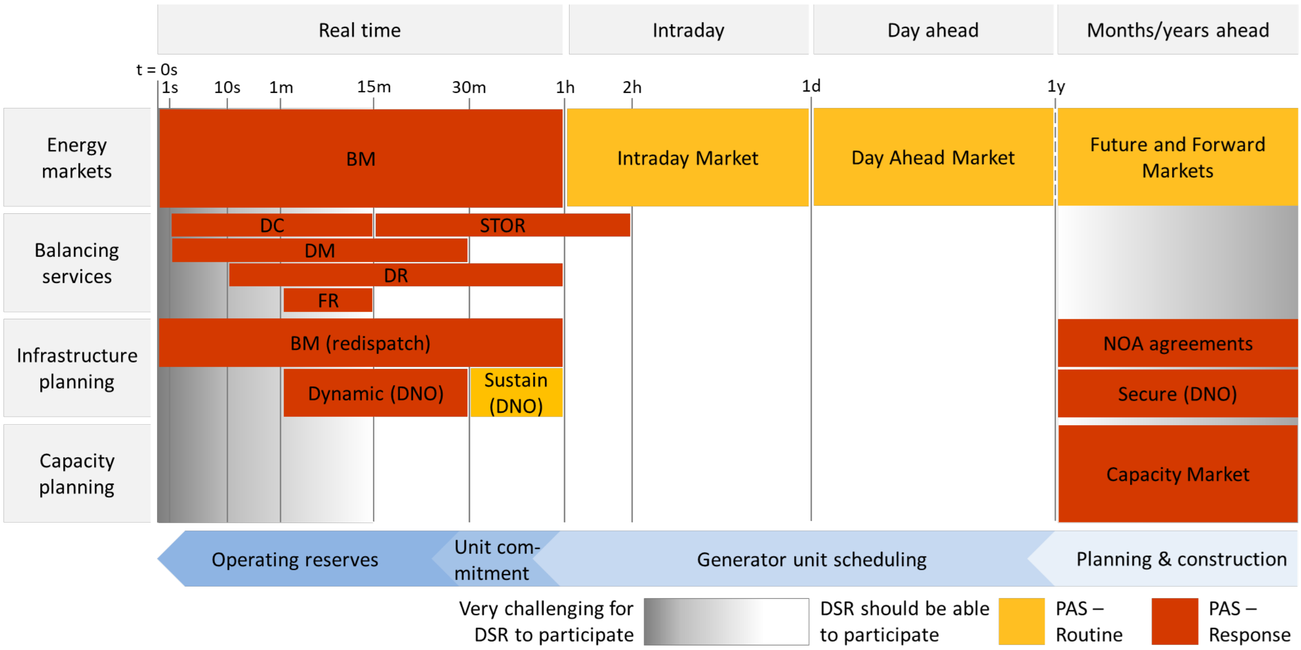

Figure 3: The timescales of imbalances/constraints that are addressed by the various energy markets and services available to flexible assets and the response time of each service[11].

National Grid ESO's top 5 active power operational costs, laid out in detail in Table 3, amount to £2.3 billion annually[12]. Additional costs are incurred procuring capacity and network infrastructure investments (for both the ESO and DSOs). All of these costs are eventually passed down to the consumer through electricity bills. Should domestic flexibility be able to participate in flexibility services for less than the current technologies participating, then a portion of these costs could be redirected back to the consumer, reducing electricity bills.

Table 3: National Grid ESO's top 5 active power operational costs in 2021 (£ million)12.

Operation	**Constraints**	**Operating Reserve**	**Response**	**Fast Reserve**	**Energy Imbalance**
Cost (*£ million*)	1,139	536	318	207	107

Respondents to interviews within the ESO commented that domestic flexibility could provide significant value by delivering energy balancing in the intraday and day ahead period. This view supports the findings of CrowdFlex: NIA which demonstrated that households exhibited a sustained demand turn-down behaviour change when moving to dynamic Time of Use (dToU) tariffs. As this service is provided via a dToU tariff tracking energy markets (Intraday and Day Ahead), it is delivered through a PAS-Routine type response.

Demand Side response (DSR) by domestic assets may face challenges when providing PAS-Response Services. One challenge for delivering PAS-Response flexibility services is that they are required to guarantee a reliable response during their contracted period of availability. This reduces the magnitude of response a DSR asset may be assumed to provide, via a derating factor, to ensure such a response can be provided when called upon. That is to say, for PAS-Response type services, the SO/DSO will not procure the full "rated" capacity[13] of a DSR asset; the full capacity will be derated by a derating factor (which may vary by asset/service/consumer/time/location etc) to ensure, with a high degree of certainty, that an asset can deliver when called upon.

In addition to this challenge, there are further technical criteria that flexible domestic assets must fulfil before they will be contracted to provide such a service. CrowdFlex: Discovery has investigated the high-level technical

[11] BM – Balancing Mechanism, DC – Dynamic Containment, DM – Dynamic Moderation, DR – Dynamic Regulation, FR – Fast Response, STOR – Short Term Operating Reserve, NOA – Networks Options Assessment.
* Exact requirements of DSO flexibility service currently vary depending on the DSO.
[12] National Grid ESO, Monthly BSUoS Summary, ESO Portal, 2021.
[13] The "rated" capacity is the intended full load output of the flexible asset.

requirements that exist for each service to understand the speed and duration of response each service requires. Unpacked in section 1.3, some services require a response that may be too rapid for the latency of the communications equipment used to control domestic assets, barring them from participating. As highlighted by interviews within National Grid ESO, this is likely the case for fast response services, such as Dynamic Containment (DC) and Dynamic Moderation (DM) which both require a response time of 1s.

At the other end of the delivery timescale, the Capacity Market and Network Option Assessments are agreed years in advance (Capacity Market auctions occur both one and four years ahead of delivery). These tendering timescales are difficult for domestic flexibility, which by nature, carries a high level of uncertainty due to its dependence on consumer behaviour. Even automated domestic assets (e.g. EV smart charging) rely on consumer behaviour (such as using and plugging-in the EV). Therefore, it will be difficult for aggregators to reliably predict the response they will be able to provide for services procured years in advance. In addition, it would be difficult for them to demonstrate that response to the SO/DSOs with sufficient evidence for them to accept the provision of such a service from a very large group of domestic consumers.

CrowdFlex: Discovery did not restrict interview respondents to existing services when considering how domestic flexibility could help solve the challenges that face the ESO and DSOs and the introduction of a new service designed specifically for domestic flexibility was discussed. However, the majority of respondents suggested that domestic flexibility could be leveraged through existing/upcoming flexibility services and markets to address the challenges the services are designed for. Therefore, a novel service has not yet been recommended or identified in CrowdFlex: Discovery. As such, this study currently sees no requirement for regulatory approval as it will operate through existing services.

Key Recommendations:

- *CrowdFlex: Alpha should further investigate whether the optimal utilisation of domestic flexibility is through existing services (in their current form or adapted to ensure they do not exclude domestic flexibility) or whether a novel service, designed specifically for domestic flexibility, is required.*
- *CrowdFlex: Alpha should also seek to understand what regulations are in place around energy markets and services updates and design in the case that service adjustments are required to remove barriers for the participation of domestic assets.*
- *If existing markets and services are chosen as the pathway for domestic assets to provide flexibility to the ESO and DSOs then CrowdFlex: Alpha must confirm which services should be trialled based on the technical capabilities of domestic assets and the commercial viability of providing the flexibility.*
- *CrowdFlex: Alpha should model the price at which domestic assets could be rewarded for providing services to reduce the operational and investment costs of National Grid ESO and the DSOs.*

1.3 Capture ESO technical requirements for domestic flexibility

CrowdFlex conducted 14 interviews with National Grid ESO to ensure that this study could accurately capture the SO's need for domestic flexibility and the technical requirements that are demanded from domestic assets participating in the services the ESO offer.

The discussions from the interviews have been summarised into a set of solutions the ESO could envisage domestic flexibility providing. These solutions will help solve the challenges the ESO faces and domestic flexibility is deemed suitable to meet the technical requirements for achieving this. They are:

1. Providing intraday balancing
2. Reducing capacity requirements
3. Reducing VRE related redispatch and network investments
4. Providing balancing services with slower response times
5. Improving demand side visibility
6. Avoiding reduced diversity associated with the uptake of domestic flexibility

Each solution is discussed in the section below.

1.3.1 Domestic flexibility could be leveraged to provide intraday balancing through participation in energy markets

Intraday balancing is a ESO challenge that is solved primarily through markets (Day Ahead, Intraday, Balancing Mechanism), which do not require DSR assets to provide a firm response. Therefore, aggregators of domestic assets can decide whether to bid into markets close to, but before, delivery, i.e. they do not have to guarantee a response far ahead of time. This enables intraday balancing to form part of a routine response through a change in consumer behaviour, where a response to market signals is at the consumers' discretion based on incentives (such as price signals).

This represents a strong opportunity for domestic flexibility to provide the ESO with an intraday balancing "service" by participation in energy markets through the mechanism of a dynamic time-of-use (dToU) tariff, potentially with notifications sent out to customers ahead of time informing them of price changes. Such a service has the potential to reduce the costs the ESO incur from balancing energy via the Balancing Mechanism following gate closure.

Key Recommendations:

➢ *CrowdFlex should include a market-based domestic flexibility service to provide routine intraday balancing, one mechanism that could be utilised to deploy this service is dToU tariffs.*

➢ *CrowdFlex should investigate how to most effectively get a response from a consumer with a market-based service, looking both at consumer willingness to change their demand in response to price signals and the automation of domestic flexibility assets.*

1.3.2 Domestic flexibility could reduce capacity requirements if it can provide a firm response

Domestic flexibility could reduce the generation capacity required by the system in two ways:

- Routine reduction in system peak demand through the use of ToU tariffs,
- Participation in the Capacity Market as a form of DSR supply, reducing the need for additional generation in the Capacity Market supply stack.

The ESO determines the future system demand in its Future Energy Scenarios (FES) modelling, which assumes a certain future uptake of dToU tariffs (depending on the scenario) which decrease the contribution of domestic demand to the system peak. The ESO then feeds this projected demand into the Power System Dispatch Model (PSDM) to determine future capacity requirements. An increase in dToU uptake as a result of CrowdFlex, beyond what is projected in the FES and modelled in the PSDM, could further decrease the gas generation procured by the Capacity Market, which made up 65% of the procured contracts in the T-4 Capacity Market auction for delivery in 2025/6[14].

Domestic flexibility participation in the Capacity Market could come in the form of a Big Turn Down type event (as performed in CrowdFlex: NIA) to provide further demand turn-down in addition to that from a routine response via dToU tariffs. This would form a system critical response as domestic flexibility would provide capacity at times where VRE supply is low and demand risks exceeding supply. Such events are likely to occur within the evening peak, over periods of low wind generation, during the winter.

Because the volume of DSR in the Capacity Market stack is low, currently the entry requirements for DSR in the Capacity Market are relatively simple – DSR assets may select their own DSR test date and settlement period[15]. If DSR became a significant proportion of the Capacity Market stack, through the entry of domestic flexibility, there would be a need to make the entry requirements more rigorous to guarantee the contracted response could be provided when called upon. Therefore, domestic flexibility must be able to demonstrate that it can provide a reliable demand turn-down response in the Capacity Market stack. This includes meeting the requirements around 'Satisfactory Performance Days' during the winter period, potentially on the worst day of the year. Domestic flexibility must also ensure any response provided can have a highly reliable derating factor for domestic flexibility, which makes the technology competitive in the Capacity Market stack.

As DSR becomes a larger proportion of the Capacity Market stack, there will be a need to disaggregate domestic flexibility into the specific assets providing demand turn-down to improve ESO visibility on assets availability to provide a response and the reliability and derating factor on individual domestic asset classes.

Unabated gas is already winning Capacity Market contracts to put it in the merit order beyond 2030, domestic flexibility must be shown to be a reliable and cost-effective alternative to unabated gas in the Capacity Market value stack.

Key Recommendations:

- *CrowdFlex should demonstrate that domestic flexibility can be reliable when providing a firm demand turn down, meeting the entry requirements for the Capacity Market on Satisfactory Performance Days occurring on the worst day of the year.*
- *CrowdFlex should provide the necessary data to determine an appropriate derating factor for domestic flexibility to ensure that any response in the Capacity Market is reliably delivered.*
- *CrowdFlex should understand how, on key days for the Capacity Market, financial incentive impacts the magnitude and reliability of response, and how this response is varied for customers on ToU tariffs.*
- *CrowdFlex: Alpha should work with National Grid ESO to understand the cost of DSR vs. unabated gas in the Capacity Market from the SO's dispatch modelling to ensure that the experimental financial incentives placed on providing a Capacity Market type service are appropriate.*

1.3.3 Domestic flexibility can help reduce redispatch costs and potentially delay Transmission reinforcement due to increasing VRE penetration

Between 2022 and 2030, on average the ESO will spend approximately £1 billion per year on constraint costs[16], primarily due to the redispatch of VRE. Diverting investment from redispatch towards domestic flexibility presents opportunities for CrowdFlex.

Redispatch occurs because the generation merit stack is first created free of network constraints. Network constraints are then applied to determine a new generation stack (redispatch). Constraints can be caused in two main ways:

- Low-cost thermal generation located on the wrong side of a network constraint to serve demand,
- VRE excess generation requiring generation turn-down – this type of constraint is becoming increasingly common as the system transitions away from thermal generation. An example is frequent (and increasing) VRE curtailment in Scotland, with generation turn-up on the England side of the

[14] EnAppSys, T-4 Capacity Market Auction Cleared An All Time High Price, 2022.
[15] National Grid ESO, DSR Testing Process, 2017.
[16] Consumer Transformation Scenario (after NOA6 optimal reinforcements) – National Grid ESO, NOA, Modelled Constraint Costs, 2021.

boundary. Such actions come at a high cost (i.e. the CfD for wind curtailment; potentially gas peaker generation prices for generation turn-up).

The Networks Options Assessment (NOA) assesses the constraints on the network and advises which parts of the network should be reinforced to alleviate constraints. It does this based on current and future generation and demand projections from the FES along with an assessment of the economic case for reinforcement based on the cost of redispatch if a constraint remains in place.

A market mechanism already exists for VRE generation redispatch in the Balancing Mechanism. By leveraging GB households, this could be redirected towards domestic flexibility providing a demand turn-up service in areas experiencing high VRE generation (e.g. strong winds in Scotland) and a demand turn-down service to avoid utilising additional thermal generation elsewhere. Domestic flexibility providing such a service would help alleviate some of the costs associated with redispatch, redirecting the benefits towards customers.

However, if domestic flexibility could demonstrate the availability and magnitude to provide a demand turn-up response to reliably mitigate redispatch, it could delay, or avoid network investment as part of a firm demand turn-up service. This type of service would be essential to system operation, as it would be procured as an alternative to network investment. Therefore, it would have to demonstrate the ability to provide a response during periods of extremely high wind generation, sustained for a period long enough to avoid a network constraint or costly redispatch that would invalidate such a service. Questions remain as to whether the volume of domestic flexibility in constrained locations or the time it could be sustained for would be sufficient to significantly delay network reinforcement. In the case that domestic flexibility could significantly delay network reinforcement, additional questions remain as to the benefits for the ESO of delaying network reinforcement without being able to replace it indefinitely.

Key Recommendations:

- *CrowdFlex should explore the magnitude of firm demand turn-up that domestic flexibility can provide, particularly in locations (e.g. Scotland) and times of day/year (windy periods) for which VRE redispatch is common, and the incentives required to encourage such a response.*
- *CrowdFlex: Alpha should estimate the demand turn-up response domestic flexibility could produce in locations where VRE redispatch is common and compare it to the volume of energy redispatched in those locations to assess whether domestic flexibility has the power to delay network reinforcement.*
- *CrowdFlex should repeat these two actions with reliable demand turn-down on the other side of the constraint to understand the magnitude of additional thermal generation that can be avoided.*

1.3.4 Domestic flexibility could be a valuable source of the slower response and reserve balancing services

The majority of balancing services offer assets payment for their availability; therefore, they demand that assets are indeed available when they are called upon. Should aggregated domestic assets be able to guarantee their availability to provide a firm response there is high value in providing such services.

CrowdFlex should consider two types of active power balancing services (domestic assets will be unlikely be able to provide reactive power services):

- Response services – these are faster responding services triggered automatically by a deviation from standard operation (such as frequency). Domestic flexibility will be challenged to meet the technical requirements of even the slowest response services,
- Reserve services – these are dispatched by the ESO Control Room when there is a need to balance the system, hence are slower responding services more suited to domestic flexibility.

Frequency response services, such as Dynamic Containment and Dynamic Moderation, have delivery requirements of 1 second that will likely be too fast for the latency associated with the communications connecting domestic assets. Domestic flexibility might be able to fulfil the technical requirements of the slowest response services.

In 2020, a home battery aggregator completed its weekly FFR contract[17], which has a response speed of 10 seconds. This demonstrates that domestic assets (especially batteries) have the technical ability to provide response services at this speed. However, further challenges persist around onboarding aggregated Low

[17] Molly Lempiere, Social Energy wins first ever fully domestic FFR contract, Current News, 2020.

Voltage (LV) connected assets for rapid response services. NIA funded, Residential Response[18] suggested that manual registration, individual asset metering, and the evaluation of aggregated assets by an independent technical expert (ITE) can be extremely costly when considering the number of assets that would be required at a domestic level to provide a firm response.

Dynamic Regulation, for which the response speed is 10 seconds, may be an option for domestic assets to participate in a frequency response service. However, CrowdFlex will have to overcome the barriers for aggregated assets outlined by Residential Response to make such an offering economically viable. In addition, it remains unclear whether demand-side assets (i.e., not batteries) have the latency to provide a sub-10 seconds response.

Domestic flexibility is more likely to be able to provide reserve services such as Fast Reserve, for which delivery must start 2 minutes following the dispatch instruction and be maintained for 15 minutes.

For both response and reserve services, DSR is performing a system critical service to keep the grid frequency within its operational boundaries. Therefore, it must be able to demonstrate that it can provide reliable and firm delivery of response in the service availability window.

Key Recommendations:

- *CrowdFlex should investigate households' ability to respond to a balancing service dispatch instruction, their availability to provide a firm response, their persistence in providing firm responses, the length of time a response can be sustained, and the magnitude of a response.*
- *CrowdFlex: Alpha should further understand the explicit requirements for onboarding and participating in balancing services. For example, the comms equipment required to receive balancing service dispatch instructions and the latency and delivery time for domestic flexibility assets.*

1.3.5 CrowdFlex can help the ESO improve demand side visibility

Visibility on the demand side is a growing challenge for the ESO as flexibility on the system moves away from large generators towards Distributed Energy Resources (DER). Currently the ESO have very limited visibility of these DER, particularly of domestic demand. Increased visibility would enable the ESO to greatly improve its understanding of how households are consuming energy at any given moment and understand how this affects system operation. This would in turn reduce the associated cost of energy balancing by shifting the balancing responsibility away from balancing services.

Visibility also relates to the location on the network where energy is being consumed. This would enable the ESO to improve the sophistication of their redispatch mechanisms and reduce the associated costs.

CrowdFlex presents an opportunity to provide the ESO with data on domestic customers behaviour both in the baseline and in a "flexible state". The approach to be devised on customer segmentation, aggregation, and metering to participate in flexibility services that could feed into the SO's demand modelling to improve visibility on the system. The ESO also expressed their interest in being able to disaggregate the sub-layers of demand, including baseline, ToU tariff behaviour, and response behaviour from participation in services to further inform their demand projections as the demand side becomes more involved in flexibility services.

Key Recommendations:

- *CrowdFlex should put equal weight both on the need to understand domestic flexibility and the baseline behaviour of households to improve visibility on the demand side.*
- *CrowdFlex should devise a rigorous baselining process (or draw on that from previous DSR studies) so that consumers' responses can be properly measured and rewarded by the SO/DSOs based on the customers deviation in their energy consumption from the baseline.*

1.3.6 CrowdFlex can seek a solution to the potential threat the loss of diversity associated with domestic flexibility poses to the ESO

The removal of diversity in consumer behaviour caused by static time-of-use (sToU) tariffs or dToU tariffs operated with automated optimisation software presents a potential challenge for the ESO by creating step

[18] National Grid ESO, Residential Response, 2020

changes in demand. Such step changes could threaten the system, rapidly shifting the frequency to beyond what the grid can handle before response services can come online to rebalance the system.

Several solutions have been suggested to mitigate such a risk, such as: staggered ToU tariffs so all households do not have the same price signals, ramp rates mandated to aggregators and automated optimisation software, and dither algorithms[19] in flexible domestic assets to reintroduce some random diversity. In addition, solutions could come from the ESO side to ensure unmanageable step changes of demand do not occur.

Key Recommendations:

- *CrowdFlex should consider the potential solutions to a loss of diversity associated with domestic flexibility services when testing the response of flexible domestic assets to understand how demand step changes can be mitigated while maximising domestic flexibility.*

1.4 Capture DSO technical requirements for domestic flexibility

CrowdFlex conducted 3 interviews with SSE and WPD to capture the needs of the DSOs for domestic flexibility and the associated technical requirements for DSO flexibility services.

The key outputs from the DSO interviews were:

1. dToU tariffs that follow wholesale prices alone will not meet the full needs of the DSOs
2. The ability to disaggregate domestic flexibility is vital for DSOs
3. Domestic flexibility alone may not be sufficient to avoid distribution network (DN) reinforcement

1.4.1 dToU tariffs that follow wholesale prices alone will not meet the full needs of the DSO

Most dToU tariffs track wholesale prices, but wholesale prices do not completely overlap with peak demand times of DN loads (as noted in Low Carbon London[20]). Furthermore, price signals or incentives that reflect opportunities and challenges in one part of the power system, may not reflect the locational needs at DN level. Therefore, DSOs could not rely on dToU tariffs alone to provide domestic flexibility to delay network reinforcement to the DN, as such a mechanism would still result in "unmanaged" peaks on the DN. DSOs also have contracted PAS-Response type flexibility services (Sustain, Secure, Dynamic, Restore)[21] which they could draw on to assist in fulfilling their needs.

Like the SO, DSOs are concerned of the impact that step changes in demand caused by the removal of diversity associated with the uptake of dToU tariffs may have on the network (specifically transformers on the network).

Key Recommendations:

- *CrowdFlex: Alpha should seek to understand to what extent the DSOs would be prepared to incentivise customers through adjusting dToU tariffs in partnership with suppliers to reflect the needs of the DN, the impact this would have on the requirements of the SO, and the potential regulatory barriers associated with this.*
- *CrowdFlex should measure the sustained demand turn down response adopted by customers on a dToU tariff during the DN peak times.*
- *CrowdFlex should build on the work of the ENA Open Networks Project to understand how domestic flexibility may be utilised to provide contracted DSO flexibility services.*
- *CrowdFlex should seek to understand how such incentives would vary based on location and the impacts this might have on consumers.*

1.4.2 The ability to disaggregate domestic flexibility is vital for DSOs

DN constraints are highly location specific, therefore any service to reduce demand, to delay network reinforcement, must also be specific to that location. The greater the disaggregation the more value a flexibility service could be for the DSO, all the way down to street and meter (MPAN) level. Such disaggregation could

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[19] Dither algorithms intentionally apply noise used to randomise quantisation patterns to prevent large-scale patterns, such as step changes in energy demand.
[20] UKPN, Low Carbon London, 2014.
[21] ENA, Open Networks Project – Active Power Services Implementation Plan, 2020

help improve visibility on the DN and also for the SO. The need for disaggregation has to be balanced by the loss of diversity, which brings challenges associated with statistical reliability of the response of these (small) pools of customers.

Key Recommendations:

- *CrowdFlex should use its results to understand how the ability to guarantee a response with acceptable certainty diminishes as domestic customers are disaggregated through the DN.*

1.4.3 Increasing demand on the DN may be so large that domestic flexibility will not be sufficient to avoid reinforcement investments

There is value in a DSO flexibility service that can delay network reinforcement by reliably and consistently reducing demand during the DN peak times. Currently the vast majority of this flexibility is being provided by assets connected at the HV level, not domestic customers connected to the LV network. However, increasing demand on the network, associated with the rapidly increasing number of LCTs on the network, means that in many cases flexibility services will only be capable of delaying network reinforcement rather than replacing it. Such flexibility services will only be available in locations where there is value in delaying network reinforcements by maintaining the peak demand below the substation's firm capacity. Once the capacity is nearly exceeded the network will be upgraded increasing its headroom. This will likely remove the need for a DSO flexibility service behind that substation, hence DSO flexibility services may not always represent a long-term revenue stream for domestic customers.

In some cases, DSO flexibility services will not be sufficient to delay network upgrades. This is because of the need to consider the decrease in transformer rating as a result of switching from a cyclic rating[22] (associated with an unmanaged demand profile) to a sustained rating[23] (associated with a demand profile where demand is spread over the evening period). Nevertheless, in the majority of cases, the provision of domestic flexibility, particularly highly flexible assets such as smart EV charging, may be able to reduce network reinforcement needs, but not eliminate them completely.

Ofgem have suggested that DSOs could move from a uniform network access for all households to a reduced "core" network access for all households and a "additional" usage to facilitate customers wishing to install EV charge points or heat pumps[24]. This "additional" network access could increase the distribution network charges for customers participating in domestic flexibility services.

Key recommendations:

- *CrowdFlex: Alpha should further engage with DSOs to understand the timelines that DSO flexibility services may be available to domestic customers and the value of delaying network reinforcement.*
- *CrowdFlex: Alpha should engage with DSOs and Ofgem to understand the implications of the changes to future distribution network access for domestic flexibility.*

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[22] A cyclic rating permits loading above the transformer nameplate capacity for parts of a diurnal cycle, compensated for by loading below nameplate at other times such that the thermal limits are not exceeded.
[23] A sustained rating is the continuous loading a transformer can manage over a diurnal cycle without exceeding its thermal limits.
[24] Ofgem, Getting more out of our electricity networks by reforming access and forward-looking charging arrangements, 2018.

1.5 Review of coordination issues to ensure ESO & DSOs requirements align

There is an ongoing effort to **align the needs and services of the ESO & DSOs in the ENA Open Networks Project**, as highlighted by all respondents in interviews. The project has work streams on flexibility services, whole electricity planning work stream, and the DSO transition. The learnings from these work streams will be of importance to CrowdFlex to ensure that domestic flexibility serves the needs of the ESO & DSOs in line with Open Networks.

- *CrowdFlex: Alpha should coordinate with the ongoing work of the Open Networks Project, where its work programme includes a determination of the primacy rules coordinating the needs of the ESO & DSOs.*

Both the ESO **& DSOs recognise the need to improve visibility on the demand side** as described in sections 1.3 and 1.4. This will assist both the ESO in understanding the demand on their network both in real-time and projected into the future, which will enable more accurate capacity and infrastructure planning for both the ESO & DSOs. A cost benefit analysis for gaining visibility of DERs is a key output for the Whole Electricity System Planning work stream of the Open Networks Project. CrowdFlex could provide valuable information for both parties to improve visibility of domestic demand both in the baseline projections and when they are providing flexibility.

The **modelling teams from the ESO and DSOs (e.g. ESO – FES, DSOs – DFES) recognise the potential beneficial system impacts of PAS-Routine and PAS-Response flexibility**. To capture this, CrowdFlex must ensure domestic flexibility is correctly represented, technically and commercially, so that unnecessary infrastructure investments can be avoided.

- *To align with expectations in FES/DFES modelling, CrowdFlex should understand assumptions used regarding the cost of domestic flexibility actions, as well as counterfactual costs for generator turn-down actions.*

Both the **ESO & DSOs are concerned about the risks that arise from the loss of diversity associated with domestic flexibility**, such as the uptake of dToU tariffs as described in sections 1.3 and 1.4. The potential for step changes in demand could cause system critical issues for both the transmission and distribution networks if left unmanaged.

- *CrowdFlex should investigate how to mitigate such risks, while maximising the potential of domestic flexibility.*

Currently **dToU tariffs serve the needs of the ESO without aligning with the needs of DSOs**. dToU tariffs, which track wholesale prices, offer useful and intrinsic demand turn-down for the ESO reducing capacity requirements, but dToU tariffs do not exactly match with peaks on the DN. Therefore, dToU tariffs may still result in "unmanaged" peaks on the DN.

- *CrowdFlex should investigate how dToU tariffs can be leveraged to meet the needs of DSOs without reducing their effectiveness for the SO.*

There is a need to **coordinate providing a demand turn-up for the ESO to replace VRE redispatch and the requirements of DSOs to avoid constraints on their DN networks**. Primarily DSOs are concerned with ensuring their networks remain unconstrained. This may involve managing the demand on the network with a demand turn-down service. Meanwhile, the service requirements of the ESO are more wide ranging, they may include the demand turn-up to reduce the need for VRE redispatch, a costly service the ESO must provide VRE generators at times of excess generation. Such a service offered by domestic assets, while valuable to the SO, could overwhelm the DN and hence have a negative impact on the DSOs needs.

- *CrowdFlex should investigate how a demand turn-up service would need to be coordinated with DSO requirements to manage potential conflicts between ESO and DSO needs.*

1.6 Condition 3 – Related funded project engagement

1.6.1 BiTraDER

BiTraDER is an Ofgem funded project to investigate, develop and trial – live on our network – options for introducing a transparent trading market for connected resources to trade curtailment obligations bilaterally, within regionally aggregated stacks.

CrowdFlex has engaged with BiTraDER partners, and we have confirmed that the technical focus of BiTraDER is quite distinct to CrowdFlex, e.g.:

- BiTraDER is focusing on generators, while CrowdFlex is focusing on demand.
- BiTraDER is focusing on commercial stakeholders, while CrowdFlex is focusing on domestic consumers
- BiTraDER is building a secondary market for sharing/pooling of flexible connections beneath a grid constraint, to support the deployment of flexible connections. CrowdFlex is focusing on domestic consumers, who will have a firm connection, but who can be encouraged via commercial incentives to adjust their consumption.

Nevertheless, the aggregator of a CrowdFlex solution (such as Octopus) could in principle participate in one of the secondary markets that BiTraDER is developing.

BiTraDER will not formally begin until May 2022, by which CrowdFlex: Discovery will have concluded. Therefore, the focus is to share the learnings of CrowdFlex: Discovery with BiTraDER and then to reengage with BiTraDER during CrowdFlex: Alpha.

1.6.2 EQUINOX

Project Equinox is focussed on residential heat and exploring three commercial arrangements for unlocking flexibility. Equinox and CrowdFlex share partners and there is clear complementarity between the two projects, however the scope of CrowdFlex is broader and the final outputs focus more on the modelling of flexibility alongside practical trials.

CrowdFlex will explore residential heat flexibility in addition to the context of all residential loads, including white goods and EV charging. Additionally, CrowdFlex will initially explore a wider range of incentives focused on the customer. While Equinox is focused on maturing flexibility to support distribution networks, CrowdFlex is intended to be broader, to develop digital services that align the requirements of the ESO and DSOs. CrowdFlex will also feed flexibility modelling directly into National Grid ESO's Virtual Energy System (VirtualES), which aims to develop a digital twin of the energy system. Therefore, it is important that the outputs of any future trial are compatible with the necessary inputs to the VirtualES. Finally, CrowdFlex will explore an independent customer base from Equinox.

Despite these scope distinctions, from discussions with partners on both projects it is clear that sharing of learning will be very useful for all. Project EQUINOX will be undertaking a quarterly horizon scan throughout its lifecycle, to avoid duplication and take in learnings in an agile way and feed out learnings via its Comms Plan. The initial scan, when the project begins in April 2022, will take in interim deliverables from the outputs of CrowdFlex: Discovery. Future scans will provide outputs to future CrowdFlex work.

1.6.3 Domestic Reserve Scarcity trial

The Domestic Reserve Scarcity (DRS) trial, fully funded by Octopus, is integrated with the wider programme of CrowdFlex domestic flexibility research. The DRS trial and CrowdFlex share partners and there is clear complementarity between the two projects.

Octopus ran two trials in 2020 to test customer ability to adjust demand on request to help manage system conditions. These trials were analysed as part of the CrowdFlex: NIA study and provided a useful first insight into customer participation and response levels. This analysis informed DRS trial design and parts of the methodology (e.g. on quantifying participation) will be adopted and refined as part of the DRS trial.

The DRS trial will test the ability of customers to reduce demand over 5-10 events in three different 2 hour time windows over February/March. The ESO will request a demand reduction by 4pm day ahead. Octopus will send ESO daily demand reduction forecasts based on opt-in numbers, and after each event will compare the actual volume of response with this forecasted response to test the reliability of the methodology. Octopus has invited some of its 1.4 million customers with an installed smart meter to take part and expects 100,000 homes to sign up. This in turn will provide some more data and methodological insights as a base to build on in the CrowdFlex programme.

The DRS trial does not address the core questions and capabilities that the CrowdFlex programme is designed around. It will give useful data points on customer behaviour from an individual trial, but it does not develop a modelling framework which captures the complexity of customer energy use and supports development of a domestic digital twin. The CrowdFlex programme is needed to build a more comprehensive architecture around prediction and understand demand statistically to enable domestic demand to be a sufficiently reliable tool for grid operations.

A CrowdFlex trial plans to contain more flexibility events, test multiple different event times and explore the asymmetry of response for turn up and down. It also plans to explore the technical potential of specific technologies, e.g. EVs, electric heating, and white goods, and will consider the impact of automation which is likely to be a very limited contribution in the DRS trial. Finally, it will investigate consumer behaviour in more detail, considering customer segmentation and the impact of information provision on participation levels.

Learnings from the DRS trial will be shared with the CrowdFlex programme. The DRS trial will provide data on customer participation rates, the reliability of the forecasting methodology and customer response to various incentive methods. By collecting customer feedback post-trial, the DRS trial will also provide insight on how people shift their demand (e.g. automatic vs. manual) and the percentage of passive participants. The SO's N has provided CrowdFlex with the DRS Trial Protocol, providing context and feedback on the design of the trial. This informs CrowdFlex's approach to identifying potential trial dimensions and commercial frameworks in sections 2 and 4 respectively. Octopus Energy will provide a final report when the post-trial analysis has concluded in May 2022 for use if CrowdFlex progresses to Alpha phase.

2 Identify key trial dimensions using learnings from CrowdFlex: NIA & Domestic Reserve Scarcity

2.1 Confirmation of technologies in scope for CrowdFlex

CrowdFlex: Discovery aimed to identify the key trial dimensions using the learnings from CrowdFlex: NIA and the Domestic Reserve Scarcity (DRS) trial. The first step was to confirm the scope of the trial accurately captured both the technical potential of the technology utilised by consumers in CrowdFlex: NIA as well as the consumer behaviour that would impact flexibility.

CrowdFlex: NIA indicated that flexible EV charging could be a resource of national significance, with a future "turn-up" potential measured in the 10's of GW. Flexible EV charging is also vital to avoid an increase in peak demands due to "passive" charging profiles. Additionally, the NIA study showed that control of white goods will be very important to "turn down" potential. Finally, CrowdFlex project partners are acutely aware of the need to minimise adverse grid impacts of electric heating and heat pumps, by making these grid responsive where feasible.

The inclusion of electricity generating technologies such as solar PV and storage technologies such as home battery systems and vehicle to grid (V2G) was also discussed. Some respondents did indicate that a household having the ability to generate sufficient electricity to cover their needs could be useful in circumstances such as an outage. Also, prior studies have indicated that V2G can generate more revenue per vehicle than would be possible with controlled charging[25]. However, respondents felt the additional value and incremental learnings these technologies would bring, was outweighed by the increase in project scope, scale needed for statistical significance, and complexity. Also, some domestic generation technology has already participated in commercial markets[26], and consumer behaviour may not be at the core of the service to the extent that it is in CrowdFlex. Thus, generation and storage technologies are out of the project scope at this time. The learning outcomes from the technologies in scope (aiming to solve whole-system issues, a broad range of consumer interventions, addressing the stochastic nature of the assets, commercial models, etc) could all be applied to these generating technologies not currently in scope. Whole house Home Energy Management Systems (HEMS) can provide consumer value when storage or generation technologies are present. Given storage and generation technologies are proposed as out of scope, HEMS are also proposed out of the current scope

Therefore, the proposed scope focuses on three key technologies: EV charging, white goods, and electric heating, including heat pumps. Respondents from the ESO and DSOs agreed that focusing on these technologies allowed for a sufficiently broad understanding of domestic flexibility while providing outcomes that would be sufficiently useful to understand the technical potential of the flexibility provision.

With white goods, the targeting of appliances is indicated by which appliances have a large baseline demand, and the extent to which their consumption is dispatchable (i.e consumption at specified time is somewhat discretionary). The Home Energy Usage Survey[27].showed that (across all UK households, and across all days, and excluding electric heating) the largest contribution to demand and which is discretionary is from:

- Cold appliances (16% annual energy) -interruptible over short periods due to thermal storage capacity,
- Washing/drying (14% annual energy) – can influence laundry schedules with energy tariffs.

Therefore, these appliance types should be in scope for CrowdFlex.

[25] For example, the V2GB study modelling showed that V2G could generate many times the revenue per vehicle compared to smart charging, due to the increased throughput of energy through the vehicle battery, as well as allowing symmetrical power up/down services to be provided.
[26] Social Energy has provided FFR via residential battery systems.
[27] UK Household Energy Survey (publishing.service.gov.uk)

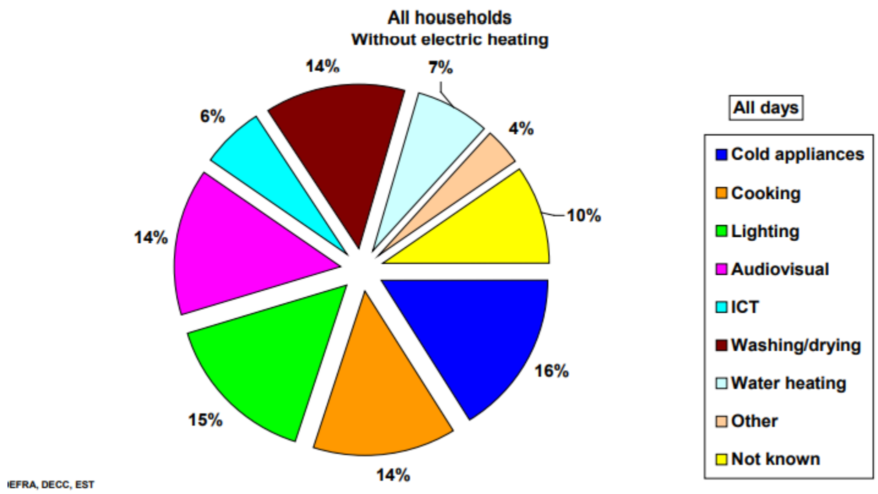

Figure 4: HEUS data showing contribution from different load types to annual household load.

Partners who are also involved in the heat pump-focussed Equinox project confirmed that the CrowdFlex scope is additional to Equinox because of the broad range of system services in scope for CrowdFlex, and the broader range of incentives and information solutions that may be offered to customers. However, CrowdFlex partners noted that including heat pumps in the trial will represent a significant increase in complexity and cost to the project. The conclusion is that heat pumps would remain in scope for the Alpha Phase of the project, where at a minimum, a 'heat pump roadmap' would be developed. This roadmap would estimate the system wide benefit of heat pumps being operated in a 'smart'/ flexible way, identify commercially sustainable models for smart heat pump operation, and how and when this could be tested in a trial. The decision to progress a heat pump component of CrowdFlex to trial, would be taken on the findings from the roadmap.

- *The core technology areas that are in scope for CrowdFlex are:*
  - *EV charging*
  - *White goods*
  - *Electric heating (including Heat pumps - initially via a roadmap undertaken in Alpha)*
- *CrowdFlex: Alpha should review these technology choices. Alpha should work to ensure the outcomes of a CrowdFlex trial should be transferrable to out of scope technologies, especially domestic electricity generating and storage technologies.*

2.2 Specification of trial requirements for service provision

The objective of the trial is to demonstrate the provision of reliable services from flexible residential assets, and to determine the revenue and cost of service provision. Task 1 identified that residential assets could be considered for provision of a very broad range of power system services, with only a few (Dynamic Containment and Dynamic Moderation) that stakeholders thought to be clearly outside the technical capability of residential response assets. As identified in chapter 0, services can be grouped under two categories, **PAS-Routine** and **PAS-Response**, and these have distinct specifications and test requirements[28]:

PAS-Routine services: For these services, the flexible capacity of the aggregated portfolio could be declared shortly before delivery (minutes to hours) and then entered into the relevant energy market for delivery in a contracted window (e.g. HH period). The portfolio flexibility capacity would be continuously updated for subsequent time periods. As the capacity is declared shortly before delivery, and is updated constantly, the aggregator can have reasonably high confidence in delivery of this total aggregated flexible capacity through demand and flexibility forecasting techniques (see chapters 3 and 4). During a delivery window, should a supplier find that consumption is deviating from their declared position, they could use the flexible asset to move back into balance.

The aggregator will need to understand how utilisation of the portfolio in the short-term (e.g. intraday markets) could degrade the capacity that might be available for longer term markets (e.g. day ahead), or other PAS-

[28] British Standards Institution, PAS 1878 Energy smart appliances - System functionality and architecture – Specification, 2021

Response type services. For example, NIA showed there is potential for infrequent charging events to be concentrated into a shorter time period, but once charged, this EV resource does not have the same flexible capability until it is discharged.

- *CrowdFlex trial should generate a timewise vector of projected flexible capacity, for each time interval, through the year. Therefore, a trial should be conducted for at least one year to provide this dataset.*
- *Assuming a business-as-usual approach to service provision, the aggregator would need to provide a value representing the firm portfolio capacity for delivery in each window. To improve confidence in an aggregator's position, the error bands in the projected flexibility/demand should be narrow. Greater statistical confidence will be required to narrow the error bands, and this would impact the required trial size and duration. The tests should extend over a long enough period and wide enough range of assets/consumers to provide confidence to the aggregator in the level of response provided, such that the aggregator can understand the uncertainty associated with bids in markets and balance this with e.g. imbalance charges associated with deviating from their declared position.*
- *PAS-Routine is encouraged through incentives or information remedies. Amongst other studies, CrowdFlex: NIA demonstrated sToU or dToU tariffs are effective incentives that can be profiled to give the required response. The generation of these incentive profiles should reflect challenges across the whole power system, i.e. across generation, transmission and distribution.*
- *Data from the trial should help the aggregator understand how utilisation of the portfolio in the short-term could degrade the capacity that might be available for future entry into markets/services, and how this would impact the aggregator's commercial strategy.*

PAS-Response services: Services under this category often require assets to guarantee availability to respond with a firm capacity when triggered by dispatch instructions/grid conditions. PAS-Response type services can occur at system critical events, such as:

- Close to real-time system operation (e.g. frequency response or close to real-time energy balancing).
- Times of system stress, such as peak network demand, peak supply capacity.

Because delivering such services are essential to system operation, i.e. if the service fails then so might the system, failure to deliver PAS-Response type services is met with significant non-delivery penalties far greater than the value of energy service. Due to this, high confidence is needed in the ability to deliver these services. Currently, markets achieve this through the derating of the nominal capacity of flexibility to produce a firm capacity that is tendered to PAS-Response type flexibility services e.g. Capacity Market derating.

Close to real-time system operation PAS-Response type services generally occur over short delivery periods and procured shortly before the contracted window of availability (e.g. Frequency Response is increasingly being procured in EFA blocks with auctions occurring a week before delivery). Therefore, as firm capacities are declared during the auction for the specific delivery period, the firm capacities can vary throughout the year depending on the forecasted availability of domestic flexibility in each deliver period. This availability can be influenced through PAS-Routine type services, as the forecasted capacity for PAS-Response type services will be impacted by the flexibility potential utilised by PAS-Routine type actions.

PAS-Response type services delivered at periods of system stress are generally procured much further in advance and over a much broader contract window (e.g. Capacity Market is procured up to four years in advance, assets may be called upon at any time in the year). The BAU energy system investments (e.g. generation, network reinforcement, etc.) are available at times of system stress, and so residential assets would need to provide an equivalent function. However the NIA study, and other reports such as CLNR, identified that the customer reaction to time of use tariffs reduces towards zero at times of peak system demand (such as the winter peak). Therefore, a distinct intervention is required to encourage domestic flexibility at these times.

While undoubtedly it is more challenging to procure and deliver PAS-Response type service dealing with periods of system stress, the system requirement for them is very significant. Many studies exploring the 2050 GB power system, decarbonised with Variable Renewable Energy Resources, show that residential DSR can primarily offset investment costs of generation capacity and network capacity expansion[29]. However, to do this, the resource has to be available at these times of peak demand, peak network flow, or peak generation.

- *The trial needs to generate a timewise vector representing the derated firm flexibility capacity of the portfolio, which may be called at any time or during a service delivery period.*

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[29] Piclo Report: Modelling the GB Flexibility Market: The Value of Flexibility.

- *For system operation PAS-Response type services:*
    - *CrowdFlex: Alpha should agree the parameters for testing to provide a reliable firm response. This will include aligning with National Grid ESO's service testing requirements. As the firm response for these types of service may vary throughout the year, response should be tested multiple times under a variety of conditions (season, weather, time of day, concurrent PAS-Routine incentives).*
  - *Given the speed of response required, it would most likely be procured via an automated response, this assumption will be tested further in alpha detailed designs. The flexibility offered at these times needs to be additional to any change observed due to PAS-Routine services.*
- *For system stress PAS-Response type services:*
  - *CrowdFlex: Alpha should agree the parameters for testing to provide a reliable firm response. One example of this is by working with (amongst others) the Capacity Market to determine what would represent the equivalent of a Satisfactory Performance Day (SPD) and what data is required to estimate derating factors. There would likely be a number of tests run during system stress events (typically cold weather periods for demand led peaks, but also potentially summertime for supply led stress). The outcome would be the specification of test cells that demonstrate to market stakeholders that the response is reliable and can contribute to system critical functions.*
  - *These services may be called via an automated response or in a manner similar to the "Big Turn up/Down" experiments conducted in the NIA study. The flexibility offered at these times needs to be additional to any change observed due to PAS-Routine services. As the portfolio may be called repeatedly, the persistence of the assets needs to be tested. This would be via multiple calls on the asset, for example every evening for a week during the peak winter period.*
  - *CrowdFlex: Alpha should investigate how to appropriately incentivise consumers to participate in PAS-Response type services. One option could be that it becomes a stipulation of their contracted and they are rewarded with a share of the resulting revenue.*

Underpinning both of these types of service provision, will be a requirement to establish a reliable consumption baseline (as flexibility provision would be defined as a deviation from this). This is required for PAS-Routine for position nomination into the energy market and for PAS-Response for proof of service delivery. Chapter 4 covers this topic and makes appropriate recommendations for future CrowdFlex work.

2.3 Trial dimensions: household demographics and house parameters

Distinct from the flexible asset, CrowdFlex should clarify how household parameters impact the level of domestic flexibility. There are two groups of parameters here:

- the occupants will have an impact on the level of response provided
- the thermal fabric of the house will impact the level of flexibility available from electrified heating, such as heat pumps.

On the first of these, there is very little definitive and robust data which relates household indicators (such as demographics) to the level of *flexibility* that might be procured from that household. The Customer Led Network Revolution Project concluded that socio-demographic factors did not shape the response to [sToU] tariffs to a significant degree[30].

However, that project did show that baseline electricity consumption does scale with household income[31]. Aligned with this, the CVEI project identified differences in EV use that were related to income, and house location (rurality), but did not identify strong links between demographics and smart charging behaviour[32].

So, even if occupants behaved in a similar way, greater baseline consumption would be expected to lead to greater potential for flexibility (i.e. some homes have a greater capacity for energy use and shifting). The NIA phase of CrowdFlex indicated a similar conclusion, in that the ownership (or otherwise) of an electric car was the primary factor in predicting amount of flexibility provision. In other words, the household capacity for flexibility was much greater due to the EV, but no other demographic factors indicated a reliable propensity to provide

[30] CLNR report on Domestic Smart Meter Customers on Time of Use Tariffs. CLNR-L243
[31] Insight Report: Domestic Baseline Profile - Customer-Led Network Revolution
[32] TRL Report

flexibility. In part this outcome may be expected, and the reason why research in the area of domestic flexibility often focusses on EV charging (see next section). Nevertheless, to extrapolate the outcomes of the CrowdFlex trial to GB figures, and to give the potential to map outcomes to parts of DSO networks, demographic indicators will need to be recorded in the trial.

- *CrowdFlex: Alpha should identify what demographic factors should be recorded during the trial, such that these would permit the trial outcomes to be extrapolated to GB, and be mapped to regions of DSO networks. This should be aligned with the modelling approached used by NG ESO, and by the DSOs.*

On the second point, it is widely accepted that the ability of heat pumps to provide flexibility is very dependent on the thermal efficiency of the property, and whether it has any thermal storage available. Some HPs may be installed in houses with poor thermal efficiency. During cold weather these HPs would need to be working constantly at or near rated capacity to maintain the required internal heating temperature, the house loses heat rapidly, and thus offer next to no flexibility. This is very much aligned with National Grid ESO's Heat Decarbonisation Model[33]. Modelling work has shown that a building's thermal performance (as measured by the Heat Loss Parameter) impacts HP flexibility, with high performance buildings offering several hours of flexibility, but average buildings no more than 1-2 hours before the internal environment cools excessively. Thermal storage can augment this flexibility time.

- *CrowdFlex: Alpha should evaluate the impact of thermal performance (potentially the Heat Loss Parameter) and availability of thermal storage, upon the level of flexible response offered by HPs. To ensure best value outcomes from the trial, CrowdFlex should seek to identify and target households that offer high HP flexibility potential. Collaboration opportunities with the SIF Flexible Heat project should be considered.*

2.4 Trial dimensions: EV test cells

Additionally, Ohme has undertaken additional consumer segmentation work to permit identification of EV drivers for trial participation.

2.4.1 Segmentation Approach

- Previous CrowdFlex NIA learnings highlighted significantly different EV charging profiles for customers utilising dynamic tariffs and fixed time of use (ToU) tariffs compared to customers on a single rate fixed or standard variable tariff.
- These different charging profiles could have a significant impact upon both the likelihood for domestic customers to participate in domestic flexibility and / or the likely value to the energy system for the flexibility provided by that customer.
- Customer segmentation has been utilised across several energy projects, attempting to better understand how customers behave and help predict future likely outcomes: -
  - Ofgem – Energy Consumer Archetypes
  - Element Energy (CVEI) for the Department for Transport
  - Project Sciurus – V2G trial
- A quantitative 'Flex' / EV segmentation has been developed within CrowdFlex: Discovery:
  - Building on the findings from CrowdFlex NIA
  - Utilising the more comprehensive data sets from Ohme's EV fleet
  - Examining behavioural / customer needs attributes alongside the potential value from each household
  - Providing a template to integrate other smart devices / LCT's
- The outputs from this segmentation can then be used to: -
  - Provide the basis for further Alpha and Beta trials
  - Enable better forecasting – micro and macro
  - Deliver pragmatic outcomes / user journeys to improve consumer engagement and future flex value

2.4.2 Methodology

- Available customer attributes were clustered to form several hypotheses relating to either: -
  - Customer behaviour and the likelihood to participate in domestic flexibility, i.e., how engaged are the customers, are they using all the features available in the App to maximise their smart charging potential, etc...

[33] download (nationalgrideso.com)

    - Customer usage and the value they can deliver within domestic flexibility, i.e., how frequently do they charge, how much do they charge, how large is the car battery, etc…
- Having recognised these two key dimensions from the available data, a simple 2 x 2 segmentation model was proposed.

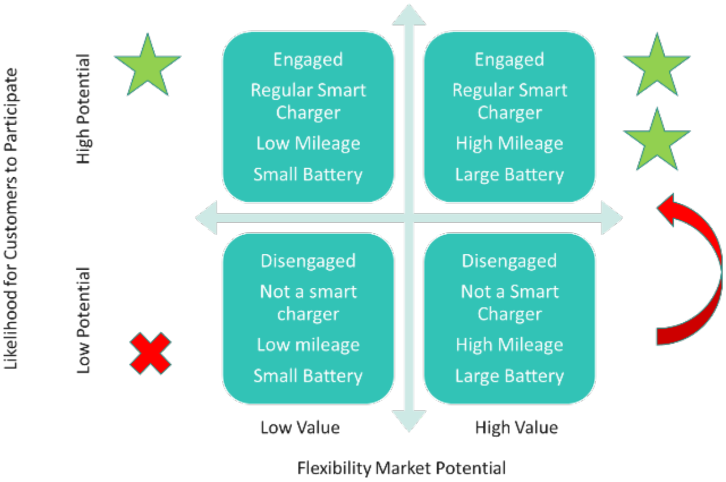

Figure 5: Consumer segmentation matrix. Stars symbolise consumer segments to be targeted, crosses symbolise those not. Arrow identifies the groups that CrowdFlex should encourage to embrace domestic flexibility.

- 49 data attributes were matched to the initial hypotheses.
- This data set was reduced to 37, case sensitive and significantly correlated dimensions
    - Dimension Reduction; PCA, t-SNE
    - Clustering; K-Means, DBSCAN, OPTICS

2.4.3 Outputs

- Through standard scaling and K-Means cluster analysis, 4 distinct segments were found to exist within a sample of over 11,000 EV drivers: -

Cluster Analysis

- **0:** High Flex Potential – Low Value, 13.5%
- **1:** Low Flex Potential – Low Value, 14.8%
- **2:** Low Flex Potential – High Vlaue, 34.6%
- **3:** High Flex Potential – High Value, 37.0%

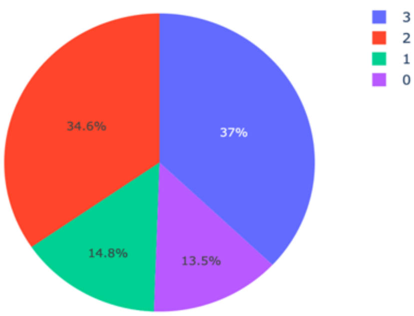

Figure 6: Cluster analysis of flexibility potential of 11,000 Ohme customers (EV drivers).

- Cluster 0 – High potential flex participation but low potential value consumers were characterised by frequent charging activity, a high prevalence of ToU tariffs and off-peak charging. However, small battery size limited the potential flex value of this cohort.
- Cluster 1 – Low potential flex participation and low potential value consumers were predominantly ‘early adopters’ – drivers purchasing a smart cable / home charger <2022, with a high mix of smart cable usage, (charging at home and on the move), who have subsequently moved on to a different solution, and have a vehicle with a small battery.
- Cluster 2 – Low potential, immediate flex participation but high potential value consumers were high mileage drivers, with medium / large battery vehicles. However, low participation in smart charging,

aligned with a low mix of ToU tariffs, suggested that these customers were not yet engaged and therefore less likely to participate in domestic flexibility.

- Cluster 3 – High potential flex participation and high potential value consumers were essentially engaged drivers, using many features to deliver smart charging aligned with a high mix of ToU / Dynamic tariffs. In addition, they were high mileage drivers with regular, frequent charging patterns aligned with large battery vehicles.

2.4.4 Potential Use Cases and Journeys

- Two segments, Cluster 2 and Cluster 3, representing c. 72% of all EV drivers, offer the highest potential value for domestic flexibility, and therefore warrant further investment in realising this potential value. These segments are likely to grow further as battery sizes increase and mass market adoption increases the mix of BEV's.
- Cluster 2 – Low Potential Flex Participation x High Potential Value
  - Whilst high mileage drivers with medium / large battery vehicles, their lack of smart charging behaviour and ToU tariff usage suggests these consumers are less likely to participate in future domestic flexibility markets.
  - Potential levers to address this low potential participation include: -

Table 4: Potential levers to address low potential participation in domestic flexibility services

Lever	Description
Incentives	Incentivise use of smart charging features aligned with more regular plug-ins Reward switch to ToU tariffs Incentivise installers to encourage tariff switch at point of installation
Products	Simple Time of Use tariffs Simple discounts for ToU behaviour, e.g. reduced standing charge / bill credit
Engagement	Regular prompts / push notifications Account reviews and advice Monthly statements highlighting potential savings Clearer comms / customer training detailing smart charging benefits

- Cluster 3 – High Potential Flex Participation x High Potential Value
  - High mileage drivers with large battery vehicles, high adoption of App features to optimise smart charging and high usage of ToU / dynamic tariffs suggests these consumers are more likely to participate in future domestic flexibility markets.
  - Potential levers to address this high potential participation include:-

Lever	Description
Incentives	Acknowledge and Reward regular 'plug-ins' Share 'Flex' benefits Encourage other 'smart home' behaviour and adoption of other LCT's
Products	Type of Use EV tariffs Broader 'smart home' ToU tariffs
Engagement	Regular cost saving / reward statements CSR reporting – CO2 savings Lowest CO2 savings / highest DSR peer group recognition Regular energy tariff updates / best ToU tariff for you

- Feedback from Citizens Advice from previous DSR, Smart Home and Smart Metering trials suggests the following considerations should be incorporated into any future testing of these segments: -
  - Transparency – Clear information about energy contracts being signed up to.
  - Risk Mitigation – Customer have control over their data and have assurances they won't be left without energy or other services.
  - Education – Access to good quality, independent advice.
- It was also recognised that whilst this analysis was a build on the previous CrowdFlex: NIA learnings, the EV market is still at an early stage of maturity which is likely to be impacted to a greater mix of 'engaged' consumers versus the norm.
- This is also particularly true of consumers accessing LCT's / Heat pumps and other smart home devices. As this behavioural / technical segmentation model is developed further to encompass other flex potential devices (other than EV charging), consumer adoption rates and likely levels of engagement will need to be considered.

2.4.5 Next steps

- The proposed quantitative segmentation approach has been recognised as a pragmatic first step to assist the development of a robust methodology for forecasting domestic 'flexibility' potential.
- However, recognising the challenge from Citizens Advice's previous experiences in developing consumer engagement, further considerations need to be addressed within CrowdFlex: Alpha: -
  - *Engaging with consumers and encouraging them to participate in domestic flexibility will be a key learning from the Alpha trials. Building upon the learnings from previous Smart Metering engagement projects, Alpha will need to address: -*
    - *How customers are communicated, and how they are educated, reassured, and motivated to participate.*
    - *How customers are incentivised / rewarded for participating in domestic flexibility with transparent products and services*
    - *How suppliers develop Time of Use / Type of Use tariffs to encourage greater participation in providing 'flexibility' for the future energy system requirements.*
    - *The impact of different interventions should be tracked, in order to identify those which are successful and for which customer segments.*
    - *Specialist consumer behaviour research may be required to enhance these approaches and ensure that the most effective approaches are adopted in the trial.*
  - *The EV market is still at a relatively early stage of maturity. As more drivers switch from ICE vehicles to EV's, this segmentation will need to be revised to recognise the expected changing mix of driver behaviour and battery technology.*
  - *LCT / Heat pump and smart devices markets, are also similarly immature. Incorporating customers adopting these new technologies is a key requirement for future segmentation, as the potential value of these households will be enhanced further with this increased 'flexibility'.*
  - *Forecasting tools / models will also need to incorporate this segmentation model to improve accuracy and reliability.*
  - *As the markets for EV's, Heat pumps and LCT's mature, forecasting models will need to be revised to constantly reflect market conditions and consumer segments.*

2.5 Trial dimensions: Technology attributes

CrowdFlex: Discovery determined the categories of technical parameters they would need flexible domestic assets to prove they can meet to provide the full set of services as described in Task 1. The table below is the outcome of a number of discussions with respondents and lists the categories and key items that need to be considered when determining what to test in CrowdFlex: Alpha.

As the response from individual assets is relatively small compared to the needs of the grid, it is inevitable that the service which is provided will be a portfolio attribute - the coordinated response of all the assets under control of the aggregator. This is important to note, as the flexible capability of a single asset will be very different from a portfolio comprised of those assets. For example, Ramp Rates, Duration of response, Persistence: these all can be tuned at a portfolio level to meet the specific requirements of each service. Due to this, a comprehensive list of technology attributes is not possible, because the technology only partially informs how the portfolio meets the requirement of each service.

Therefore in addition to the parameters in the table below, services will also require the portfolio to have certain parameters such as:

- Size of response – e.g. MW of response provided relative to the baseline demand
- Direction of response – e.g. increase or decrease, of supply or demand, relative to the baseline
- Length of response – e.g. 30 minute or 4 hour delivery duration

Table 5: Technical delivery requirements.

	Parameter	Description and examples of parameter settings to be tested	
	Service category	**PAS-Routine**	**PAS-Response**
1	**Notice Period**	**This is the advanced notice given to the asset to perform a service.**	
		Service contracted via defined windows (e.g. day-ahead contract for flex within defined HH period, via a ToU tariff)	N/A for frequency services which require very short notice period. Automated response test cells required
			For Capacity Avoidance and Network services, firm capacity needs to be declared well ahead of notice/dispatch. Consider separate Big Turn Up/Down trials exploring Opt in and Opt out alternatives, with automated dispatch
2	**Daily/Seasonal timing of trial**	**This specifies when a trial should be run, to demonstrate reliability of flexibility, (either to meet entry requirements for markets or provide commercial confidence in the level of response to the aggregator).**	
		Service delivery within defined windows; trial should establish statistically reliable predictions of portfolio capacity during those windows.	Portfolio capacity to be evaluated at or close to system stress events corresponding to each service the asset provides. Repeated tests may be needed to provide sufficient confidence (and minimise any derating needed to firm the capacity)
3	**Persistence**	**This is the maximum number of consecutive events that a service might be called**.	
		N/A: CrowdFlex NIA showed response was sustained despite repeated calls via ToUT.	For each service, CrowdFlex should identify historical patterns of repeated calls for service, and design trial to test capacity under these conditions. Trial should determine impact of both Routine and Response being called over the same time frame.

4	**Firmness of supply**	**The extent to which a given level of asset response can be guaranteed. This would be an outcome to be measured.**	
		For BAU, trial should provide aggregator with sufficient confidence to enter a firm capacity into markets with minimal impact of derating factor. For PDF, trial should improve precision of projections	For BAU, firm portfolio capacity required. Trial should determine reliable capacity and provide evidence to minimise impact of derating factors.
5	**Location**	**Geographic information on the location of the asset**	
		The ESO requires knowledge of which Grid Supply Point to know whether assets at that location can solve a network constraint (reduce wind curtailment)	
		The DSO may require very high geographic resolution as there may be clustering of demand (such as adoption of EVs, or resistance heating) and associated DN challenges. It will need to be recorded if the asset is in an Active Network Management zone as this will constrain response.	
6	**Ramp rates**	**This is the rate of change of flexible response over time**	
		Stakeholders were concerned about signals reducing the natural diversity of demand, signals coordinating rapid responses/step changes in demand, and gaming (changing baseline conditions to inflate benefit of response). Trial should demonstrate how erosion of baseline consumption diversity can be avoided.	
		A portfolio of assets will need to demonstrate ability to control ramp rates of the portfolio (i.e. a test cell which specifies a ramp rate, and sends a staggered control signal to the assets in the portfolio, and measures response)	
7	**Asymmetry of response**	**This is the difference in turn up versus turn down capability of the asset.**	
		Asymmetry of flexible response will need to be determined in order to enter the appropriate capacity into markets. An asymmetric response would need to be declared.	
8	**2nd Peak Effects**	**The potential for control signals to shift in time (rather than eliminate) demand.** Reducing demand at certain times could result in an (unwanted) increase in demand in subsequent periods. This may be more problematic when shifting assets such as heating, as more energy might be required overall. Stakeholders may specify that portfolio dispatch algorithms are quality assured such that unintended 2nd peak effects are not possible.	

- *CrowdFlex: Alpha should determine, for each of these parameters, the distinct levels or settings to test. It should then group these settings as appropriate to construct the specification for each test cell (trial).*
- *CrowdFlex: Alpha should also determine a prioritisation of which parameters / combinations of parameters that should be tested in a trial.*

3 Understanding the impacts of statistical nature of the domestic flexibility asset

Domestic flexibility is a new type of asset for grid operations. It is essentially a probabilistic resource - quantifying and predicting this relies on a i) statistical forecast of demand, ii) an understanding of the maximum potential shift in demand and iii) the likely outturn shift in demand. These quantities vary based on time of day and day of the week, they have different magnitudes on the up and down sides, and are influenced by customer participation. CrowdFlex seeks to make this available as a resource to grids. To do this will require better forecasting of demand and flexibility, developing system operator capability to use probabilistic / distribution forecasting, and translating expectations of flexibility from distribution to point forecasts with accuracy. These are key tasks for the CrowdFlex project to look into – not just testing levels of flexibility, but developing reliable frameworks for forecasting and building capability for deploying this resource. Plus contribute to a possible output of combining with the Virtual Energy System (VirtualES) to build a digital twin for demand and flexibility.

For this section of CrowdFlex Discovery, we seek to understand the nature of flexibility as a statistical asset by looking at existing approaches for flexibility and demand forecasting, to investigate how system operators handle variable resources, and to look at the application to VirtualES.

Core recommendations for Alpha:

- *Plan general improvements in demand and flexibility forecasting, including*
    - *Research best in class demand forecasting methodologies and create detailed methodology for probabilistic demand forecasting*
    - *Create detailed methodology to move from today's static flexibility forecasting to dynamic half-hourly flexibility forecasts and possibly more granular minute-by-minute forecasts for fast responding or short duration flexibility services*
    - *Incorporate locational granularity into demand and flexibility forecasting e.g. at grid supply point (GSP) for ESO and potentially street level for DSOs*
    - *Develop a methodology for translating probabilistic flexibility forecasts into deterministic point source estimates for use in system operations*
    - *Determine the best method(s) for decomposing the forecasting of demand and flexibility into constituent underlying factors, and for modelling a counterfactual baseline*
- *Engage with system operators to help develop use of probabilistic forecasting and statistical methods, including*
    - *Investigate inputs necessary to support stochastic forecasting in ESO/DSO decision-making, for example in:*
        - *ESO Control Room demand forecasts*
        - *Reserve setting*
        - *Acceptance and dispatch of flexibility offers from aggregators of domestic assets*
        - *System planning and network upgrade decisions*
    - *Investigate the extent to which it is more appropriate for system operators to devise their own forecasts, compared to leveraging those from aggregator partners*
- *Coordinate with VirtualES program to scope a domestic demand and flexibility digital twin:*
    - *Possible areas for Alpha include the following, with 1-2 areas to be selected as priority in Alpha, once more information from VirtualES programme is available:*
        - *Understand how the National Digital Twin Programme information management framework (IMF) applies to a VirtualES demand and flexibility model*
        - *Understand how the Common information Model (CIM) applies to a VirtualES demand and flexibility model*
    - *Decide on specific use case for the model to deliver and undertake analysis to determine what a minimum viable product would be*
    - *Investigate the availability of necessary datasets for model functionality and propose methods to ensure that any lacking datasets are made openly available.*
    - *Decide on the model sub-structure and whether the model is bottom-up or top-down*

3.1 Domestic flexibility forecasting - statistical techniques & inputs

Previous studies and general experience in the market make it clear that flexibility is an inherently different type of asset to large-scale generation, industrial or commercial point sources of demand, or energy storage. Domestic flexibility is distributed, highly reliant on customer behaviour, variable on time of day and underlying demand, and has asymmetric amounts of turn up and turn down potential. The complex interaction of different components of demand and sources of flexibility make it hard to solve in a deterministic sense how much flexibility potential there is at any given moment. This makes flexibility potential, expected outturn and dispatchability hard to predict. A core objective of the CrowdFlex programme is to i) create a common definition of various aspects of flexibility; ii) use statistical techniques to improve forecasting on the flexibility provider and system operation sides; iii) facilitate adoption and use of flexibility in grid operations. To do this, we need to start from an understanding of current approaches and identify areas for improvement. This section looks at existing approaches for forecasting, statistical methods that could be used, and makes recommendations for Alpha phase.

At a high-level, we propose the following modelling approach:

1. Demand forecast (baseline/counterfactual) – forecast demand per household per half hour
2. Flexibility potential (i.e. max up and down shift) forecast – forecast max shift possible per house for each flexibility delivery period based on historical & known loads
3. Expected flexibility outturn forecast – forecast expected deliverable flexibility over a single period based on participation and depth estimates applied to the flexibility potential forecast.

The intention is that stages 1 and 3 should be probabilistic, but stage 2 will be deterministic as it consists of the maximum and minimum bounds on potential outturn. As well as carrying through the output of each stage to the next, the model will be able to output results from each stage for external use. For stages 1 and 3, this could either be a distribution forecast or a point forecast computed by collapsing the distribution to a single point (for example based on historical average participation for the given delivery period). A discussion of the classes of statistical approaches that might be used in model stages 1 and 3 can be found in Section 3.3.3, though final model design will need further investigation in Alpha and beyond.

Note: The CrowdFlex programme is focused on domestic flexibility. Any references to demand or flexibility refer to each in a domestic context, unless otherwise indicated.

3.1.1 Review existing forecasting approaches for demand and flexibility

To operationalise domestic flexibility, better prediction is needed around both demand and flexibility.

Demand forecasting is a well established process. In the past, underlying household electricity demand was mainly dependent on weather patterns and stable over time. This meant a reliable forecast could be derived from looking at historical days with similar weather patterns and adjusting for day-specific events (e.g. the classic example of demand pick-ups during sporting event intervals as Brits put the kettle on). Another common demand forecasting approach is to use profile coefficients. Profile coefficients give an estimate of household half hourly load shape across different seasons and day types (weekday, Saturday and Sunday), with data sampled from several thousand energy users. Forecasters use the shapes and customers' expected annual consumption to predict demand on a given day.

There are a couple of trends that are creating more permanent shifts in demand and starting to see usage change from purely historical levels. First, household or other embedded renewable generation is realised as a negative demand; second, the growing use of electric heating and electric vehicles will lead to higher household loads; and third, the growing use of time of use (TOU) tariffs are explicitly shifting customer demand out of peak times, not always in a predictable manner especially for dynamic TOU tariffs that change on a half hourly basis (Economy 7 is an established tariff but is more predictable).[34] While these trends are in early stages, compared to expectations in e.g. National Grid ESO Future Energy Scenarios, they are already starting to have an impact and new methods are needed to predict variable, distributed renewable generation and the impact of new loads, which can also be variable according to prices or household behaviour (demand forecasting at National Grid ESO is discussed in more detail in Section 3.2).

Compared to demand forecasting, flexibility forecasting is more nascent. The most common approach is a static estimation of dispatchable load from specific low carbon technologies (LCTs). The type of LCT often has specific influences on flexibility potential. For example, if a customer has 7kW electric vehicle supply equipment - this can provide 7kW of turn up on demand when the car is plugged in or 7kW of turn down while the car is charging. The flexibility provider would normally de-rate by expected plug-in rates, normally 2-3 times per week. The typical energy load informs how many hours of charging a customer would need per night (akin to the width of 7kW charging on the load curve).

Providers also need to consider the baseline position in forecasting flexibility. The baseline is important for establishing a counterfactual of what the household would have done. Different groups have proposed

[34] See CrowdFlex: NIA Final Report for more detail on how time of use tariffs influence demand

baselines, including ENA Open Networks WS1A P7 and WPD for its Sustain-H trial, but no consensus exists on the best option for domestic. These baselines tend to revolve around nomination (i.e. the provider commits to a position the asset will take, which is followed if the asset is not dispatched), historical (i.e. looking at a period one year or several days prior), or reference (i.e. standard curves of behaviour for LCT assets based on observed experience). This is an area where more work would be useful.

Flexibility forecasts must be made in a communicable form. Often this comprises a single point estimate for the baseline and another for a (fixed) magnitude of deviation from the baseline over a given window. However, this does not capture uncertainties nor bounds on the potential range of flexibility magnitudes that could be utilised. PAS 1878[35] proposes an improvement on this, whereby at least three power-time traces are forecast and communicated: 1) intended operation; 2) most delayed); 3) least delayed. In this way, bounds are provided for the ability to enact a demand shift. This should be explored in CrowdFlex Alpha, alongside investigations of how to encode uncertainties on the range of potential deviations from the baseline.

CrowdFlex Alpha should:

- *Research best in class demand forecasting methodologies and create detailed methodology for probabilistic demand forecasting*
- *Create detailed methodology to move from today's static flexibility forecasting to dynamic half-hourly flexibility forecasts and possibly more granular minute-by-minute forecasts for fast responding or short duration flexibility services*
- *Plan how to incorporate locational granularity into demand and flexibility forecasting e.g. at grid supply point (GSP) for ESO and potentially street level for DSOs*

3.1.2 Identify key parameters / variables for forecasting demand and flexibility

Demand and flexibility forecasting rely on a wide set of parameters with complex interactions, a list of the main ones is given in Table 6. We split these into three categories - i) Demand – informing the forecast of baseline position; ii) Flexibility Potential – informing the forecast of maximum turn up and down; and iii) Expected Outturn – the expected amount of actual outturn for a given period.

Table 6: List of key parameters for demand and flexibility.

Category	Parameter	Effect	Relevant to Alpha
Demand	Temporal - time of day, day of week, season	Influences load curve shape	High
	Weather - solar irradiance, external temperature	Influences load curve shape	High
	Expected annual consumption	Influences total consumption and peak demand	High
	House characteristics - house type, size of house, number of occupants	Influences total consumption and peak demand	Medium
	Residence type - rural or urban, house of flat	Influences total consumption and peak demand	Medium
	Energy supply - electricity only or dual fuel	Influences total consumption (i.e. homes with electric only appliances have higher electric load)	Medium
	Heating - electric or gas heating; insulation quality	Influences total consumption and load curve shape	Medium
	LCT presence - electric vehicle, heat pump, battery, etc.	Influences total consumption and peak demand (including secondary peak for shifted demand if using with TOU tariff)	High

[35] British Standards Institution, PAS 1878 Energy smart appliances - System functionality and architecture – Specification, 2021

	Tariff structure - flat vs. static or dynamic time-of-use	Influences demand shape	High
Flexibility potential (up and down maximum)	Peak & minimum household demand	Sets min and max for underlying household load	High
	LCT power rating	Sets min and max for LCT	High
	Automation - third party asset scheduling vs direct customer action via notifications or tariff signals	(Time-of-day dependent) derating to flexibility potential	High
Flexibility expected outturn (forecast actual flexibility)	Participation - manual vs. automated flexibility & expected values	(Time-of-day dependent) derating to flexibility actual	High
	Expected kW depth	May derate flexibility potential (if customer flexes only part of consumption)	High
	Time since last flexibility window	Influences shiftable load	High
	LCT availability (EV) - plug-in, plug-out times, driving load	Influences EV flexible capacity	High
	LCT availability (heatpump) - required heating load, external temperature, insulation quality	Influences heatpump flexible capacity	High

CrowdFlex Alpha should:

- *Consolidate these parameters with any other variables listed in the report and from Ohme segmentation, and build a statistical model based on these parameters*

3.1.3 Describe probabilistic demand forecasting approaches

The CrowdFlex project is investigating the provision of flexibility services from domestic assets. Unlike dedicated flexible assets such as grid-scale batteries, a key property of domestic assets is that their use for flexibility provision is bounded by a primary objective: for example, transport using an Electric Vehicle or home heating using a Heat Pump. As a result, the flexibility potential of this asset class is dependent on a wide range of factors. When quantifying this potential, even if many influential factors are considered, it will never be possible to exactly capture the dependencies underpinning the available flexibility; to capture this uncertainty, the model must be *probabilistic.*

A system operator is responsible for balancing supply and demand in real time. Given the uncertainty present, the system operator is therefore tasked with *stochastic optimisation* when it enacts any decision problem incorporating domestic flexibility. By this, we mean that decisions must be made while taking into account the inherent risk involved in choosing one dispatch action: in this case the potential for supply and demand to be out of balance, resulting in unexpected costs to take emergency balancing steps: such as paying generators above-market fees to increase supply or specific loads to switch off. Stochastic optimisation must encode potential deviations in modelled variables - usually through scenarios or probability distributions - and collapse this complex information into a single decision via cost functions such as the expected total cost or minimax regret (choose the scenario that has the least potential cost).

To perform real-time balancing, the system operator considers timeframes from years to fractions of a second ahead of real time, with the intention to achieve reducing imbalance residuals at each stage, down finally to a perfect balance in real time. These timeframes tend to be partitioned into different groups, allocated to different teams within the system operator. Usually, *system planning* occurs at timescales from months to years ahead of real time, when infrastructure investment decisions are made. At days to minutes ahead, *balancing* actions are taken, followed by *frequency response* with more onerous requirements on response times and delivery behaviour.

As balancing decisions take place ahead of real time, *forecasting* is required to estimate the system state at the point of operation. The system state tends to be split into two categories: 1) system balancing requirements; and 2) available flexibility. This split is convenient, as it allows for service operators and service providers to each retain proprietary information, but it relies on a successful information sharing at the boundary between these two entities. As both the system needs and available flexibility are stochastic (uncertain; not able to be precisely modelled), *stochastic forecasting* is required. Key questions exist around the extent to which this forecasting is undertaken by the aggregator or by the system operator. While interviews indicate that ESO will require flexibility providers to do their own forecasting and submit point-source forecasts, providing probabilistic or distribution forecasts of demand or flexibility may help system operators improve decision making. To date, services have tended to be framed around large, dedicated assets for which the available flexibility is able to be precisely known based on historical inputs. The services have been set up so that a single value for the available flexibility is communicated from the aggregator to the system operator and the system operator incorporates this into its stochastic optimisation problem (note: this is still a stochastic problem as other variables remain uncertain, even if the available flexibility does not). In order for domestic assets to take part in such a framework, the aggregator must therefore approximate the aggregate stochastic flexibility with a point estimate. Given that this is decoupled from the decision-making process, it tends to lead to sub-optimality on a system level, as either 1) the aggregator allocates too much headroom to ensure delivery, leading to underutilisation of assets; or 2) the aggregator allocates too little headroom and under-delivers in its promised flexibility provision (which is assumed to be provided in full by the system operator). In addition, the decision of headroom allocation is not factored into decisions at planning timescales.

To overcome these issues, stochastic forecasting must be explicitly incorporated into system operator decision making processes and probabilistic information shared at the information boundary between the two entities. We propose the adoption of probabilistic forecasting outputs in the following settings:

- ESO Control Room demand forecasts
- Reserve setting (currently a point estimate produced as the 97.5th percentile of a probability distribution on the demand forecast errors)
- Acceptance and dispatch of flexibility offers from aggregators of domestic assets
- System planning and network upgrade decisions

Even with probabilistic information being communicated between entities, the exact information sharing framework remains an open question. For example, does the system operator plan the build-out of its network based on its own forecasts, or leverage data from aggregator partners (see, for example, UKPN project Envision[36])? In either case, the sharing of richer information between parties is necessary in order to target a global optimum. To date, forecasting has been split among a variety of companies, targeting different subsections of the information landscape from primary variables such as temperature through to available flexibility. The CrowdFlex project intends to explore unifying techniques and increasing transparency of data sharing. As described later, the intention would be to ensure that the demand and flexibility forecasting module produced during the project was compatible with a wider Virtual Energy System model, by adhering to data sharing and model verification standards.

A key consideration in stochastic optimisation and forecasting is that the solution space tends to be intractably large; a typical approach in such a setting is to use *sampling* to explore the space. The datapoints chosen need to form representative scenarios that would be under consideration by ESO, however tailoring these models to work in realistic situations requires many trials of these situations during training, to fine-tune the models. Often, starting with simpler models and adding complexity is the best solution to scale, since the use of complicated models over small sample sizes leads to poor results. In addition, a means to convert from many scenarios to a single solution is needed by the system operator: examples of this include computing the expectation or minimax regret. Again, probabilistic information must be shared at any boundary between ecosystem players in order to target a global optimum. Entities might communicate probability distributions, or error bounds as proxy for these.

CrowdFlex Alpha should:

- ➢ *Develop a methodology for translating probabilistic flexibility forecasts into deterministic point source estimates for use in system operations*
- ➢ *Determine the best method(s) for decomposing the forecasting of demand and flexibility into constituent underlying factors, and for modelling a counterfactual baseline*

CrowdFlex Alpha could:

- ➢ *Investigate the extent to which it is more appropriate for system operators to devise their own forecasts, compared to leveraging those from aggregator partners*
- ➢ *Investigate inputs necessary to support stochastic forecasting in ESO/DSO decision-making, for example in:*
    - ○ *ESO Control Room demand forecasts*

[36] https://innovation.ukpowernetworks.co.uk/projects/envision/

- Reserve setting
- Acceptance and dispatch of flexibility offers from aggregators of domestic assets
- System planning and network upgrade decisions

➢ *Compare a range of model complexities and probabilistic outputs*

3.1.4 Review segmentation approaches in industry

Typically, flexibility forecasting is achieved via demand forecasting. While domestic flexibility is relatively new, domestic demand and its forecasting is not. As the set of domestic customers, and therefore potential flexibility participants, changes, a key question for the aggregator is the extent to which the consumption of existing customers (for which the aggregator has historical data) can be used to predict the consumption of new customers (for which the aggregator does not have historical data). For an energy supplier, the solution to this problem directly feeds into procurement, hedging strategy and settlement. An obvious starting point to solve this problem is to assume that all customers match the same profile, for example computed by finding the average of the existing customer base. To improve on this, it is common to multiply the nominal profile by a coefficient based on factors such as weather and maximum likely demand (see Table 6 for a list of key parameters).

Alternatively, customer *segmentation* could be applied to assign customers the most relevant nominal profile corresponding to their *archetype* (the "typical" customer that is closest to the one under consideration). Segmentation is common across all industries and predominantly used for marketing purposes (see the Experian Mosaic[37] platform for an example of the type of functionality and insights commonly utilised). In the energy sector, this marketing application is also commonly considered.[38] Perhaps more relevant to the CrowdFlex project, however, is the use of segmentation in energy regulation.[39,40] Ofgem uses customer archetypes as a means to better understand consumer needs on a group-by-group basis.[41] Applied to the domestic flexibility setting, segmentation could be used to determine the function mapping static data (address, affluence, owned LCTs, and other factors) to demand, via three stages: 1) choosing groups of existing customers; 2) computing the expected profile for each group; and 3) assigning new customers to one of the groups. This process can be seen in the below figure.

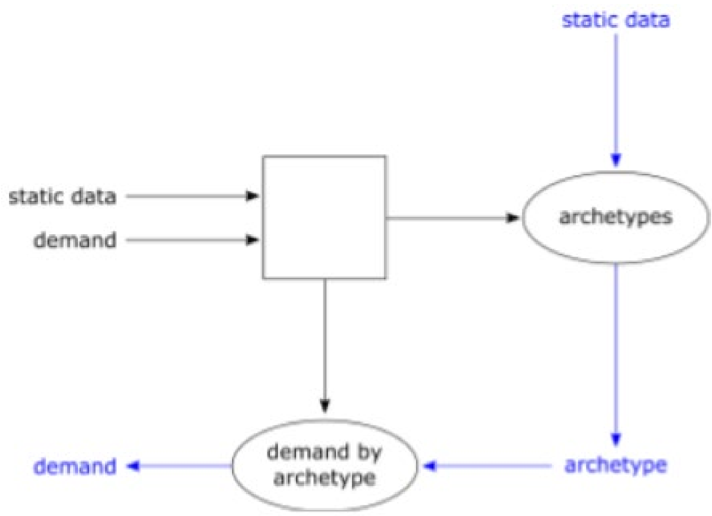

Figure 7: The process of creating archetypes and using them for demand predictions, Quantities in black correspond to existing customers, for which demand data exists, whereas quantities in blue correspond to new customers, for which predictions are needed.

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[37] https://www.experian.co.uk/business/platforms/mosaic
[38] https://www.pwc.nl/nl/assets/documents/pwc-customer-engagement-in-an-era-of-energy-transformation.pdf
[39] https://www.ofgem.gov.uk/sites/default/files/docs/2020/05/assessing_the_distributional_impacts_of_economic_regulation_1.pdf
[40] https://www.frontier-economics.com/media/4040/smarter-impact-assessments.pdf
[41] https://www.ofgem.gov.uk/sites/default/files/docs/2020/05/ofgem_energy_consumer_archetypes_-_final_report_0.pdf

A key parameter for this approach is the number of archetypes to consider, as there is a trade-off between under- and over-fitting the model to observed datapoints. In addition, as the number of segments grows large, the interpretability of customer groups quickly diminishes. Also important are the variables upon which to segment. When the output of the demand forecasting is used for flexibility forecasting, the penetration of Low Carbon Technologies is often used, being a key driver of both demand and available flexibility. Also important are statistics on power consumption (e.g. daily maxima/minima) and expectations of whether the flexibility will be enacted through direct dispatch or tariff signals and whether the response will be automated or manual; different response characteristics and certainty bounds will exist in each setting. CrowdFlex phase one included trials to investigate the effects of many of these variables on the available flexible capacity.

There are broadly two approaches to choosing the most representative archetypes: feature extraction and clustering. Feature extraction has the benefit of being more explainable, since the features are manually defined, but might lead to modelling biases such as missing out on a key cluster of behaviour when a particular feature hasn't been considered as a dimension. Clustering can lead to a lack of explainability, particularly if the number of archetypes is large, and can also incorporate biases if not all input features are considered. Once the archetypes are chosen, a single demand trace must be assigned to the group. This should be computed based on relevant data for all members of the group, an obvious example being the mean across the year of the historical demand traces (pointwise in time; perhaps with some smoothing applied). Static inputs used for the Ofgem segmentation that should be considered when choosing relevant archetype features in future stages of the CrowdFlex project include (see Table 6 for more comprehensive list of parameters):

- Whether gas is used for heating
- Energy consumption
- LCT ownership
- Home ownership
- Household composition

In addition, other factors that should be taken into account include:

- Dwelling size
- Quality of insulation

CrowdFlex Alpha could:

- ➢ *Explore the use of both feature extraction and clustering to choose archetypes, in order to compare relative performance.*

3.1.5 Methodology for identifying minimum levels of trial participants for a significant trial

A key consideration in the following phases of the CrowdFlex project must be the number of customers required for the trial in order to gain *statistically significant* learnings. The intention of the trial is to be representative of the wider GB domestic population and, as such, a large enough sample size must be chosen that the results can be extrapolated more broadly. Given the expected noise in the uncertain samples provided by each individual household, a key determination for the minimum population size is the extent to which *statistical smoothing* effects are observed, whereby the noise from individuals cancels out so that the aggregate behaviour is smoother and more consistent. By the Central Limit Theorem, the variance in the observed mean of the dataset will reduce as the population grows, leading to better and better results. However, there is clearly a practical limitation on the size of the population that can be included within the CrowdFlex trial. A trade-off must be made to choose enough trialists for representative results while maintaining practicality. We propose to use the mean annual demand trace, pointwise in time, to reflect each archetype's expected demand. Statistical significance will then be achieved when the maximum variance, as a proportion of the mean, observed across the 17,520 half-hourly periods is reduced to a low value (the exact threshold will be chosen during the alpha phase).

At a population level, the maximum normalised variance determines whether the choice of segments can be believed to be representative. This decision must also be made such that the number of participants allocated to each archetype is sufficiently large; as it will be the archetype assigned to the fewest customers that determines whether the trial is statistically significant or not. To determine this, analysis should be run on data from CrowdFlex Phase 1 to locate any inflection points in the variance of observed sample means, across a range of number, as well as definitions, of archetypes. We should also perform cross-validation (whereby a model is trained on part of the data and tested on the remainder) to ensure that we do not overfit these archetypes. By this we mean that we need to ensure not to define archetypes which capture the existing customer base overly precisely, at the expense that they do not extend well to new customers.

CrowdFlex Alpha should:

- *Investigate, and locate inflection points in, the variance of the sample mean (within each archetype) across a range of archetype choices, on the CrowdFlex Phase 1 dataset.*
- *Choose a threshold for the maximum allowable variance to correspond to statistical significance. This threshold will dictate the per-archetype sample size required in CrowdFlex Beta.*

CrowdFlex Alpha could:

- *Utilise cross-validation during archetype definition to avoid overfitting to observed data.*

3.2 Forecasting variable resources in System Operations – state of play and key gaps

3.2.1 Summary

Forecasting is a key skill for system operations. National Grid ESO (ESO) forecasts peak demand and generation buildout scenarios years in advance through its Future Energy Scenarios (FES) team, which is used to inform grid planning. Closer to real-time, ESO also predicts underlying demand and variable renewables production to understand system balance and set levels for reserves and other balancing needs. ESO uses a range of probabilistic techniques from Monte Carlo analysis in FES, to predictions of demand and renewables outturn, to derating for reserve setting. CrowdFlex undertook a series of interviews to understand the state of play, identify key lessons for forecasting from ESO for the project, and clarify key gaps where improved demand or flexibility forecasting could enhance ESO's current capability.

Key learnings:

- At the moment, ESO uses some statistical techniques in forecasting variable resources, especially for renewables. These are used as one input to operational reserves planning but the Control Room also uses a range of other inputs to then adjust, such as historical demand and weather forecasts.
- In general, demand forecasting is done at a very aggregated level, using 6 points in the UK that sum up to national demand. Usable individual home forecasts are not currently available.
- DSOs use Distribution Future Energy Scenarios (DFES), along with substation monitoring, data from trials as exist, and smart meter data to forecast daily peak demand at the substation.
- There are two distinct tasks that CrowdFlex should address: i) Improving inputs to ESO's forecasting of demand; ii) Providing domestic flexibility as a service including improving operational forecasting of flexibility. The demand forecast is needed for business-as-usual (BAU) balancing, the flexibility forecast is only needed if flexibility is used as a service for balancing.
- As a service ESO will probably look to receive deterministic, single estimates, though there is some appetite for improving sophistication of forecasting.
- Areas for further development or work are incorporating probabilistic forecasting into the process, something the Reserve Team are most interested in, as well as improving reliability of the baselining methodology.

CrowdFlex Alpha should:

- *Investigate providing ESO with a methodology for forecasting baseline demand and flexibility and investigate a process for quantifying forecast errors in flexibility forecasting*
- *Investigate the extent to which it is more appropriate for system operators to devise their own forecasts, compared to leveraging those from aggregator partners*

CrowdFlex Alpha could:

- *Investigate inputs necessary to support stochastic forecasting in ESO/DSO decision-making, for example in:*
  - *ESO Control Room demand forecasts*
  - *Reserve setting*
  - *Acceptance and dispatch of flexibility offers from aggregators of domestic assets*
  - *System planning and network upgrade decisions*
- *Inform better forecasting of demand and/or flexibility in a couple of areas:*
  - *The FES team would like more insight on the uptake of domestic assets and smart charging to better forecast the capacity of available DSR.*

- *The National Demand forecasting team indicated that the CrowdFlex model should look to provide extrapolated data about GB demand, as well as more insight into how the counterfactual works.*
- *CrowdFlex should investigate whether consumers reduce their demand permanently, or shift it outside of peak time slots, so that we can better understand whether there is a net energy change.*
- *It would also be helpful to have visibility of each GSP where demand could be shifted to help with planning, as well as a breakdown of the baseline to have visibility on which Behind-the-Meter (BTM) assets it is made up of. The conversations with system operators informed service requirements - to be considered in Alpha:*
- *In the near-term at least, NGESO services will require point source forecasts, not probabilistic estimates. The responsibility will lie with the flexibility provider to translate the probabilistic resource into a deterministic estimate.*

3.2.2 Methodology

The aim of this section was to understand the current state of play in forecasting and statistical analysis in ESO and Distribution System Operators and see what lessons could be learned for the CrowdFlex project.

We interviewed people in a range of different functions across National Grid ESO and DSOs to understand approaches for forecasting variable resources, including how demand, wind and solar are forecasted, how these are used in operational planning and setting reserves requirements, and identifying barriers to flexibility and opportunities for greater use of statistical methods.

Interviews included:

- ESO Future Energy Scenarios analysis team
- ESO Labs & Data Science
- ESO Strategy & Energy planning
- ESO Reserves planning
- ESO National Demand Forecasting
- ESO Markets Development Team
- DSO Forecasting Team

3.2.3 Interview summary

One of National Grid ESO's main functions is to ensure the system is balanced at lowest cost. Fulfilling this role requires a complex set of forecasts for different resources conducted at different timescales across different teams (Figure 8). We spoke to a range of these teams to understand how forecasting is used in system operations, the techniques used and any key gaps.

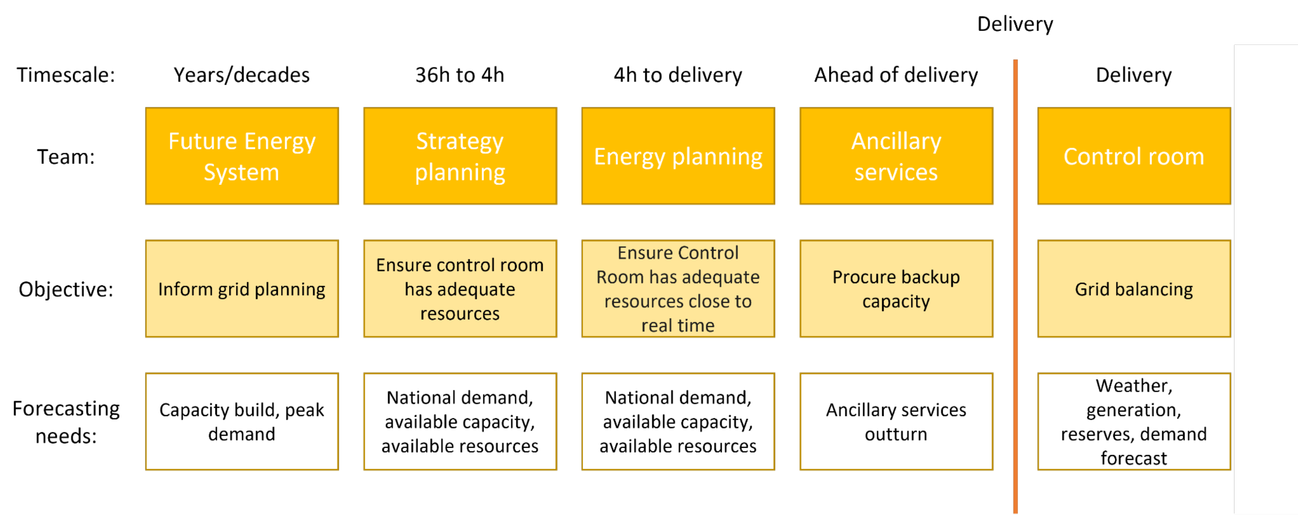

Figure 8: Map of forecasting in National Grid ESO.

Future Energy Scenarios (FES) planning

- **Objective:** Forecasting scenarios of energy system evolution through to 2050 to inform system planning.
- **Approach & relevant statistical methods:** The FES team creates a forecast of demand out to 2050 for four different scenarios based on uncertainties around the speed of decarbonisation and the level of societal change. Currently, the effects of demand-side response on peaks is modelled based on uptake of time-of-use tariffs, the driver being ownership rates of EVs and heat pumps, with a randomised delay to reflect the replacement lifecycle. Forecasting approaches include Monte Carlo techniques and triads vs. triad-avoidance methods.
- **Key gaps (if any):** A key blocker to more sophisticated forecasting is problems with data, such as small sample set sizes, short lifecycle and inconsistencies; moving towards a higher granularity at a more regional understanding would improve representation.
- **How CrowdFlex could inform this:** To expand forecasting capability around domestic flexibility, FES would like more information on consumer uptake of domestic assets and smart charging to better model consumer choice and forecast the capacity of available DSR. Better understanding the baseline for long-term forecasting would also be valuable, as well as ramp rates (particularly of 30 minutes or more).

ESO National Demand Forecasting

- **Objective:** The National Demand Forecasting team use mathematical models to forecast demand from day-ahead to 3 years ahead, which is also used as advice within-day by the Control Room engineers.
- **Approach & relevant statistical methods:** The current methodology takes national demand, adds distributed wind and PV to get a stable shape, forecasts that stable shape at Cardinal Points, fills it in to get half-hourly forecasts (48 numbers), and then subtracts the forecast for wind and PV - this takes the forecast down to a half-hourly national demand curve, which can then be aggregated back to Cardinal points. The forecast models are reviewed twice a year, when the clocks change. The range of uncertainty comes from wind speed uncertainties and solar radiance uncertainties, for example.
- **Key gaps (if any):** In order to model total GB demand, the total GB outturns are needed - more sophisticated forecasting models could then be built from this data. Another main gap is concerns relating to the methodologies used to determine how much effect demand services have (i.e. having to model on the counterfactual).
- **How CrowdFlex could inform this:** The team indicated that CrowdFlex model should look to provide extrapolated data about GB demand, as well as more insight into how the counterfactual works. Ideally, data per settlement period on how much domestic demand has been used for the last 10 years should be provided, to better inform changes over time and future. The feasibility of this is for CrowdFlex to pick up in Alpha, subject to GDPR and data privacy restrictions.

ESO Strategy & Energy Planning

- **Objective:** The Strategy & Energy Planning team forecast demand at energy management timescales (4-0 hours) and strategy timescales (36-4 hours).
- **Approach & relevant statistical methods:** The core forecasting process looks at historical data, maps that forward, and then adjusts demand based on what has previously been seen. Demand is taken as a single point-source estimate (the sum of controllable generation), and then a probabilistic assessment based on historical error is used to forecast the reserve requirements.
- **Key gaps (if any):** Demand signal is becoming increasingly polluted by generator and behaviour change - there is an open question on what National Grid ESO should be modelling (e.g. demand forecast, EV uptake, Time of Use uptake) and what suppliers should be providing. Going forwards, the Control Room would like to see more probabilistic methods in the tools used so that specific adjustments to the demand number could be made, for example. Updated demand forecasting in energy management timescales would also be helpful (4-0 hours), as well as a layered forecast to include a pure baseline, the Time of Use adjustment, and the Flexibility Service adjustment.
- **How CrowdFlex could inform this:** CrowdFlex should investigate whether consumers reduce their demand permanently, or shift it outside of peak time slots, so that we can better understand whether there is a net energy change. It would also be useful to develop a demand forecast for the Control Room, which can then be extrapolated up to national interest.

- **Any other key learnings:** There has been significant behaviour change because of the pandemic, but day-on-day people are fairly consistent in what they do. Anything in the Balancing Mechanism is used in price order - it doesn't matter what it is as long as the characteristics are met.

ESO Reserves Planning

- **Objective:** The ESO Reserves Planning team forecast the operational reserves required, i.e. the amount of electricity that needs to be procured to account for any change in the system plan.
- **Approach & relevant statistical methods:** A reserve requirement is forecast for summer and winter. There are 10 Cardinal points, which are the inflection points on the demand curve shape. These change throughout the year depending on the season, and each require different reserve levels (both positive and negative). They are based on data from 3-years prior for each season. Reserves are currently set.
- **Key gaps (if any):** The Reserves Planning team need a forecast for four hours ahead of time, for the 10 Cardinal Points of the day, at national level and with a 30-minute time step.
- **How CrowdFlex could inform this:** One use case of the CrowdFlex demand forecasting model should be to fill the aforementioned gaps by improving the demand forecast
- **Any other key learnings:** The Dynamic Reserves Setting project has been looking at new ways of forecasting operational reserves in a more dynamic way, by calculating the total system requirement error based on historic time series of the wind forecast error. Similarly, the Control React project is looking at how visibility on forecasting uncertainty can be provided to the Control Room.

ESO Labs & Data Science

- **Objective:** The Labs & Data Science team use machine learning to forecast demand and how weather will impact solar and wind production in GB.
- **Approach & relevant statistical methods:** Historically, a load-factor model based on capacity and solar radiance in certain areas of the country was used to forecast solar. Now, an expanded model using machine learning that inputs data points such as radiance, wind direction, speed and temperature is used, to output 8-9 different predictions. These are then merged into a single solar output prediction using a 'meta' neural network model. The ensemble set of predictions aren't visible to the Control Room, only the meta prediction. The Control Room does not tweak the wind or solar forecasts, instead they adjust the demand forecast ahead of time depending on their experience and instinct on solar, wind and demand. Wind, on the other hand, is forecast fairly differently: for BMU wind historical out-turn data is used to produce curves, which wind speed and direction is then applied to.
- **Key gaps (if any):** One of the biggest gaps in forecasting capability is weather data: The data fed through the model is a mean of a huge ensemble of satellites with different scenarios, so there is no view of the most likely scenario.
- **How CrowdFlex could inform this:** To bring evolution to the Control Room, better models and forecasts to be developed. The CrowdFlex model should therefore be designed so that it can be extrapolated up to national interest as well as go hand-in-hand with the general IT evolution. It would also be helpful to have visibility of each GSP where demand could be shifted to help with planning, as well as a breakdown of the baseline to have visibility on which Behind-the-Meter (BTM) assets it is made up of. Weather will likely be an input into any demand digital twin, and lessons could be learned from this team.

ESO Markets Development Team

- **Objective:** The Markets Development Team works with stakeholders to develop electricity market roadmaps for the ESO.
- **Approach & relevant statistical methods:** The current baselining methodology involves a physical notification (PN) provided 60 minutes ahead of time. The operating profile of the asset is then locked-in through the PN, and any generators/demand users who stray away from that demand baseline when not instructed will be charged. Alternative methodologies are being investigated, such as using a virtual meter to differentiate between site load and individual assets within the site, as well as a methodology looking at 10 previous days of consumption.

- **Key gaps (if any):** The key concern at the moment is with recent history baselining: with large changes in weather, seasonal effects, and increasing uptake of EVs for example, usage patterns can be very variable.
- **How CrowdFlex could inform this:** The CrowdFlex model should look to improve the reliability of the demand forecast, as well as providing a higher locational granularity to give visibility on potential clashes between distribution and transmission connected assets. Different services need different frequency of metering e.g. 20Hz for dynamic containment vs. 1Hz for operational metering, which may make it hard for standard residential half hourly meters to capture.
- **Any other key learnings:** In the future, the ESO want to have an API upload to make it much easier to upload a large group of assets.

DSO Forecasting

- **Objective:** DSO forecasting teams have two forecast focuses: 1 year to 10 years out, then a load model for closer to real-time.
- **Approach & relevant statistical methods:** DSOs use a mix of top-down and bottom-up approaches: they look at HV monitoring at primary substations, profile classes & Estimated Annual Consumptions (EACs), previous observations in trials and smart meter data. They can now forecast daily peaks and are progressing this further. They also use DFES, which take a steer from FES as well as any engagement with DSOs, community groups and the local authority. The first couple of years is almost wholly informed by the DSO pipeline, and after that the FES starts to take over.
- **Key gaps (if any):** At the moment, key barriers to accurate forecasting models at scale include a lack of data availability due to challenges around data privacy, for example.

Glossary

- Distribution Future Energy Scenarios (DFES): A range of credible futures for the growth of the distribution network, taking a steer from FES as well as any engagement with DSOs, community groups and the local authority.
- Estimated Annual Consumption (EAC): An estimated rate of consumption, nominally expressed in kWh/Year
- Future Energy Scenarios (FES): A range of different, credible ways to decarbonise the UK's energy system to meet the 2050 Net Zero target.
- Monte Carlo techniques: Simulations used to model the probability of different outcomes in a process that cannot easily be predicted due to the intervention of random variables.
- Physical Notification (PN): a notification from a generator or a supplier of the amount of electricity that it intends to produce or consume in a given half-hour period.

3.3 Improving domestic flexibility forecasting through the Virtual Energy System

National Grid ESO and others are developing a Virtual Energy System (VirtualES) - including a common framework for enabling the development of an ecosystem of connected digital twins for the GB energy system. One potential output for the CrowdFlex programme is to develop a digital twin around domestic demand and flexibility. This would be a mechanism for improving forecasting of these variable resources and making this available to system operators.

In Discovery, we sought to make an initial survey of how this model would work. We interviewed the VirtualES team to understand requirements of a new digital twin, scoped out use cases for domestic flexibility, propose a high-level structure for how the model will work, and identified key gaps that could be filled with more data.

3.3.1 Requirements for a digital twin from VirtualES common framework

National Grid ESO is actively working to develop thinking around the VirtualES that it will develop moving forwards, including the feasibility phase of a SIF-awarded project that is running concurrently with the CrowdFlex project. As such, this thinking is in its early stages and is predominantly focussed on high-level principles and common frameworks that will be applied in the future.

From a high-level perspective, it is envisioned that the VirtualES will be formed of a collection of modules, each covering a different aspect of the energy system as a whole, for example:

- Transmission network
- Distribution network
- Wind production
- Solar production
- Domestic demand
- Commercial demand

A potential application for the CrowdFlex project would be to develop a domestic demand model that can interface with the rest of this system; while remaining generically applicable across a range of other settings as well. Open questions remain around the extent to which this module should attempt to capture *national* domestic demand, via extrapolation, or be restricted to the set of customers that are covered by the Octopus Energy dataset. For National Grid ESO, it is in general the national demand that is of most interest, enabling conclusions to be drawn on the potential for domestic assets to provide flexibility at a system level. However, there remains a need to incorporate diversity of customers, including any differences between the customers sets of different suppliers. Perhaps the best way to incorporate these requirements into the CrowdFlex model would be to design it with the intention that it will be extrapolated to national levels, but also allow for compatibility with equivalent modules built by other suppliers in the future. In that way, the ESO will be able to use the model for its intended purpose as soon as possible, but improve on the aggregated forecasts when additional datasets become available. In addition, learnings from the development of the CrowdFlex demand model can underpin a replicable process and set of requirements for other suppliers to implement in the future.

As part of the SIF-funded VirtualES project, principles are being developed to set requirements for such modules. These principles can be categorised as in the following figure.

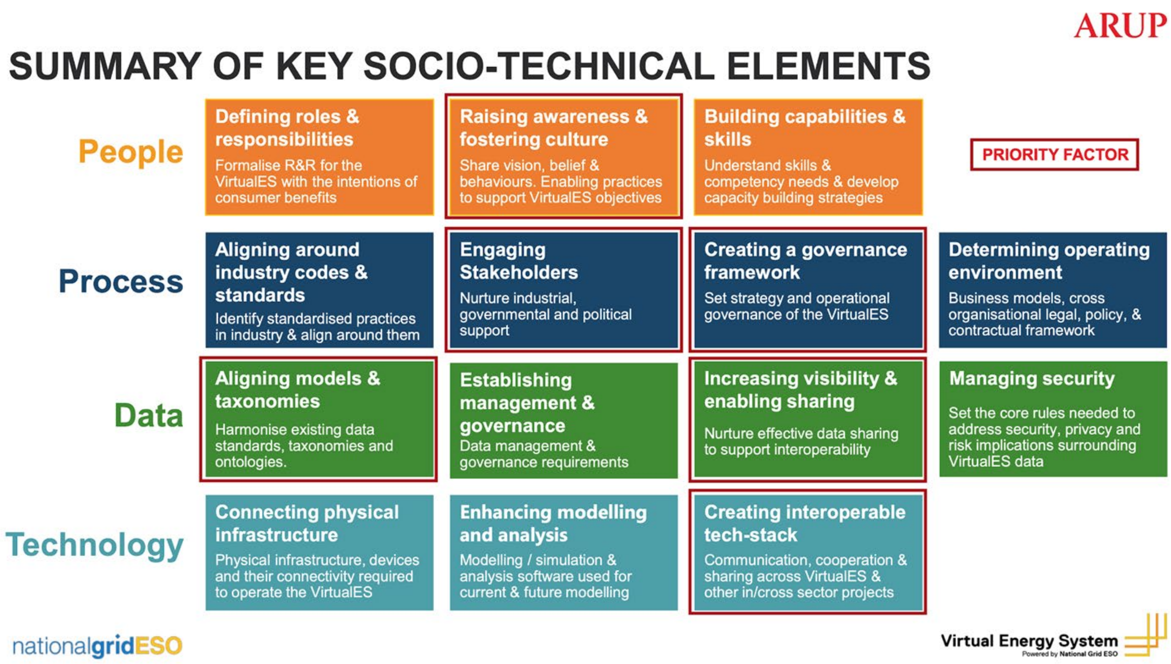

Figure 9: categorisation of the principles that are being developed for the whole VirtualES ecosystem as part of the SIF-funded project on the VirtualES.

Highlighted in the above figure are factors deemed to be of high priority. An important requirement is model alignment: in order for any sub-module to be able to successfully integrate with the rest of the VirtualES, its data structures, inputs, outputs and model verification processes must be compatible. When designing these interfaces, confidentiality and data privacy must also be carefully considered; this is of particular importance for models which ingest and process domestic customer data. A suggestion for the alpha phase of the CrowdFlex project would be to determine how the ENA Data Triage Process would apply to a domestic demand model. There is also an open question around the optimum data lifecycle, i.e. when the data change ownership between parties. For example, when a customer registers an EV with an aggregator, does the ownership of the associated static data change hands from the OEM to the aggregator? In addition, critical to achieving compatibility and interoperability will be factors such as temporal and spatial resolution, aggregation level and metadata standards. As far as possible, the CrowdFlex project should align with decisions made on these parameters, concurrently, in the VirtualES project. It is already seen as likely that the Dublin Core will be adopted as the metadata standard. Another suggestion for the Alpha phase of the CrowdFlex project would be to understand how the Dublin Core applies to, and what the implications are on, a VirtualES domestic demand module.

In order for the domestic demand model to be a valuable tool, it is important that it is designed with the intended uses in mind. The intention is that the VirtualES should form the energy segment of the national digital twin, so it will have a wide variety of applications nationally. Within the ESO itself, the main user of the VirtualES will be the Control Room, so that the tool is used predominantly for system balancing purposes. As part of the VirtualES project, its application to system planning could also be demonstrated, in particular the connection of the transmission network module to the distribution network module to model constraint management.

At present, national demand is forecasted by computing the total national *supply*. The domestic demand module would improve on this via a ground-up forecast that is truly based on demand patterns. Moreover, an additional benefit of this ground-up approach is that it directly enables model outputs at aggregation levels below the national level. For example, GSP level forecasts could be used to assess constraint boundaries on the transmission system. In the future, this same requirement will cascade down to the distribution networks, to enable DSO assessment of network loads in a more flexible system. Currently, scenario generation and forecasting at a local level is challenging, in particular due to the inability to separate domestic demand from industrial and commercial demand and DERs. The capability to share a domestic demand and flexibility digital twin at locally aggregated levels would improve joint operation of the system by ESO and DSO.

In addition to the output of nominal demand, error bounds of the national demand forecast dictate the amount of reserve flexibility that is procured ahead of operational timeframes; again this presents a potential application for the domestic demand model. Given that system balancing is a key use-case for the VirtualES, the CrowdFlex module could also provide forecasts of available flexibility capacity from domestic sources. More details on this will be given in the following subsections.

CrowdFlex Alpha should:

- *Select 1-2 of the following interest areas as priority, once more information from VirtualES programme is available:*
    - *Understand how the National Digital Twin Programme information management framework (IMF) applies and implication for the model.*
    - *Understand how the Common information Model (CIM) applies and implication for the model.*
    - *Determine how the ENA Data Triage Process would apply to a domestic demand model*
    - *Investigate the optimum ownership lifecycle for static data*
    - *Understand how the Dublin Core applies to, and what the implications are on, a VirtualES domestic demand module*

3.3.2 Use cases for domestic flexibility

As mentioned above, a suggestion for CrowdFlex later phases would be to develop a VirtualES module that produced forecasts of domestic demand and available flexibility capacity. The VirtualES is applicable across a variety of use-cases, and as such it is important that the model be designed with a subset of these in mind. In the design stage during the Alpha phase of the project, a key task would be to identify one or more critical use-cases to initially target, based upon a chosen combination of the following criteria (more criteria can also be included at the Alpha phase):

- Effort required to build out the model to Minimum Viable Product level
- Value to the system as a whole
- Value to Octopus Energy as an individual company
- Relevance to the CrowdFlex project

As a first pass, the below tables summarise a selection of potential use-cases that might be considered, in terms of constituent data and external interfaces that would likely be included. These use cases are a selection from the 24 in the Arup report[42]. Descriptions of these use-cases are reproduced from the Arup report as follows:

- **Prosumers.** Matching demand to the needs of the overall system in real time opens up the opportunity for millions of consumers and producers to sell electricity or provide valuable services to the grid. With sufficient connectivity it allows the linking, monitoring, aggregation and control of large numbers of individual energy-producing units and consuming equipment - so these can be used to best match demand. These assets could be, for example, a rooftop solar PV system on a home, or a boiler on an industrial site, or an EV.
- **Smart demand response.** Digitalisation will allow for a greater number of electricity consumers to respond flexibly to signals from the system. Digital connectivity allows appliances and equipment to be monitored continuously and connected to the grid. This connection could be used to shape demand profiles to respond to specific supply scenarios – with consumers and/or their assets receiving and acting upon specific signals and instructions from the network.
- **Flexibility modelling for increased renewables.** Monitoring of generation plants, storage and demand can help to improve the predictability of the systems and increase the rate in which renewable generation is added onto the network. Flexibility in the power system becomes crucial for maintaining reliability and cost-effectiveness, impacting how infrastructure is planned and operated long term.
- **Planning of local LCT implementation.** Bringing together data from several parties around local distribution networks, demand forecasting, power generation forecasting, and emissions monitoring will enable local actors such as Local Authorities and Smart Local Energy Systems (SLES) to model and understand the best mix of Low Carbon Technology to achieve 2030 net zero goals. A specific Local Authority use case is currently being delivered through Modernising Energy Data Access (MEDA) via Open Energy. MEDA is also exploring EV set up in housing developments.
- **Transition to net zero.** In response to the need for achieving net-zero, and the changing landscape of generating, managing and consuming energy, it will be necessary to simulate real world scenarios, develop decarbonisation strategies to build long term strategic pathways, and guide diversification into non-carbon intensive areas – whilst accounting for policy and regulatory processes.
- **Improve demand forecasting.** By collecting and aggregating in real time energy consumption information, retailers will be able to understand actual consumption patterns. This will enable better services to be delivered to their customers, and if shared would benefit the overall balancing of the grid. More granular consumption data can then drive sophisticated analysis and modelling to predict and forecast demand more accurately.
- **Better services to customers.** By utilising aggregated open data on electricity consumption, production by source, trade, CO2 emissions, transmission line capacity, and price on the wholesale market, new consumer products and services can be developed. This will enable retailers to lower consumer turn-over and provide more holistic solutions.

[42] Arup, Virtual Energy System: Benchmarking Report, 2022

CrowdFlex Alpha should:

- *Decide on specific use case for the model to deliver, from those listed, and undertake analysis to determine what a minimum viable product would be.*

Table 7: Description of the use cases of a domestic flexibility model for key stakeholders/external interfaces.

		Use-case					
		Prosumers/ smart demand response	**Flexibility modelling for increased renewables**	**Planning of local LCT implementation**	**Transition to net zero**	**Improve demand forecasting**	**Better services to customers**
External interfaces	**Supplier/ BRP**	settlement, verify flex service delivery				offer new services to customers	offer new services to customers
	DSRSP	offer flex services					
	TSO/DSO	verify flex service delivery	determine new markets needed			grid balancing	
	DER developer		determine location and size for assets	determine location and size for assets	determine location and size for assets		
	Network planner		determine location and size for network upgrades				
	Policy maker		determine future generation/network/market needs				
	DSO			determine location and size for network upgrades	determine location and size for network upgrades		
	Local Authority			determine future generation/ network/ infrastructure/ asset needs	determine future generation/ network/ infrastructure/ asset needs		

Table 8: Description of key data specification for each use case of the domestic flexibility model.

			Use case					
			Prosumers/ smart demand response	**Flexibility modelling for increased renewables**	**Planning of local LCT implementation**	**Transition to net zero**	**Improve demand forecasting**	**Better services to customers**
Data owner/ originator	**consumer**	**real-time usage**	✓				✓	
		historical usage		✓	✓	✓	✓	✓
	OEM	**real-time operation**	✓				✓	
		historical/ future trends		✓	✓	✓	✓	✓
	supplier	**historical/ future trends**		✓	✓	✓		
Candidate data standard(s)			PAS 1878	IEC 61850, CIM	IEC 61850, CIM	IEC 61850, CIM	PAS 1878, IEC 61850	TBC
Spatial Resolution			MPAN, postcode, BSP, GSP	MPAN, postcode, BSP, GSP	MPAN, postcode, BSP	GSP	MPAN, postcode, BSP, GSP	MPAN
Temporal resolution			operational metering 2/20Hz, SMETS 12sec/30min	weekly/ monthly/ quarterly/ annually	SMETS 30min, weekly/ monthly/ quarterly/ annually	SMETS 30min, weekly/ monthly/ quarterly/ annually	operational metering 2/20Hz, SMETS 12sec/30min, weekly	SMETS 12sec/30min, weekly/ monthly/ quarterly/ annually
Aggregation level			individual to (sub-)fleet	individual to (sub-)fleet	individual to (sub-)fleet	fleet	fleet	individual

3.3.3 High-level model structure & key gaps

The CrowdFlex domestic demand and flexibility model would offer a user (examples given by the external interfaces in the above table) the ability to generate a forecast of these quantities. User inputs/outputs can be seen in the below table:

Table 9: User inputs/outputs of CrowdFlex domestic demand and flexibility model

	User inputs			User outputs				
	Time of day/week/month	**Location**	**Period length**	**Demand**	**Demand error bounds**	**Flexible capacity**	**Flexible capacity error bounds**	**Cost to provide flexibility**
Demand	✓	✓*	✖	✓	✓	✖	✖	✖
Flexibility	✓	✓*	✓	✓	✓	✓	✓	?

** unless a lumped national model is used*

In addition to user input parameters, key factors influencing the forecast will need to come from continuous updating of the model with new data observations. The first of these is the demand in preceding periods (if an autoregressive model is used). To this end, the model should ingest observed meter data with as little latency as is practical. This also has the added benefit that it enables use-cases where meter data is required, such as settlement, and thereby avoids the current standard practice of bilateral data sharing. Similarly, the available flexible capacity is heavily dependent on any dispatches that are received. To feed this back into the model, a candidate approach would be for the user to "order" the flexibility provision at the time of interaction.

There is an open question around the way in which the available flexible capacity is parameterised. Often, in line with many flexibility services, this is chosen as a fixed magnitude (that must be *at least* delivered) over a service window. An important factor influencing the ability of the customer portfolio to provide flexibility is the extent to which they have done so already; as there is a rebound effect since at least part of the domestic flexibility will be provided by demand shifting, rather than demand destruction. We propose the amount of time since the last dispatch be investigated as a way to capture this, alongside other candidate factors, in the Alpha phase of the project.

The above table outlined the *user* inputs, but in order to train the model may require additional inputs. The extent to which this is true will depend on how the model is composed: if it aims to generate the demand by building up dependencies on constituent factors, then each of these will need to be modelled. Examples of such factors might include the following *static* parameters (for a more comprehensive list of parameters please see Table).

Housing type

- Household makeup
- LCT presence

as well as the following *dynamic* parameters:

- Consumption
  - At the boundary meter
  - LCTs
- Historical response to control signals (some of these may be simulated signals designed for information gathering)
  - Direct asset dispatches
  - Human-in-the-loop dispatches via e.g. notifications
  - Tariff signals
- Weather
  - Solar irradiance (for heat requirement, solar PV output)
  - Temperature (for heat requirement)
  - Wind (for heat requirement)

This list (and the true version resulting from the Alpha phase) also offers the potential for the CrowdFlex project to inform data gaps that currently exist. For example, given that the presence of one or more controllable assets on site will have a large effect on the demand and available flexibility, it may be worth implementing a central asset register for system benefits. This will be the subject of BEIS innovation project funding under the Net Zero Innovation Portfolio. As well as a lack of necessary datasets, the CrowdFlex project may uncover a lack of necessary meter data being recorded. Depending on the use-case, the domestic demand and flexibility VirtualES module will require data that is of high granularity (up to the order of 2-20 Hz for operational metering) and high accuracy (e.g. MID Class 2 to enable financial settlement). There will be a trade-off present between the use of boundary smart meters, which are MID Class 2 compliant but can only record total site demand and at frequencies up to every few seconds, compared to the use of LCT asset meters with varying accuracy and frequency characteristics. Latency should also be taken into account when considering which readings are used, as this affects both the technical ability for assets to participate in various flexibility services, but also the speed with which new readings can be incorporated into the model.

There are different ways to construct such a model for demand: a top-level model would forecast the total demand, whereas a bottom-up model would model the forecast across different customer archetypes (or sub-portfolios) and then aggregate this demand upwards. The model used to predict demand in a given time-step can vary in its input complexity. For example, demand at a given time-step can depend on the timestep itself, demand at the previous timestep (autoregressive models), other temporal factors (e.g seasonality, day of week, and bank holidays) as well as other extraneous variables such as the weather. It will be necessary in CrowdFlexAlpha to decide the extent to which intermediary building blocks are composed, for example: is total demand forecasted based on time and date alone, or via the generation of a weather forecast that feeds a heat demand forecast that feeds a total demand forecast? If a bottom-up model is used, other information about the archetypes of the subpopulations would also need to be considered, for example LCT ownership.

The decision on target aggregation level should be based on alignment with the key target use-case(s) chosen: since disaggregation is difficult, forecasting should be done at a level of aggregation no higher than the lowest which will be used in application. Since flexibility is fundamentally the ability to deviate from a nominal demand profile, it is clear that any flexibility forecasting functionality must be built on top of demand forecasting functionality. This requires a modular structure so that any potential flexibility provision can be converted into the corresponding demand profile.

Clearly, both the demand and flexibility models are inherently probabilistic - since the underlying demand load and flexibility potential is variable. A range of modelling approaches can be used to construct such models, from purely data-driven approaches which look at historical data to build models that predict future events to physics/statistical-based approaches which explicitly model the distribution based on the range of factors described above.

The available flexible capacity is as compared to the *baseline* demand, i.e. the counterfactual of what would have been observed had the response not been triggered. As such, it must be computed by first finding the nominal demand, and then finding the ability to deviate from this. Critical to flexibility provision is a determination of the associated price to participate, as this dictates the extent to which a given portfolio takes part. In general, there are two ways in which flexibility markets can be setup to incorporate the price-to-participate: 1) a price is communicated to the System Operator, which accepts or rejects the offer (usually based on a merit order process); 2) the System Operator broadcasts a price and the customer (or aggregator) chooses whether or not to participate. Note that, in addition to System Operator dispatched flexibility, the model should allow for load shaping via tariff signals. This replicates the latter of the aforementioned options, however it is the supplier rather than the System Operator which generates the broadcast signals. Given that the price is critical to flexibility provision, it must be incorporated into the model. For some use-cases, depending on the user, it would be necessary to have this as a direct output: for example, this would be required by a DSRSP using the model to generate offers to provide flexibility services. In other applications, analyses include whether or not flexibility *would* be utilised under given scenarios; in this case the price forms an internal variable which sets the extent to which dispatches are agreed between parties.

It may prove useful to separate the demand and/or flexibility forecast into different sub-categories. In the case of demand, this could be a distinction into the types of asset that are consuming electricity: for example heating, transport, lighting. In the case of flexibility, this segmentation could be into the dispatch mechanisms that can trigger a response: i.e. whether through tariffs, customer notifications or direct scheduling of controllable assets; and in each case the extent to which effects are achieved manually or through automation (see Table 6 for complete list of parameters).

CrowdFlex Alpha should:

- *Investigate the availability of necessary datasets for model functionality and propose methods to ensure that any lacking datasets are made openly available.*
- *Investigate the extent to which current metering standards enable domestic demand and flexibility modelling.*
- *Decide on the model sub-structure, for example whether demand is forecast based on fundamental factors (such as time of day) or whether intermediate factors (such as weather) are forecast first.*
- *Choose whether to use a bottom-up or top-down model and the target aggregation level for the output.*
- *Explore which modelling techniques provide the best results in this setting and choose one or more candidates for CrowdFlex Beta.*

CrowdFlex Alpha could:

- *Design the model to continually ingest meter data.*
- *Design the model to continually ingest flexibility dispatches, for example via "orders".*
- *Investigate how best to encode prior flexibility dispatches, e.g., via the time since the last dispatch.*
- *Determine the most suitable way to incorporate price-to-participate into the model.*
- *Investigate the decomposition of demand by asset type and flexibility participation mode.*

4 Clarify the services that could allow monetisation of domestic flexibility

Previous chapters identified that value to markets/stakeholders could be categorised as:

1. Domestic Baseline Consumption predictions
2. Domestic Flexibility Capacity (aligned with PAS-Routine, supporting energy markets)
3. Domestic Flexibility Capacity (aligned with PAS-Response, supporting critical system operation and system/network planning)

In addition, Chapter 3 identified that across each of these is the tension between market desire for "firm" predictions/capacities, and the stochastic nature of the asset. This chapter expands on what is required to deliver each of these digital services. Also, it explores how the provision of PAS-Routine and PAS-Response type flexibility should be delivered and monetised via two routes:

- Where a single value for expected portfolio value is declared to markets; this aligns with BAU approaches in energy markets, but risks significantly understating true portfolio value.
- Where a probability density function (PDF) of expected portfolio capacity is declared to the market. This approach is highly innovative, and is expected to unlock value for the aggregator and across the system. However, its innovation means it represents a significant deviation from BAU and requires collaboration with markets to mature this option.

4.1 Domestic baseline consumption predictions

Stakeholders have identified that, separate from flexibility, they would value having more accurate data on baseline consumption. This could comprise a vector of historical baseline consumption, with prediction bands, aggregated up to a level according to the needs of the data customer. This could be updated on a continuous basis, at regular intervals with real time consumption data, with prediction bands pushed out into the future.

The principle is shown in the diagrams below. The level of future energy demand cannot be predicted precisely, but rather will be a distribution around an expected level of demand. Given the lack of live metering of residential demand, the width of this distribution is quite large. On the supply side, the ESO needs to ensure there is enough generation to cover under-delivery of thermal plant, variation of VRES output, and demand being greater than expected. As a result, the Operational Reserve Requirement is large. If demand predictions can be more accurate, the ORR can be lower while still ensuring the system operates with equivalent level of system adequacy.

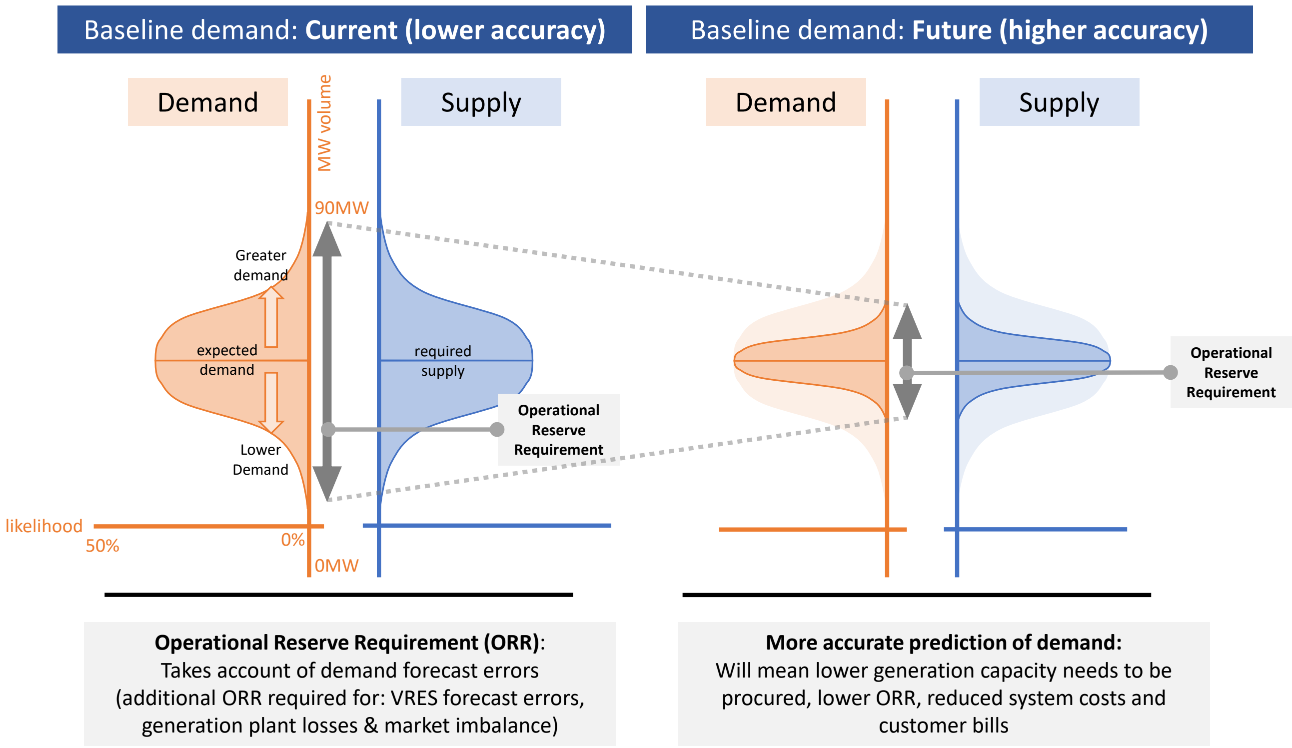

Figure 10: System cost savings arising from improved baseline energy predictions

- Customers for this dataset could be the ESO and DSO, for improved day ahead/close to real time scheduling of assets in the Control Room, and/or local flexibility markets, provided they were more accurate than current methods (e.g. using Profile Classes, and national net-demand forecasting)
- Location and accuracy of predictions will be important to the ESO:
    - Table 2 showed that the largest system operating cost is constraint management. Flexible resources located on the correct side of a transmission network constraint could help ESO alleviate that constraint, and thereby unlock significant system value.
    - The 2nd largest system operating cost incurred by the ESO is operating reserve. These are additional sources of power that the ESO procures, in case that electricity demand runs ahead of forecast. Having a much more accurate picture of demand would permit the reserve requirements to be reduced, with the potential for significant system savings.
- There would be a need to establish the "pure" baseline – reference consumption before any form of demand/flexibility incentive is offered to the customer, this is required to show the true underlying requirement, its driving factors and the value-add of flexibility. To do this reliably would require a large dataset for accurate prediction of consumption, also the method for baselining would need to be transparent and agreed to avoid potential for gaming.
- To address these, CrowdFlex should explore how best to validate predictions (according to the needs of each market) and what might be the requirements to enable adoption/development of standardised methods (i.e. a federated learning type models).
- Additionally, there would be a need to establish the layer on top of this "pure" baseline caused by PAS-Routine type services, as this will more accurately reflect the demand seen operationally in control rooms in real time, before the dispatch of flexibility services. (The final layer on top would be caused by PAS-Response type services, which would be dispatched according to system need).

4.1.1 Data aggregation: temporal (historical) and geographic (number of households)

Chapter 3 explored the stochastic nature of residential demand (and flexibility potential). To provide a reliable baseline, data would need to be aggregated across a number of households, and across time. ESO and DSO may be expected to have different geographic aggregation requirements for the data. The ESO may expect data to be aggregated to GSP level, while the DSO may require aggregation to LV level or even street level. While there may be 50k-100k households under a GSP[43], there are far fewer below a LV transformer (100-500 houses typically).

The graphs below show the rate at which residential consumption data stabilises across households, both in terms of the value of demand averaged across that set of households, and the confidence in that number as represented by the expected spread of demand across that set. Both figures are important: for example, the ESO may want to have an accurate number, and the aggregator would wish the number to be precise (low spread) so they can avoid derating of the portfolio. DSOs routinely use After Diversity Maximum Demand graphs to determine the estimated transformer ratings to support a specified number of households. ADMD across a population of customers represents the annual maximum demand when averaged across the group. The graph (including one-standard deviation intervals) shows that household consumption is incredibly variable: ADMD continues to decrease above 100 customers, and a population of many hundreds of customers is required before group statistics stabilise. As the population of customers under an LV constraint is far smaller than under a GSP, aggregation to GSP level would give more stable demand statistics compared to LV[44].

The equivalent data for EV charging is shown on the right. Somewhat more hopefully the diversified peak demand does stabilise once a population of 50-100 cars is reached[45]. While the data is not conclusive, it does indicate that EV usage patterns may be more regular than household energy.

Nevertheless, even at greater populations, there will always be a distribution of demand that is characteristic of such stochastic assets. Therefore, CrowdFlex should determine how to establish reliable/steady population characteristics from a small sample size, specifically to support DSO demand prediction.

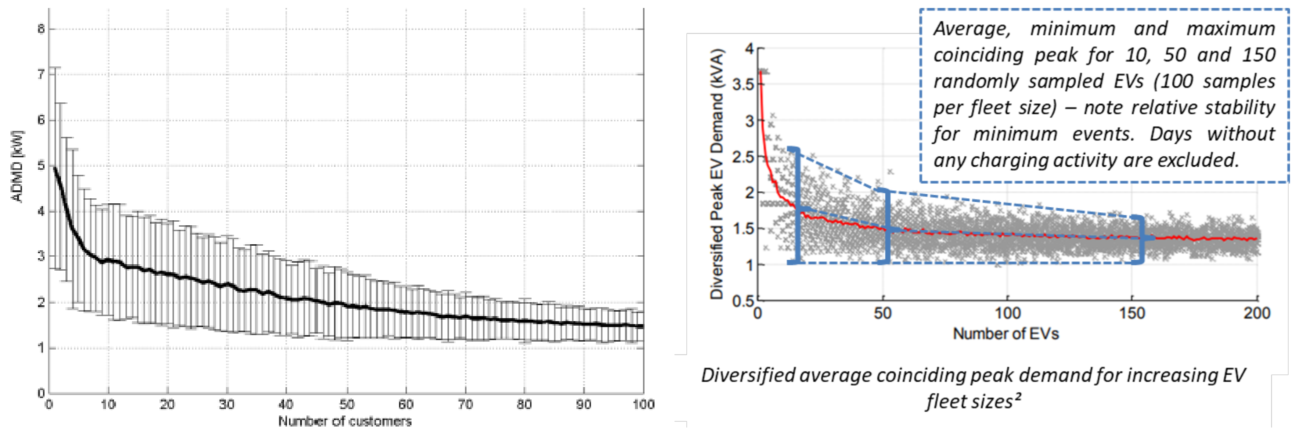

Figure 11: Left, ADMD for medium income household (UKPN Low Carbon London Diversity Maximum Demand ADMD report). Right: Diversified average coincident peak demand for increasing EV fleet size (Uni. Manchester analysis of My Electric Avenue Data.

To achieve a given level of statistical power for consumption prediction requires the use of historical data. However, there is a tension between the need for more data, and relying on older consumption data which may be polluted with other factors (the weather may have changed, household may have gone on holidays etc). CrowdFlex will need to determine what approach gives the most reliable predictions, and if explicit

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43 ESO Data Portal: Grid Supply Point Info - Dataset| National Grid Electricity System Operator (nationalgrideso.com)

44 i.e. because the ADMD across a larger group more precise.

45 The Intraflex project also concluded that a minimum of 50 vehicles is required for achieving stability of demand characteristics across an EV group.

compensation can be made for factors such as weather, which would allow more historical data to be used with confidence.

- *CrowdFlex should develop statistical techniques to predict portfolio baseline demand with narrow prediction bands. These should develop stable statistics from small portfolios of assets and smaller amounts of historic data, and will need to balance the desire to offer markets "firmness" (i.e. accurate and precise predictions), with temporal/geographic limits (which reduce portfolio sizes) given the stochastic nature of the resource.*
- *Continued engagement with DSO stakeholders is necessary to develop clear use cases for CrowdFlex baseline data to solve their network challenges.*
- CrowdFlex should explore how best to validate predictions (according to the needs of each market) and what might be the requirements to enable adoption/development of standardised methods (i.e. a federated learning type models).

4.2 A firm vs. probabilistic declaration of flexibility capacity

As with baseline residential demand predictions, flexibility capacity data is inherently stochastic, and even across very large populations the capacity is best described by statistical, rather than deterministic methods. However, power sector stakeholders indicated that, at least at present, they would continue to require a declaration of firm capacity. This gives rise to two alternatives for value generation: providing a firm (albeit derated) value for portfolio flexibility capacity and providing markets with a full probability distribution representing the range of expected portfolio capacity.

The principle is shown in the diagram below. On the left, the portfolio owner has an expectation of the level of flex capacity they can provide, but they cannot be certain of this as the underlying asset is stochastic. To provide a "firm" capacity to the market, the portfolio owner needs to derate capacity from the expected value. This means value is lost to the portfolio owner, while the ESO would need to procure the required capacity elsewhere. The alternative approach is the portfolio owner is fully transparent in declaring the full distribution of expected capacity to the ESO. The ESO already has processes to deal with distributions of outcomes related to VRES forecasts, thermal plant under-delivery etc. The ESO would "stack" the flexibility-PDF along with others to develop a compound distribution, and use this to schedule reserves in a more efficient way.

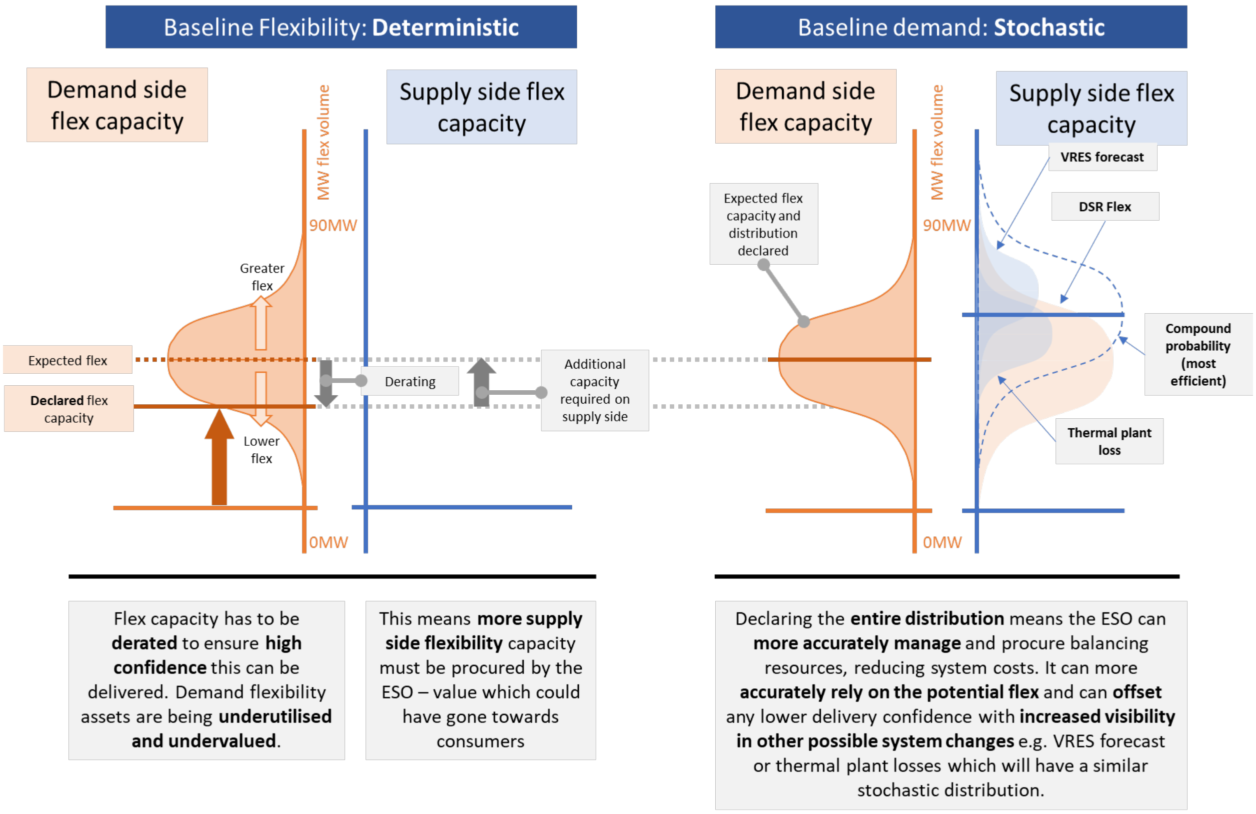

Figure 12: How flexible asset value can be increased through a stochastic declaration of capacity

4.2.1 Firm declaration of flexibility capacity

With this approach, the portfolio aggregator will need to "collapse" the probability distribution of the portfolio to a single value which is declared to the market.

- As there may be penalties to under/over-delivery, the aggregator would need to derate the portfolio capacity from its theoretical value to its most likely/expected value. A practical example is the Intraflex project, which showed that the DSO would need to procure 140% of the required capacity from a demand response portfolio to ensure delivery. Any derating, and certainly one as large as was identified in Intraflex, would represent significant erosion of portfolio value, and would not reflect true potential portfolio value.
- This approach appears suboptimal. The aggregator loses value on its side of the market, due to derating from expected flexibility capacity. In parallel, the ESO always needs to procure reserves to manage the risk of under-generation, or of consumption running ahead of prediction. Declaring a firm (but derated) value for flexible demand, means that more capacity will be required on the ESO side.
- Nevertheless, the approach has the advantage that it does not require any alteration to business-as-usual market arrangements.

➢ *Initially, CrowdFlex should develop and deploy an approach where the aggregator collapses the PDF of portfolio flexible capacity to a single value, offered to the market as a firm (derated) capacity.*

➢ *While this appears sub-optimal (as the aggregator has to derate the asset base) nevertheless the approach does not require any alteration to business-as-usual market arrangements.*

4.2.2 Probabilistic flexibility capacity nomination

Here the aggregator would offer a probabilistic capacity profile to the market operator (e.g. ESO). The market operator already has techniques for delivering system security despite the risk of under generation of dispatchable generation, and increasingly the variability of renewable supplies (VRES).

- The ESO could then combine probabilities on the supply (dispatchable and VRES) and demand side to deliver the required level of system reliability.
- Procurement of resources could be based on the true, compound probability of demand and supply, and could therefore be *adequate* (to deliver required level of system security), but not excessive.
- The market value assigned to this demand flexibility PDF would be based around its most expected value and its width. In principle, by reflecting the true nature of demand assets, and the process of ensuring system security, this approach should unlock additional value for the aggregator by reducing reserve costs to the ESO.
- CrowdFlex would need to work closely with the ESO and other system stakeholders, to identify if additional value can be generated in this way, what the barriers are to adopting this, and a programme of work to overcome these.

Recommendations for CrowdFlex: Alpha:

- ➢ *In parallel, CrowdFlex should work with ESO/DSO to identify if greater system value can be unlocked by providing a PDF of portfolio flexibility capacity, rather than a single value, to the market operator and what current barriers to this approach are.*
- ➢ *CrowdFlex should develop effective methods to produce this PDF and identify what a service could look like which supports this statistical approach.*
- ➢ *It is expected that all parties would need to work with the regulator as utilising and deployment of this approach is not under business as usual market arrangements.*

4.3 Domestic Flexibility Capacity (aligned with PAS-Routine)

As identified in Chapter 2, the aggregator would use predictions of (time varying) capacities for bidding to energy markets. These predictions would be continuously revised with recent historical data to update future flexibility capacity.

At present, through the deterministic approach, aggregators forecast their demand and position themselves on energy markets accordingly. A failure to position themselves correctly would result in imbalance charges. Aggregators could exploit the stochastic nature of the portfolio, continuously adjusting demand in real time to achieve a desired outcome, such as mitigating imbalance charges, moving themselves closer to their agreed position on the market.

CrowdFlex: Alpha should:

- ➢ *Trial TOUT type incentives or information remedies to deliver energy market services*
- ➢ *Consider how Routine affects commercial stacking with response services*

4.4 Domestic Flexibility Capacity (aligned with PAS-Response)

Another source of value is where domestic flexibility would be declared as firm and available during system stress events, such that it is seen as equivalent to BAU solutions to long term system planning, generation and network capacity requirements. Specific dispatch calls would be required to instruct the asset to provide its flexible capacity. As identified in T2, the equivalent of NIA “Big turn Up/Down” trials will need to be undertaken to determine capacity, these would need to be layered on top of TOU tariff flexibility.

This service has the same challenges as those services outlined above, in that a large dataset will be required to generate sufficiently stable dataset, and that some (possibly larger) element of derating may be needed before nomination of firm capacity. But in addition, this value stream is challenging because some markets will require capacity to be guaranteed during system stress events, which are very uncommon. If a power system is designed to handle one-in-twenty year weather events, it is unlikely that such an event will occur during a one-year trial. CrowdFlex will need to test PAS-Response type capacity, at or close to stress events, as well as working with stakeholders to determine if and how that flexible capacity would behave during even more extreme events. The alternative is that all parties would have a lower confidence in portfolio performance, and a heavy portfolio derating would reflect this.

As with PAS-Routine, there may be an alternative to firm nomination of flexible capacity, via a PDF. Discussions with stakeholders about this statistical approach to capacity, should also include its use for PAS-Response services.

- *CrowdFlex should trial NIA type Big Turn Up/Down interventions to elicit flexible response, at or close to system stress events. The trial should be repeated to give confidence in the capacity provided.*
- *CrowdFlex will need to work with stakeholders to determine how to provide confidence in trial outputs to be applied to more extreme events.*
- *CrowdFlex should trial Routine and Response services separately, as well as both layered together.*

4.5 Commercial requirements

4.5.1 Commercial framework

Stakeholders confirmed a key attraction of CrowdFlex is its aim to transmit an incentive signal to residential customers that reflects Whole System challenges. To do this will require the aggregator (flexible service provider) to be engaged in multiple markets and to stack services, before offering an appropriate incentive to customers (see figure below).

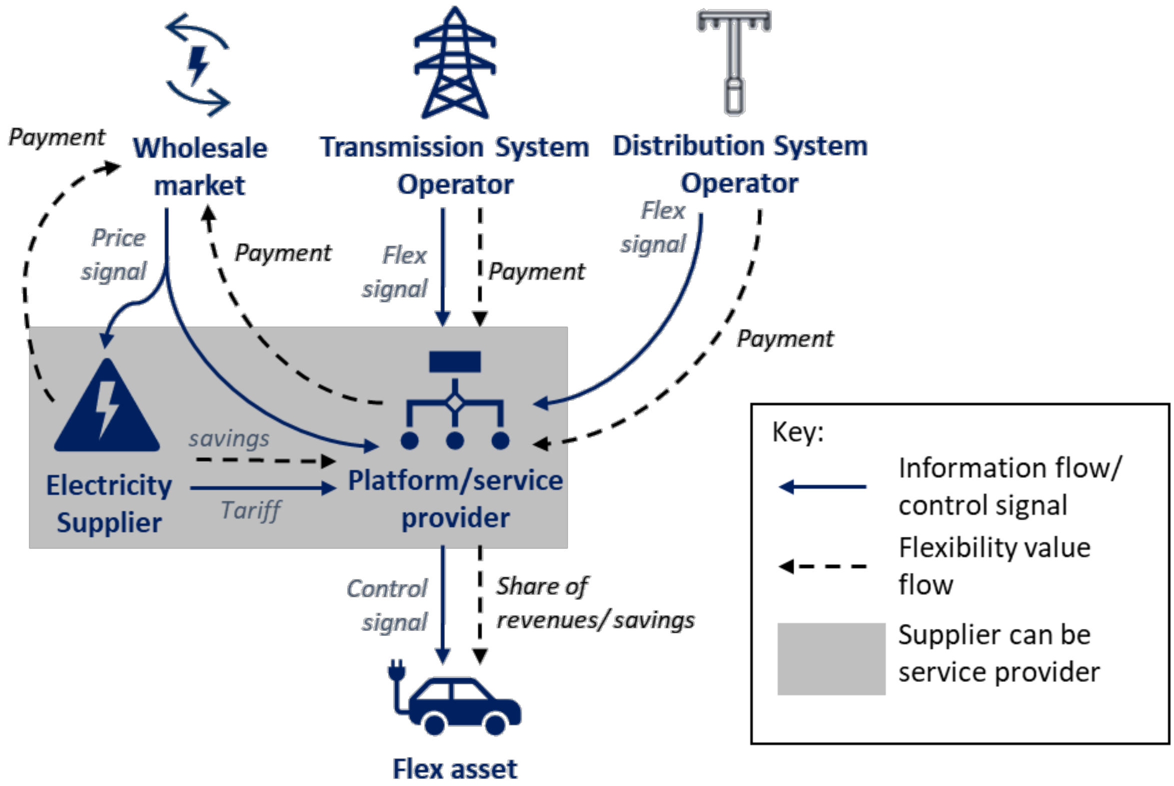

Figure 13: General commercial framework approach for revenue stacking of domestic services.

Recommendations for CrowdFlex: Alpha:

- *Partners felt that their existing commercial structure, where the platform/service provider acts as an intermediary between the domestic customer and grid stakeholders to support whole-system service stacking, was fit for purpose for subsequent stages of deploying digital services in CrowdFlex. Note the platform may be owned/operated by the energy supplier*

4.5.2 Energy market modelling and asset co-optimisation across revenue streams

The NIA stage of CrowdFlex provided customers with a price signal which reflected changes in the wholesale market. Further stages of the project will need to provide signals to customers which reflect challenges across the power system, to reduce whole system costs and alleviate challenges across generation, transmission and distribution. Therefore, CrowdFlex will need to have the capability of predicting market movements (across multiple energy markets/services) and to develop a co-optimisation strategy for trading in these markets/services, which maximises the value of the flexibility potential of the portfolio. The planned dispatch schedule for the assets within the portfolio, will need to be updated constantly, reflecting updates to baseline use, weather, flexibility utilised to date, and energy market predictions. A number of organisations have/are developing such Distributed Energy Resource Management Systems (DERMS).

To allow this, automation of data collection and analysis on resources, and well as performance validation will be critical.

- *CrowdFlex will need to develop new or leverage existing DERMS which can identify dispatch schedules for flexible portfolios, optimised over a number of energy markets/services, and noting the path dependency of dispatch strategy up to the optimisation horizon.*
- *Automation of data collection analysis will be critical to the efficient operation of the portfolio.*

4.5.3 Machine Learning versus physics-based predictions of flexibility

With an emerging digital service relating to residential flexibility, a key capability will be to understand the current state of each asset (with regards its potential to provide flexibility), and how that is expected to change in the near term (for example as a result of baseline utilisation, or as a result of calling on its flexibility). A review of commercial organisations providing flexible capacity to energy markets in the UK, has identified two distinct approaches to this challenge:

Physics based models: Here, the characteristics/specifications of each asset is known, and a physics-based model of its operation is created. The expected utilisation of the asset is imposed on this, to create a prediction of the future state/availability of the asset.

- This is used by organisations providing flexibility from diverse types of demand response assets. Due to diversity of assets, consumer use cases, and weather dependency, there may be insufficient data for a machine learning approach to be reliable.
- It has the advantage that it explicitly reflects the depletion status/availability of each asset, and so provides greater confidence to the asset owner, that the asset is available for its primary (i.e. non energy market) function. For example, with API interface to an EV, a physics based would be the obvious choice as the physics model and parameters are available.
- The disadvantage of this approach is the need to define which physics model to use for each asset, and generating the parameters which describe it.

Machine Learning: This approach seeks to identify patterns/correlations in datasets which can be used to infer current state and guide future actions. To generate reliable correlations, large datasets are required. The technique is used by some organisations monitoring battery assets (e.g. for degradation modelling).

Within ESO there is an example of both approaches being used/evaluated. For example, ESO has database of registered wind farm capacities, and applies live windspeed datasets to predict generation from each windfarm – a physics-based model. Separately, ESO is trialling the use of Machine Learning to identify cloud movements relative to a database of PV sites, in order to support prediction of PV generation. It may be that some combination of both techniques is optimal, i.e. a physics-based approach to feature extraction, and then classification within a large dataset via a ML approach.

While there may be significant commercial value in commercial parties developing accurate predictive methods, for grid reliability purposes the ESO may wish to generate (and improve) such predictions themselves, given its role as the balancer of last resort. Early engagement with ESO will be needed to clarify requirements and determine where it is most suitable for forecasting to be undertaking.

- *CrowdFlex will need to develop techniques which can identify and predict the state of residential flexible assets. Physics-based and Machine Learning based approaches should be considered.*
- *CrowdFlex will need to work with ESO and DSOs to clarify where in future forecasting should be undertaken.*
    - *As the balancer of last resort, the ESO may wish to generate and improve its own predictive methods, or:*

- *The aggregator could provide these predictions, where there would be an appropriate incentive to improve the accuracy of such predictions.*

4.6 Condition 4 – Relevant project engagement and approach to access assets under BAU market arrangements

During the discovery phase CrowdFlex engaged with multiple relevant projects integrate demand side flexibility in markets:

- Through literature reviews CrowdFlex leveraged learning from prior innovation projects: Sustain-H, Customer-Led Network Revolution (CLNR), Low Carbon London, Consumers (LCL), Vehicles and Energy Integration (CVEI).
- As part of Condition 3 (see section 1.6) CrowdFlex engaged to share learnings with Equinox, BiTraDER, and the Domestic Reserve Scarcity trial.
- CrowdFlex also held specific meetings with Equinox, the Domestic Reserve Scarcity trial, and SIF Flexible Heat SPEN project to share learning on scope and alignment; discuss opportunities for future collaboration to avoid duplication; and to share expertise for planning trial technical aspects and commercial models.

During alpha we propose to continue engagement to consider alignment or collaboration opportunities and ensure projects are coordinated to deliver value for money and avoid duplication of effort.

This chapter describes what is required to deliver flexibility services from domestic assets and sets out two routes through which could be monetised.

As a foundation, CrowdFlex should develop statistical techniques to predict portfolio capacity. These will need to balance the desire to offer markets firm capacity, and the temporal/geographic limits given the nature of the resource. Initially, these techniques should conform to the needs of existing markets, where the aggregator collapses the PDF of portfolio capacity to a single value, offered to the market as a firm capacity. While this is sub-optimal (as the aggregator has to derate the asset base to ensure declared performance), the approach does not require any alteration to business-as-usual market arrangements. This has the advantage of bringing domestic flexibility services to market, without regulatory revision.

In parallel, CrowdFlex should work with ESO to identify if greater system value can be unlocked by providing a PDF of portfolio flexibility capacity, rather than a single value. This could reduce operating reserve requirements (over £0.5 billion spent in 2021) while avoiding the need for the aggregator to derate the portfolio. As a key innovation action, Alpha will work with stakeholders to determine potentially unlocked system value should market participants use probabilities to express capacity. If a new stochastic domestic flexibility service was designed, it would need regulatory approval. Therefore, engagement with policy and regulation stakeholders should be maintained in alpha.

Therefore, CrowdFlex has a plan to access assets under business as usual market arrangements, while in parallel pursuing innovative and valuable approaches, alongside continuing engagement with regulatory and policy stakeholders to identify and remove any barriers.

5 Outline specification of the trial

5.1 Summary of key learning outcomes of CrowdFlex

In the near term the ESO and DSO believe that **domestic flexibility can be a highly valuable source of flexibility participating in existing, technology agnostic energy markets and flexibility services**. However, before a Trial, CrowdFlex: Alpha should revisit a **potential new digital stochastic service tailored for domestic flexibility, which takes a more stochastic approach to contracting flexible services**.

Existing energy markets and flexibility services can be **broadly distinguished into two types, PAS-Routine and PAS-Response type services**. CrowdFlex must investigate both of these DSR operations in a trial to understand the complete value of domestic flexibility.

For **PAS-Routine** services the flexible capacity of the aggregated portfolio could be declared shortly before delivery (minutes to hours) and then entered into the relevant energy market for delivery into the contracted window. This often equates to an intraday balancing service.

PAS-Response services are called upon at or near system stress events or for day-to day operation events. Rather than being declared close to the time of delivery, the firm capacity would need to be declared ahead of time, and available for use whenever called or within a specified window depending on the service. CrowdFlex should demonstrate that domestic flexibility can be reliable when providing the response during the following critical events:

- Demand turn-down at times of system stress (e.g. Capacity Market Satisfactory Performance Days)
- Demand turn-up/down following frequency/dispatch instructions for Ancillary Services
- Demand turn-down/up on the correct sides of constraints to mitigate VRE redispatch
- Demand turn-down at system peak to delay or replace network reinforcement

DSO domestic flexibility services would be highly locational and temporal, delaying reinforcement on the DN. CrowdFlex: Alpha should seek to understand to what extent the DSOs would be prepared to incentivise customers to provide DSO services and how the locational and temporal variability may impact consumers.

There is a **potential for conflicting interest between the ESO and the DSOs** when providing flexibility service (e.g. a demand turn-up for the ESO when the DSO requires demand turn-down). CrowdFlex: Alpha should coordinate with the ongoing work of the ENA Open Networks Project, for the determination of the primacy rules coordinating the needs of the ESO & DSOs.

There are **additional risks in expanding domestic flexibility**, including the potential loss of natural demand diversity associated with moving to ToU tariffs and impacting consumers with low flexibility potential on ToU tariffs. These must be addressed in CrowdFlex: Alpha to ensure that a trial can investigate how to mitigate such risks.

The ESO and DSOs expressed that **improved visibility and forecasting of domestic demand would be of high value**. This could benefit the SO/DSOs in several areas, including:

- FES/DFES teams seeking more information on domestic demand behaviour, uptake of LCTs, and smart charging to better forecast the capacity of available DSR to inform future network investments.
- It would also be useful to develop demand forecasting for the Control Room, improving system operability, decreasing balancing costs.
- Location specific visibility could improve the sophistication of redispatch mechanisms and reduce the associated costs.

CrowdFlex should place equal value on understanding domestic baseline demand as it does on the flexibility potential of domestic assets.

5.2 Specification for CrowdFlex Trial

The **core technology** areas that are in scope for CrowdFlex are:

- EV charging
- white goods
- Electrified heat (e.g. heat pumps, storage heaters – to be confirmed in Heat Roadmap in Alpha)

Technologies will be reviewed and finalised in CrowdFlex: Alpha, ensuring that the learnings from a trial are transferable to out of scope technologies.

CrowdFlex Trial should produce a vector of **baseline consumption**, expressed at time intervals of no more than 30 minutes, with prediction bands, aggregated up to a geographic level according to the needs of the system stakeholder.

PAS-Routine Trials:

- CrowdFlex trial should generate a timewise vector of projected flexible capacity, for each time interval, through the year. Therefore, a trial should be conducted for at least one year to provide this dataset.
- Assuming a business-as-usual approach to service provision, the aggregator would need to provide a value representing the firm portfolio capacity for delivery in each window. To improve confidence in an aggregator's position, the error bands in the projected flexibility/demand should be narrow. Greater statistical confidence will be required to narrow the error bands, and this would impact the required trial size and duration. The tests should extend over a long enough period and wide enough range of assets/consumers to provide confidence to the aggregator in the level of response provided, such that the aggregator can understand the uncertainty associated with bids in markets and balance this with e.g. imbalance charges associated with deviating from their declared position.
- PAS-Routine is encouraged through incentives or information remedies. Amongst other studies, CrowdFlex: NIA demonstrated SToU or dToU tariffs are effective incentives that can be profiled to give the required response. The generation of these incentive profiles should reflect challenges across the whole power system, i.e. across generation, transmission and distribution.
- Data from the trial should help the aggregator understand how utilisation of the portfolio in the short-term could degrade the capacity that might be available for future entry into markets/services, and how this would impact the aggregator's commercial strategy.

PAS-Response Trials:

- The trial needs to generate a timewise vector representing the derated firm flexibility capacity of the portfolio, which may be called at any time or during a service delivery period.
- For system operation PAS-Response type services:
    - CrowdFlex: Alpha should agree the parameters for testing to provide a reliable firm response. This will include aligning with National Grid ESO's service testing requirements. As the firm response for these types of service may vary throughout the year, response should be tested multiple times under a variety of conditions (season, weather, time of day, concurrent PAS-Routine incentives).
    - Given the speed of response required, it would most likely be procured via an automated response, this assumption will be tested further in Alpha detailed designs. The flexibility offered at these times needs to be additional to any change observed due to PAS-Routine services.
- For system stress PAS-Response type services:
    - CrowdFlex: Alpha should agree the parameters for testing to provide a reliable firm response. One example of this is by working with (amongst others) the Capacity Market to determine what would represent a Satisfactory Performance Day (SPD) and what data is required to estimate derating factors. There would likely be a number of tests run during system stress events (typically cold weather periods for demand led peaks, but also potentially summertime for supply led stress). The outcome would be the specification of test cells that demonstrate to market stakeholders that the response is reliable and can contribute to system critical functions.

    - These services may be called via an automated response or in a manner similar to the "Big Turn up/Down" experiments conducted in the NIA study. The flexibility offered at these times needs to be additional to any change observed due to PAS-Routine services.

- Assuming a business-as-usual approach to service provision, the aggregator would need to provide a single derated firm capacity representing the portfolio capacity. To minimise excessive derating of the portfolio capacity, the error bands in the projected capacity should be narrow. Greater statistical confidence will be required to narrow the error bands, and this would impact the required trial size and duration. The tests should extend over a long enough period and wide enough range of assets/consumers to provide confidence to the aggregator in the firm capacity of response provided, such that the aggregator can understand the uncertainty associated with bids in markets and balance this with non-delivery penalties.
- As the portfolio may be called repeatedly, the persistence of the assets needs to be tested. This would be via multiple calls on the asset, for example every evening for a week during the peak winter period.
- CrowdFlex: Alpha should investigate how to appropriately incentivise consumers to participate in PAS-Response type services. One option could be that it becomes a stipulation of their contracted and they are rewarded with a share of the resulting revenue.

CrowdFlex: Alpha should **determine, for each trial parameter, the distinct levels or settings to test**. It should then group these settings as appropriate to construct the specification for each test cell (trial), including **determining a prioritisation of which parameters / combinations of parameters** that should be tested in a trial.

CrowdFlex should trial **offering consumers financial incentives as well as information remedies**.

- The financial incentives will have a number of levels to test elasticity. This could include a combination of tariffs or other business models, such as one-off incentives.
- Implicit financial penalties (passive behaviour on a ToU tariff) and explicit financial penalties should be considered, noting consumer protection regulation.

Both **automated and manual responses** should be tested in CrowdFlex trial, both for the PAS-Response and PAS-Routine trials.

Before any trial, the number of participants for each test cell must be determined to **ensure that the results carry the statistical significance** to be extrapolated to the wider population

- This process will inform the scale of recruitment required for the trials.
- Once the recruitment process has identified the realistic potential size of trial achievable, the expectations on statistical significance should be revised, and tests that turn out to be onerous removed.

5.3 Specification for supporting work in CrowdFlex

To be successful, **CrowdFlex will have to establish general improvements in demand and flexibility forecasting**, including

- Develop probabilistic demand and flexibility forecasting techniques
- Move from today's static flexibility forecasting to dynamic half-hourly flexibility forecast
- Develop a methodology for translating probabilistic flexibility forecasts into deterministic point source estimates for use in system operations that minimise the penalty of derating.
- Determine the best method(s) for decomposing the forecasting of demand and flexibility into constituent underlying factors

The following **high-level approach is proposed for modelling domestic flexibility** in CrowdFlex: Alpha:

- Demand forecast (baseline/counterfactual) – forecast demand per household per half hour
- Flexibility potential (i.e. max up and down shift) forecast – forecast max shift possible per house for each flexibility delivery period based on historical & known loads

- Expected flexibility outturn forecast – forecast expected deliverable flexibility based on participation and depth estimates applied to the flexibility potential forecast. This could either be a distribution forecast or a point forecast based on likely participation based on historical average participation for given half hour

Engage with system operators to help **develop use of probabilistic forecasting and statistical methods**, including:

- Investigate inputs necessary to support stochastic forecasting in ESO/DSO decision-making, for example in:
    - ESO Control Room demand forecasts
    - Reserve setting
    - Acceptance and dispatch of flexibility offers from aggregators of domestic assets
    - System planning and network upgrade decisions
- Investigate the extent to which it is more appropriate for system operators to devise their own forecasts, compared to leveraging those from aggregator partners

CrowdFlex: Alpha will have **parallel workstreams to investigate how flexible domestic assets can engage in flexibility services**:

- The first will confirm the current services which domestic assets meet the technical criteria to participate in.
- The second further developing the possibility of a highly innovative, digital service, which expresses capacity as a probability. We will engage with the SO/DSOs to explain the benefits of stochastic flexibility offerings and understand the barriers for implementing such a service.

This approach improves confidence in the services and revenues available to domestic flexibility in the near term, ensuring it can be rolled out quickly and effectively to provide flexibility, while laying out a long-term pathway to introduce a stochastic approach to flexibility, which would provide system savings for all stakeholders for procuring and providing services via a probability density function approach (PDF).

Coordinate with VirtualES program to scope a domestic demand and flexibility digital twin:

- Understand how key frameworks and standards e.g. IMF, CIM, ENA data triage process and Dublin Core metadata standards, apply to a VirtualES demand and flexibility model
- Decide on specific use case for the model to deliver and undertake analysis to determine what a minimum viable product would be
- Determine relevant data gaps, both in terms of missing datasets and lacking meter data flows
- Investigate and choose a structure for the demand and flexibility mode

There is a need to **prove the conditions for commercial viability** of domestic participation in any market/service:

- A service will only be viable if the revenue from the service exceeds the cost, installation, and testing of equipment (e.g. metering) and the financial incentive that must be offered to customers for participating.
- CrowdFlex: Alpha must model these services in a high domestic flexibility future to understand the potential value/revenue from these services and estimate the associated costs
- CrowdFlex: Trial will then determine the financial incentives that should be offered.

The domestic flexibility associated from electrifying heat is being investigated in parallel trials to CrowdFlex (e.g. Equinox which investigates the flexibility available from heat pumps, and the SIF Flexible Heat project). Going forward, **CrowdFlex should develop a Heat Roadmap to understand how a trial could be planned to minimise any overlap** with other work.

Engage with stakeholders (such as SO, DSOs, Ofgem, BEIS) to i**dentify and understand potential regulatory, policy, or implementation barriers** that may impact CrowdFlex and will need to be overcome, including:

- Stochastic service requirements for non-BAU markets and services

- Regulation may limit/prohibit development of coordinated services
- Including locational element into ToU tariffs to encourage DSO flexibility services
- Requirement for asset level MID meters for asset level settlement

CrowdFlex has found **no strong evidence currently that derogation is required for the CrowdFlex trials to take place.** CrowdFlex: Alpha will review this when detailed plans are developed. If there are scenarios that may require derogation, CrowdFlex will approach Ofgem to request to establish a ‘sandbox’ environment to test the new scenario.