CrowdFlex: Alpha

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D1.1 - Current & future system needs

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ESO

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1.1. Current & future system needs and associated parameters

1.1.1. Context, aims and methodology

CrowdFlex seeks to unlock the nascent and largely untapped source of domestic flexibility to help solve the broad physics-based system needs that face the transmission and/or distribution systems. National Grid ESO and Distribution System Operators (DSOs)[1] currently address these system needs through the encouragement of external market incentives to serve system needs, the procurement of commercial flexibility services, and infrastructure investment. Domestic flexibility may be used to take advantage of market opportunities or provide commercially procured flexibility services, ultimately enabling the network operators to avoid infrastructure investment. Commercially procured flexibility services, known by National Grid ESO as Balancing Services[2], are constantly evolving both as the needs of the system evolve and as the technology that can provide the service improves. Similarly, DSOs are increasingly exploring delaying or mitigating network reinforcement through the procurement of local flexibility services[3]. While these services are currently primarily provided by I&C demand side response (DSR) and energy storage, there is no fundamental reason why domestic flexibility cannot increasingly provide these services in the future.

To ensure that a CrowdFlex large-scale consumer trial remains relevant in the medium and long terms, it is imperative that we ensure that the results of a trial are adaptable to the changing energy system. This includes the needs faced by the system and the commercially procured flexibility services that are offered to mitigate these challenges.

As such, Task 1 seeks to understand:

- the categorisation of the current broad physics-based system needs that pose challenges to National Grid ESO and the DSOs.
- how these system needs align with the ESO's current suite of commercially procured Balancing Services and DSOs' current local flexibility services,
- how decarbonisation and other factors may change these system needs in the medium to long term,
- the extent to which domestic flexibility could effectively serve each of the system needs.

To achieve this, we have reviewed ESO documentation including the Operability Strategy Report, Market Roadmap to 2025, Bridging the Gap to Net Zero, and A Day in the Life 3035 as well as the various Energy Networks Association documentation on local flexibility services to identify the current and future system needs and associated services. We have then worked with subject matter experts (SMEs) within the ESO, Scottish and Southern Electricity Networks (SSEN), and National Grid Electricity Distribution (NGED)[4] to validate our outputs and prioritise areas best suited to domestic flexibility.

1.1.2. Current system needs

National Grid ESO's system needs are laid out in their annual Operability Strategy Report, which defines the five broad categories of physics-based system needs on the transmission network that pose challenges for National Grid ESO[5]. The five broad categories named in the report are Frequency, Stability, Voltage, Thermal, and Restoration. Additionally, through interviews with SMEs within National Grid ESO, we have also identified Adequacy and Within-day Flexibility as additional challenges that will be faced for zero carbon operation of the system[6]. Each of these system needs have been defined in detail below. For each system need we have identified the current commercial services procured by National Grid ESO to address the challenge. This will enable us to align the technical capabilities of domestic flexibility to the current requirements of flexibility

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[1] Also known as Distribution Network Operators (DNOs).
[2] National Grid ESO, Balancing Services, https://www.nationalgrideso.com/industry-information/balancing-services, Accessed Sep 2022.
[3] Energy Networks Association, Flexibility services, https://www.energynetworks.org/creating-tomorrows-networks/open-networks/flexibility-services, Accessed Oct 2022.
[4] Formerly Western Power Distribution (WPD).
[5] National Grid ESO, Operability Strategy Report 2022, Dec 2021.
[6] These challenges are currently being scoped by National Grid ESO and will likely feature in the 2023 Operability Strategy Report.

services. We will use this to develop a shortlist of system needs that domestic flexibility should focus on within CrowdFlex. The same approach has been used to identify the DSO system needs that should be focused on in CrowdFlex.

The technical requirements of flexibility services include, but are not limited to:

- the required response rate of a service/dispatch period,
- the duration of the response,
- the duration of the availability period,
- and other requirements related to tendering (such as metering requirements and non-delivery penalties and charges).

In addition to aligning the technical requirements of flexibility services, the business-as-usual status of each market was also assessed to understand if the introduction of domestic flexibility could actively reduce costs or the carbon intensity for National Grid ESO/DSOs and therefore consumers. This included assessing the cost and size of the market for National Grid ESO/DSOs in the current BAU scenario. These technical and market features of each service are summarised in Table 1.

Later work in the CrowdFlex: Alpha project (WP5) will comprehensively address the technical capabilities and characteristic of the domestic assets that will be considered in a large-scale consumer trial. For now, the high-level technical capabilities of domestic flexibility are set out below:

- We expect that automated domestic assets (such as EVs and HPs with thermal storage) will be able to respond to relatively rapid dispatch signals, on the order of minutes, and will be able to sustain a response from minutes to hours, by deploying individual assets sequentially for aggregate delivery.
- Meanwhile, manual domestic assets (such as non-smart white goods) will be able to respond based on day ahead instructions, as proved in the CrowdFlex: NIA project and the Domestic Reserve Scarcity Trial. These assets have been shown to be able to provide 2-3 hours of response[7] without the application of any deliberate sequencing that could potentially extend responses for longer periods.

Based on aligning the high-level technical capabilities of domestic flexibility with our assessment criteria for current system needs and their commercially procured services, we have applied a Red-Amber-Green (RAG) rating to the suitability of domestic flexibility to act as a resource to mitigate the system needs facing National Grid ESO, SSEN, and NGED. The RAG rating system is as follows:

- Red indicates that domestic flexibility is not unsuitable to addressing a system need,
- Amber indicates that there may be some cases for which domestic flexibility is suited to addressing the system need,
- Green indicates that domestic flexibility is likely well suited to address the system need and it should be explored further in CrowdFlex.

[7] National Grid ESO, CrowdFlex: NIA, 2021.

Table 1: National Grid ESO physics-based system needs on the transmission networks, the corresponding commercial services and products, and a RAG rating for domestic flexibility's suitability for meeting the system needs.

System need	Commercial service	Current commercial product	Response rate[8]	Response duration[8]	System cost 21/22[9]	Suitability for domestic flex
Frequency	Response	Dynamic Containment	1 sec	15-30 mins	£341m	R
		Dynamic Moderation				
		Dynamic Regulation	10-30 secs	30-60 mins		Y
		Firm Frequency Response				
	Reserve	Quick Reserve	1-2 mins	15 mins	£920m	G
		Fast Reserve				
		Slow Reserve	15-30mins	2 hours		
		Short Term Operating Reserve				
	Energy balancing	Balancing Mechanism	~ secs – 1 hour	30 mins	£110m	G
Stability	Inertia	*Pathfinder product only*[10]	0.5 secs	12 secs	N/A	R
	Short Circuit Level	*Pathfinder product only*[10]	0.5 secs	12 secs	N/A	R
	Dynamic Voltage	*Pathfinder product only*[10]	~ ms	~ ms	N/A	R
Voltage	Reactive Power	Obligatory Reactive Power Service	Continuous		£190m	R
		Enhanced Reactive Power Service	Continuous			R
Thermal	Constraint management	Balancing Mechanism	~ secs – 1 hour	30 mins[11]	£1,474m	G
	Ahead of time contracts	Constraint management contracts	Various			
Restoration	Restoration	Restoration	8 hours	120 hours	£63m	R
Adequacy	Capacity Market	Capacity Market	4 hours	No limit	£1,671m[12]	Y
	Day-ahead adequacy	Demand Flexibility Service	24 hours	30 mins (3 hours max)	N/A	G
Within-day flexibility	Energy Arbitrage[13]	Wholesale market	24 hours	1-3 hours	-	G

[8] National Grid ESO, https://www.nationalgrideso.com/, Accessed Sep 2022.
[9] National Grid ESO, Monthly Balancing Services Summary (MBSS) Apr-2022, April 2022.
[10] Formally these needs were fully met by thermal generation complying with their Grid Code obligations.
[11] Balancing Mechanism periods are 30 minutes long, but thermal constraints can last significantly longer than 30 minutes (in some cases days).
[12] ERM Delivery Body, Capacity Market Published Round Results 2021-2022, 2022.
[13] Energy arbitrage on the Wholesale market is not an ESO procured service, but is a commercial mechanism that can leverage intraday flexibility to address the needs of National Grid ESO.

Frequency is the operability need to ensure the balance of active power (supply and demand) on the network to keep the frequency in statutory range. Energy balancing is largely addressed by power markets, with the vast majority of energy traded in future and forward contracts, topped up in the Day Ahead and Intraday markets as we approach real time. However, following Gate Closure (30 mins before delivery), it is the responsibility of National Grid ESO to ensure energy is balanced on the system and the frequency of the network is maintained. The ESO achieve this through a range of services and markets that can be dispatched from 30 minutes before real-time (Slow Reserve) to just 1 second before delivery (Dynamic Containment).

Reserve services generally have the slowest dispatch times of the services that address Frequency, ranging from 30 mins (Slow Reserve) to 1 min (Fast Reserve – although as this is phased out, the quickest response will be 5 mins from Quick Reserve). Meanwhile, Response services require extremely quick response rates, with Dynamic Containment and Moderation the fastest at 1 second and Dynamic Regulation the slowest at 10 seconds (Non-Dynamic Firm Frequency Response is slower still 30 seconds but is in the process of being phased out). Even when automated, flexible domestic assets are unlikely to meet the technical requirements to be able to provide Response services while competing with battery storage, the incumbent technology. This reinforces the findings of CrowdFlex: Discovery[14].

Reserve makes up a large component (30%) of the ESO's balancing costs, £920m in the 2021/22 financial year[15]. Therefore, should domestic flexibility prove to be able to competitively provide an alternative to Reserve in a large-scale trial, it could significantly reduce the balancing costs.

The final way energy is balanced is through the Balancing Mechanism (BM). The BM is a "pay as bid" short term energy market, run by the ESO in the last hour before real time. Dispatchable (or flexible) assets submit "bids" and "offers" the ESO in the run up to gate closure. Based on the Net Imbalance Volume, the ESO instructs assets to adapt their generation/demand in the form of Bid Offer Acceptances (BOAs). The BM is the ESO's primary means to balance the system, supplemented by the services above. Each BM participant details the specification of their Balancing Mechanism Unit (BMU) including the characteristics such as its technical capabilities and location. This alongside the price of its bids/offers will influence the Control Room's decisions when deciding which BMUs to dispatch. BM participants providing Reserve receive utilisation payments through the Balancing Mechanism. However, non-BM participants may still provide Reserve and receive utilisation payments through a bespoke dispatch platform.

Stability is the inherent ability of the system to quickly return to acceptable operation following a disturbance. There are three main areas in which Stability can be provided to National Grid ESO as a service – Inertia, Short Circuit Level, and Dynamic Voltage. Currently these are available as Pathfinder trial products only. These Stability products are provided either by large spinning devices (such as synchronous condensers) or ultra-rapid (ms) responding stationary assets. As domestic assets largely do not fill these technical criteria, CrowdFlex should not focus on Stability going forward.

Voltage is the operability need to ensure the balance of reactive power on the network to keep voltage within the operational range. Domestic flexibility is not well suited for voltage control on the transmission network as voltage injections/absorptions on the LV distribution network would have a negligible or small effect on the wider transmission network. Therefore, domestic assets could not meet the transmission system needs for voltage.

Thermal is the requirement to manage power flow across the transmission network avoiding overheating of transmission equipment. As outlined in CrowdFlex: Discovery, thermal export constraints require location-specific either generation turn down or demand turn up behind the constraint and generation turn up or demand turn down in outside of the constraint. Import constraints require the inverse action, i.e. generation turn up/demand turn down behind the constraint and generation turn down/demand turn up outside the constraint. Currently, transmission network constraints are primarily resolved in the Balancing Mechanism, with actions dispatched in the hour period before real-time. This well suits the capabilities of domestic flexibility.

As outlined in the Operability Strategy Report, constraints are rapidly increasing on the network and with them the cost of redispatch to resolve the constraints. In the 2021/22 financial year they were the single greatest balancing cost for National Grid ESO (48%), £1.47b[15]. By providing demand turn down/up on the respective sides of constraints, domestic flexibility could be a very cost-effective alternative to redispatching generation. In addition, as the vast majority of generation turn up is currently from thermal generation, domestic flexibility has the potential to greatly reduce the carbon intensity associated with these actions.

However, the largest, and therefore most costly, constraints can often persist for several days and involve redispatching extremely high volumes of energy. These constraints are generation driven and are often a result

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[14] National Grid ESO, CrowdFlex: Discovery, 2022.
[15] National Grid ESO, Monthly Balancing Services Summary (MBSS) Apr-2022, April 2022.

of attempting to transport power from wind turbines across the network. Therefore, the constraints are the result of weather patterns (e.g. periods of strong winds), which can often take days to cross the country. As domestic flexibility can only produce a response a few hours long in duration, it is wholly unsuited to resolve this type of constraint.

Nevertheless, demand driven constraints and short bursts of peak wind power that lead to short constraints on the network (hours in duration) may be able to be resolved through action from domestic flexibility. These constraints present a clear opportunity for domestic flexibility. In fact, one of the most costly constraints in GB is an import constraint around London. It's frequently active, especially over the peak period and depending on the interconnectors in the area. Demand turn down within the constraint, particularly from domestic flexibility has the potential to greatly reduce this constraint.

There is potential that import constraints on the transmission network could be considered alongside constraints on the distribution network as both are reliant on demand turn down during the evening peak. The extent to which these needs can be aligned will be explored further in WP4.

Restoration is the need to restore power after partial or total shutdown of the national electricity transmission network. Restoration requires extensive coordination with the providers of Restoration services. In addition, restoration requires hardened comms in the event that standard comms equipment (e.g. internet routers) lose connection. As domestic flexibility is unable to provide the exceptionally high reliability requirements necessary for Restoration services, we have been advised that CrowdFlex should not focus on Restoration going forward.

Adequacy is another system need that is vital for National Grid ESO, particularly as the system increasingly decarbonises. Adequacy is there to ensure that there is sufficient capacity on the system to meet demand at all times and equally to ensure there is sufficient demand on the network to keep it in acceptable operation. To ensure there is always adequate electricity generation available on the system, capacity is procured by the UK Government via the Capacity Market. In a system stress event, National Grid ESO can issue a Capacity Market Notice. This signals that generation in the Capacity Market must be available to generate during the period the Capacity Market is in effect.

Fundamentally, energy security is the Government's responsibility. It must ensure that the total aggregate capacity of generation (and their fuel supply) is sufficient to meet the demand on the energy system. Therefore, while the ESO advises on the capacity required by the system and issues Notices when it is required, Capacity Market volume decisions are decided by Government. Just as a turn up in generation can be part of the Capacity Market stack, so can a turn down in demand. In the 2021 T-4 auction, 988MW of the 42,000MW of procured capacity came from DSR[12,16]. Should domestic flexibility be able to demonstrate its ability to provide a firm and reliable response based on a demand turn down request, potentially from a Response type intervention, then it could potentially contribute to this stack in the future. Alternatively, Routine type flexibility, consistently reducing demand during the evening peak, could help reduce the additional capacity that will need to be procured in the Capacity Market as more Low Carbon Technology comes onto the system. This could be incentivised through time of use tariffs, as demonstrated in CrowdFlex: NIA[17].

The Demand Reserve Scarcity trial has proved in concept that domestic flexibility can help secure adequate balance of demand and supply on the system when demand is at its highest. This is being procured in the 2022 winter as a commercial pay-as-you-generate product by National Grid ESO, Domestic Flexibility Service[18]. CrowdFlex will seek to build on this service, understanding how domestic flexibility could act as a more reliable provision of system Adequacy in the future. The Demand Flexibility Service is a last-resort, non-daily service that may run for a single year only. CrowdFlex should test a 'first-resort', enduring, business-as-usual demand service alongside traditional services above.

A vital role of the ESO in tackling the challenge of Adequacy is to understand how Adequacy can be secured in a zero carbon operating system. Should CrowdFlex be able to demonstrate that domestic flexibility can provide 'first-resort' demand turn down at system peak either via Response or Routine type flexibility[19], then this could be of great value to the ESO.

Within-day flexibility is ability to shift supply/demand within the period of a day to serve the wider challenges of the ESO. This includes reducing demand at peak times (e.g. evening peak), increasing demand during the

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[16] NB. DSR does not necessarily mean demand turn down, only response on the demand side. Therefore, it also includes generating technologies such as diesel generators and BTM batteries.
[17] National Grid ESO, CrowdFlex: NIA, 2021.
[18] National Grid ESO, Demand Flexibility Service, https://www.nationalgrideso.com/industry-information/balancing-services/demand-flexibility, Accessed Sept 2022.
[19] The definitions of Routine and Response type services are laid out in CrowdFlex: Discovery.

summer minimum, and shifting demand to follow the output of renewable generation. The exact need for Within-day flexibility is still in the process of being fully defined by National Grid ESO, however, it is already clear that domestic flexibility will be well suited to shifting demand intraday to serve system needs. While it is primarily the role of the Wholesale (Day-ahead and Intraday) markets to incentivise Within-day flexibility, the role of the ESO in Within-day flexibility is to leverage it to enable net zero operation, as it is with Adequacy.

The Within-day variability of VRE supply and inflexible demand can be met by dispatchable gas generation. However, in a net zero system, dispatchable low carbon generation and flexible technologies must meet this requirement. CrowdFlex should determine the extent to which domestic flexibility can be one of the sources of Within-day flexibility in a net zero system. This could include how domestic assets can respond to Wholesale market signals linked to ToU tariffs. However, additional incentives including time dependent DUoS, TUoS, and carbon intensity signals that drive the shape of a ToU tariff should also be considered as enablers of Within-day flexibility

In summary, the current ESO system needs that domestic flexibility has the potential to be leveraged to solve are:

- **Maintenance of network frequency at slower time scales** (i.e. Reserve and energy balancing via the Balancing Mechanism),
- **Resolving short duration import and export driven thermal constraints**,
- Providing **day-ahead demand turn-down/turn-up adequacy**,
- **Within-day flexibility** (through Wholesale market and other signals linked ToU tariffs).

Table 2: DSO physics-based system needs on the distribution networks, the corresponding commercial services and products, and a RAG rating for domestic flexibility's suitability for meeting the system needs.

System need	Type of Service	Current commercial product	Response rate[22]	Response duration[22]	NGED cost 21/22[20],[21]	Suitability for domestic flex
Constraints	Reduction of peak demand on network	Sustain	Contract Stage	30 mins	£58k	G
		Secure	Contract Stage	30 mins	N/A	
		Dynamic	3 mins	30 mins	£398k	Y
	Replacement of Load Managed Areas (LMAs)	*Currently undecided*	-	-	N/A	G
Voltage	Reactive	Reactive	N/A	N/A	N/A	R
Restoration	Restoration	Restore	3 mins	30 mins	N/A	Y

Constraints presents the requirement for the mitigation or deferral of network upgrades by managing peak demand loading on the network and pre-emptively reducing network loading. DSOs currently aim to mitigate or defer network upgrades through the procurement of three local flexibility services, defined in the ENA Open Networks Project Active Power Services Implementation Plan[22] as the following:

- Sustain: The Network Operator procures, ahead of time, a pre-agreed change in input or output over a defined time period to prevent a network going beyond its firm capacity.
- Secure: The Network Operator procures, ahead of time, the ability to access a pre-agreed change in Service Provider input or output based on network conditions close to real-time.
- Dynamic: The Network Operator procures, ahead of time, the ability of a Service Provider to deliver an agreed change in output following a network abnormality.

[20] National Grid, 2021 Flexibility Dispatch Report, 2022.
[21] Note only 11 months of data available at time of reporting. NGED have yet to procure Secure, Reactive, or Restore services at time of reporting and do not have Load Managed Areas with Load Switching. SSEN data not available.
[22] ENA, Open Networks Project: Active Power Services Implementation Plan, Dec 2020.

Such local flexibility services are extremely locational and temporal as they only exist in areas where the network is constrained and only for the time period before it becomes more economically efficient to upgrade the network.

Both NGED and SSEN expressed their interest in CrowdFlex exploring domestic flexibility to provide demand turn down to reduce network loading on both the HV and the LV network. They suggested that they would be willing to explore the participation of aggregated domestic customers in local flexibility services to achieve this. While LV network peaks are relatively consistent aligning with the evening peak of domestic demand, HV network peaks can be more variable. Therefore, CrowdFlex will need to confirm the reliable reduction of peak demand during the evening peak as well as various times surrounding the evening peak to align with both the HV and LV networks.

SSEN also highlighted the potential of CrowdFlex to help continue to manage potential future constraints in Load Managed Areas (LMAs). LMAs are a legacy system, covering approximately 93,000 customers in rural areas, used to manage network capacity in the SHEPD licence area. LMAs reduce the maximum demand on circuits and at substations by controlling customer space heating and water heating load at different times during day and night via Long Wave Radio Tele-Switching (RTS). They were historically introduced as an alternative to traditional reinforcement in rural parts of the network where costs are prohibitively expensive. However, as customers increasingly come off this legacy system, the loss of diversity in demand from space heating and water heating could cause significant constraints on the network. In their RIIO-ED2 Business Plan[23], SSEN set out that they plan to use market flexibility services to replace LMA mandated switching patterns, including activities to define, develop and stimulate the market. SSEN are keen to leverage CrowdFlex to further understand how this could be achieved, helping to mitigate costly network reinforcements in areas which would be constrained without the diversity currently provided by LMA switching.

It is worth noting that when delivering DSO services to resolve constraints, over delivery of demand turn down is not an issue as the only objective is to reduce the loading on that part of network. This contrasts with ESO Balancing Services, where like under delivery, over delivery also poses a problem for the network as the ultimate goal is to balance the system.

Voltage is the operability need ensure balance of reactive power on the network to keep voltage within the operational range. To date, neither NGED nor SSEN have deployed reactive power services to manage voltage on the distribution level.

While it is out of scope of CrowdFlex to investigate whether domestic assets can be modified to provide reactive power to the network, it was suggested that in the future similar turn down services to those that resolve constraints could be offered to improve the voltage quality on the network during peak times. This will not form the focus of CrowdFlex, but we will aim to ensure that the outcomes from any trial into resolving constraints could be applicable to providing an active power service to improve voltage operability on the distribution network.

Restoration is the need to restore power after partial or total shutdown of the distribution network. DSOs procure Restore service to support the network in an outage. The Restore service is intended to help with restoration following rare fault conditions. Such events are rare and offer no warning as they depend on failure of equipment. Under such circumstances, response can be used to reduce the stress on the network.

Restore is defined as: following a loss of supply, the Network Operator instructs a provider to either remain off supply, or to reconnect with lower demand, or to reconnect and supply generation to support increased and faster load restoration under depleted network conditions.

There are potential issues surrounding the capability of domestic flexibility to provide Restoration of the DSO, namely ensuring the comms infrastructure is resilient to power interruption. However, if these issues could be overcome then domestic flexibility could provide a service such as Restore. While there is potential that domestic flexibility could provide such an active power response, following discussions with NGED and SSEN, CrowdFlex will not focus on restoration, as domestic flexibility has potential to make a larger impact on the other system needs of the distribution network.

In summary, the current DSO system needs that domestic flexibility has the potential to be leveraged to solve are:

- **Constraint management by reducing peak demand** on both the HV & LV networks via a routine daily service,

[23] SSEN, SSEN Distribution RIIO-ED2: Load-Related Plan Build and Strategy, 2021.

- Mitigate potential future constraints by **providing an alternative method of introducing diversity in domestic appliances** to Load Managed Areas switching.

1.1.3. Future system needs

Throughout NG ESO's 2022 Future Energy Scenarios (FES) and additional documents, it is firmly acknowledged that demand flexibility will be a key aspect of managing the Net Zero transition and increases in variable renewable generation.

Domestic flexibility is a welcome asset, anywhere it can achieve the fundamental characteristics needed to provide grid services as outlined in section 1.1.2.

The need for Balancing Services will be particularly great in the near to medium term as supply and demand move forward, but the wholesale market reforms are not yet completed to accommodate this. Where suitable, domestic flexibility offers an effective mitigation for increasing balancing costs (£2.65bn in 2021).

Future system

As the GB energy system moves towards Net Zero, there will be significant changes in both the supply and the demand sides of the system. The extent and speed of these changes is not certain, but there are key themes through each of the four likely scenarios described in NG ESO's FES.

On the **generation** side, there will be a dramatic (200%) increase in low carbon generation and a corresponding move away from using unabated natural gas to generate electricity. Variable generation sources, such as wind and solar will increase as a proportion of the generation mix and wind generation in particular is expected to represent the single largest source of generation by 2030 in all scenarios. Further infrastructure investment and additional interconnectors are expected in all scenarios, though these are more significant in the most optimistic scenarios that see GB achieving Net Zero and net energy exporter targets by 2050.

Energy demand is expected to grow in all scenarios, particularly in the transport sector as consumers move to electric vehicles and the ban on new petrol and diesel vehicles comes in (2030). Similarly, the decarbonisation of heat (e.g. heat pumps replacing gas boilers) and commercial transport (heavy goods) will create significant demand. It is looking increasingly likely that both sectors will do so via electrification, with hydrogen the main challenger low carbon fuel. Even in scenarios where there is significant uptake of hydrogen technologies, this hydrogen is expected to be generated by electricity (green hydrogen) and therefore will lead to similar dramatic increases in electricity demand.

In all areas, external factors such as availability of new technologies (supply chain factors) and the cost of those technologies will impact the rate and extent of uptake.

The role of **consumer behaviour** is key to the differences between ESO's scenarios. Where consumer engagement is high, demand-flexibility emerges, energy efficiency increases, and the growth in peak demand is reduced. Distributed generation (solar PV) and storage (home batteries, V2G) contribute to this relative reduction in demand, as do increased thermal efficiency (insulation) of buildings and increased automation and efficiency of appliances and EV chargers. Optimistic scenarios that meet Net Zero and energy exporter targets rely on a moderate to high level of consumer engagement and, inherently, domestic demand flexibility. To drive sustained high levels of consumer engagement, domestic customers will need to:

- understand what is being asked of them by way of providing flexibility and why,
- trust their supplier/aggregator to deliver this service without impacting their core needs,
- are appropriately rewarded, via ToU tariff or other incentive mechanisms, to maintain trust and deliver long term capability of these new services.

Another NG ESO report, Bridging the Gap, lists end-consumer flexibility as one of the key summaries of their review. This is drawn from the **FES projection of customers moving up to 18% of their peak demand to other times of lower demand**. Results from CrowdFlex could be an important study in informing NG ESO how to achieve this customer behaviour change.

Effect on system needs

As generation becomes more variable and weather dependent, there is a day-to-day need for **balancing** generation with demand. Within-day imbalances could be as simple as the wind blowing across lunch time and not across peak demand hours. On a larger scale, prolonged periods of still weather or particularly windy weather could lead to extended periods of supply and demand imbalance. Inter-seasonal solutions will be needed for these scenarios, which are unlikely to be able to be provided by domestic flexibility, as well as Within-day balancing, an area domestic flexibility is far more suited.

With generation becoming increasingly location dependent (e.g. off-shore wind farms, on-shore wind in otherwise low-use land), there is the potential for **new locational export constraints** to appear. Short term locational constraints may continue to be met by Balancing Services, which can include domestic flexibility. It is recommended that large-scale storage solutions be incentivised to build where they can support managing these constraints. The same principle applies to electricity intensive industries, such as hydrogen generation. Although these larger solutions will mitigate constraints, a need for short term locational constraint management is likely to persist.

Similarly, with the ramp up of demand as the roll-out of LCTs accelerate, **import constraints** will dramatically increase on both the transmission and distribution networks. This will inevitably require significant investment in reinforcing the network, which will prove costly to the consumer. BEIS estimate the increase in demand required to reach net zero could increase network costs by £40-110bn[24] between 2021 and 2050, which could increase consumer bills by between £100-300 per year[25]. However, both the ESO and DSOs may increasingly take advantage of flexibility services to defer or mitigate the need for network reinforcements. This has the potential reduce bottlenecks caused by multiple parts of the network requiring reinforcement at the same time and the overall cost to the consumer. BEIS estimate this could reduce distribution network costs by ~£15bn.

Physical demands of the system will change as traditional generation sources decrease and new technologies make up the difference. Properties such as **inertia and voltage** will be impacted, as well as the effect on commercial services of the loss of these known technologies as providers of those services.

Meanwhile, as supply becomes more variable and demand increases, increasing the volume of flexibility the system requires increases (from 60GW in 2021 to 202GW in 2050[26]), coupled with the decreasing availability of traditional sources of flexibility, the value of domestic flexibility will increase. This will be increasingly true in a paradigm where Balancing Services account for carbon intensity of service providers.

System responses to those changing needs

Although the Wholesale market is expected to eventually manage many ongoing aspects of demand flexibility (e.g. consistent shifting of EV charging outside of peak hours; charging of batteries during windy periods), there is a meaningful period before market measures (e.g. a shift to half-hourly settlement for customers, locational pricing) are in effect which can fully enable this system operation approach. In this interim period, and outside the capabilities of the Wholesale market in general, it falls on ESO to procure commercial services and to direct investment in a way that balances the system in the most cost efficient manner. The need for these interim services will increase as generation becomes more variable.

Service procurement is currently technology (and carbon[27]) agnostic, focusing solely on the physical system needs (as previously discussed), the cost offered for providing the service, and the performance of providers who fulfil those services. Accounting for carbon intensity in service procurement would be a development towards net zero goals, but is not planned for the immediate future. Although the performance parameters of services are fundamentally dictated by physics and by the needs of the ESO (e.g. response rate and reliability of service), there is scope and willingness to assess these parameters and make sure that they remain at the fundamentally necessary level so that they do not unnecessarily exclude new participants, small participants or new technologies.

Market innovation activity is ongoing in areas such as Reserve and Regional Development Programs. CrowdFlex must ensure that the results of any trial in domestic flexibility are applicable to the outcomes of this market innovation.

Domestic flexibility could be considered at two response rates, that of manual delivery actions and that of automated delivery actions. Domestic flexibility (or wider demand-side flexibility in general) could extend the duration of response it can provide through sequential deployment of flexibility from different, aggregated sites. Although this comes at the expense of capacity. Such complexity of asset deployment should be considered in CrowdFlex trials.

[24] BEIS, Appendix I: Electricity Networks Modelling, 2022.
[25] EE analysis.
[26] FES 2022, Electricity system flexibility capacity, Consumer Transformation.
[27] Currently carbon is only included through carbon costs of power generation. The cost of carbon is currently too low to make a significant difference to the outcomes of service tenders.

1.1.4. Considering a demand-first paradigm for system balancing

The environment for grid services is rapidly changing. One example is the Demand Flexibility Service, which was brought to the market in only a few months to meet an urgent potential need this winter. In addition to testing the services listed above, CrowdFlex must also retain enough flexibility to consider new types of service in response to conditions that could change between conclusion of SIF Alpha and start of SIF Beta activities, if successful. We propose, alongside services listed above and to be chosen in WP4, that a space be left to imagine a new type of service, that could be tested if conditions require, or adapted to current needs at the time.

One traditional principle of grid service participation is technology neutrality. In practice, historical grid services were designed around parameters that traditional plants (coal and gas, pumped storage) could meet to ensure the mechanisms designed were successful in their operation. Inevitably this has been a barrier to domestic flexibility participation. Technology neutrality does means that if demand could meet the inverse characteristics of generation – to turn down with as much predictability and precision as generation could turn up – then it could participate. However, the influence of technology capability over the parameters of those services meant that, in reality, it was very hard for domestic flexibility to participate in services that had been designed around large-scale generating plants. The 'technology neutrality' principle has also been weakening in recent history as the new suite of dynamic frequency services take advantage of battery storage capability but are very difficult for other technologies to enter.

One benefit of bulk domestic flexibility shift is that by reshaping the demand curve ahead of time, balancing costs can be reduced by balancing around a lower demand position. Even if the absolute MWh amount of balancing is greater, by balancing around a lower demand position when there is a lot of slack generation capacity and not around a demand peak when the system supply is tight. Therefore, supply can be accessed from the cheaper end of the merit order, rather than more expensive options at the higher end of the merit order. In this way, overall balancing costs can be reduced. Such a service would focus on a bulk demand shift ahead of time, in a manner that would maximise demand participation and predictability (e.g. at day-ahead).

CrowdFlex should consider a service focused around this opportunity, alongside more conventional services discussed in this section. To do this would retain optionality in the CrowdFlex programme and maximise potential participation of demand flexibility in grid services. This could be through testing an evolution of the Demand Flexibility Service, or through another type of service designed in WP4. The Demand Flexibility Service is a last-resort, non-daily service that may run for a single year only. CrowdFlex should test a 'first-resort', enduring, business-as-usual demand service alongside traditional services above.

1.1.5. Work Package 1.1 Recommendations

We propose the **key system needs for consideration in WP4** are:

- **ESO:**
  - Energy balancing (via Reserve and the Balancing Mechanism)
  - Day-ahead adequacy ("first-resort", BAU, daily service)
  - Constraint management (short duration import and export constraints)
  - Within-day flexibility
- **DSO:**
  - Constraint management (reducing HV & LV peak demand)
  - Constraint management (Load Managed Areas)

CrowdFlex must **consider the implications of future system needs**, initially as an increasing volume for each of the shortlisted services, but should continue to evaluate the application of domestic flexibility to different services, informed by trial data. Some of the future system needs are already manifest. They include:

- The need for **peak demand shifting** as demand increases from LCT uptake,
- The need to **encourage high consumer engagement,**
- The **increased need for balancing**, in the interim via ESO-procured services and in the long term via wholesale,
- The **increase in import constraints** which domestic flexibility can support.

CrowdFlex should **test the full technical capabilities of domestic flexibility to inform future service design** on how domestic flexibility can be included in technology agnostic services.

CrowdFlex should **consider various aggregation approaches to understand the full extent of the duration and magnitude of flexible response** that domestic assets can provide via e.g. sequential dispatch of different assets should be evaluated to prolong delivery of service.

CrowdFlex should consider a new type of service that could become **an evolution of the Demand Flexibility Service (last-resort, non-daily service that may run for a single year only)** to retain optionality and understand how a different evolved ''first-resort', enduring, business-as-usual demand service could operate alongside the traditional services above.