CrowdFlex: Alpha

December 2022

D8.1 – Use Case Approach and Justification

Strategic Innovation Fund

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ESO

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1 Context

Domestic consumers comprise the largest sectoral share of electricity demand in the UK, accounting for a third of total electricity demand.[1] Therefore, households represent a key component of the demand system and can drive systemic change. The ESO's Future Energy Scenarios 2022 report emphasises the need for demand flexibility to meet system needs and expects the total volume of flexibility to increase from current levels of around 6 GW to 100 GW by 2050 in order to reach Net Zero.[2]

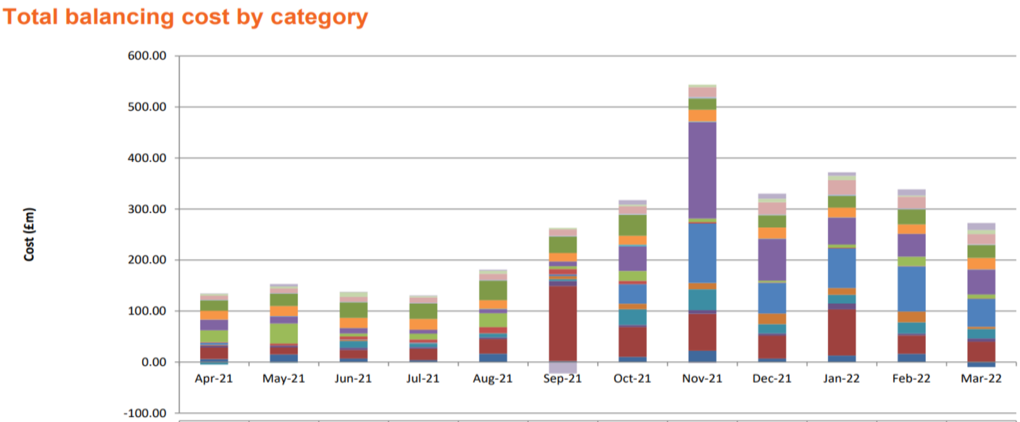
Domestic demand flexibility has been investigated through the Demand Flexibility Service starting in Winter 2022/23. However, domestic flexibility has the potential to be deployed across multiple Electric System Operator (ESO) and Distribution Network Operator (DNO) services if operators gain more confidence in the magnitude and variance of flexibility potential available from domestic consumers.

1.1 Recommended CrowdFlex trial services

Work Packages 1 and 4 of CrowdFlex: Alpha project have identified key CrowdFlex: Beta 'trial services' as:

- Entry of domestic portfolios into the Balancing Mechanism that can be used by the Control Room for 'real-time' energy balancing.
- A locational demand flexibility service that provides Thermal Constraint Management on the transmission network through demand turn down and demand turn up.

These services comprise major portions of the grid's system operations costs. Constraint management costs have risen significantly over the past decade, from £170 million in 2010 to £1.3 billion in 2021-22. The highest single day expense was on 24 November 2021 - with ESO spending over £60 million on the balancing market. These costs have already crossed £1.22 billion in 2022-23, projected to reach £1.35 billion for FY 2022-23.



	Apr-21	May-21	Jun-21	Jul-21	Aug-21	Sep-21	Oct-21	Nov-21	Dec-21	Jan-22	Feb-22	Mar-22
Minor Components	0.93	4.84	0.76	1.22	2.18	-22.33	8.73	-1.85	9.94	6.93	12.08	13.63
Black Start	3.70	4.06	9.62	2.64	5.92	2.96	3.30	4.88	6.83	8.34	2.60	8.01
Reactive	7.73	8.95	9.25	10.88	12.05	12.51	14.68	19.30	23.67	28.42	22.70	20.01
Other Reserve	1.40	1.32	1.18	0.96	1.27	1.52	1.96	2.81	1.77	2.18	1.86	1.58
Response	20.43	24.02	30.28	30.23	38.28	32.14	41.22	22.15	23.91	23.35	29.65	25.23
Fast Reserve	17.15	19.64	19.88	21.10	16.90	16.51	17.40	23.08	21.62	18.89	18.18	22.20
Negative Reserve	0.34	0.36	0.08	0.13	0.90	0.47	3.40	1.24	0.83	0.55	0.25	0.56
Constrained Sterilised HR	20.64	14.27	10.97	7.68	7.88	8.92	48.16	189.13	81.91	52.69	44.89	48.77
ROCOF	23.16	39.23	5.73	11.11	27.18	5.59	19.30	6.87	3.39	6.55	17.88	7.97
Constraints - Ancillary	1.26	3.86	5.83	6.27	11.61	10.32	6.55	2.65	0.62	1.21	1.07	0.86
Constraints - Scotland	3.94	0.25	0.87	1.55	0.30	3.37	38.10	116.71	60.37	77.72	88.47	54.45
Constraints - Cheviot	1.06	0.00	2.33	0.85	0.57	5.98	11.01	12.34	20.88	13.08	21.08	4.22
Constraints - E&W	-4.73	-1.39	13.01	6.51	7.62	3.85	30.57	40.88	18.13	17.39	21.86	18.69
STOR	4.35	3.69	4.36	3.35	3.20	9.91	4.35	7.18	4.53	11.23	3.73	6.30
Operating Reserve	22.71	13.67	16.74	22.30	28.82	146.79	58.49	72.34	44.70	90.44	36.12	40.19
Energy Imbalance	5.93	14.95	7.07	3.85	16.50	2.22	10.22	22.29	6.99	12.96	16.30	-9.63

Source: Monthly Balancing Services Summary Report, March 2022, accessible here.

[1] Digest of UK Energy Statistics, Chapter 5: Electricity. Available here.

[2] ESO Future Energy Scenarios 2022 report. Available here.

In the UK, constraint management costs arise in large part due to physical constraints of the system, such as the heating of transmission wires from resistance to increased energy flow (thermal constraint), and the need to operate within defined safety parameters.

Therefore, where there is “too much” power on one side of such a constraint (e.g., high levels of wind generation in the North Sea), ESO must pay to curtail generation, but may also need to pay generators on the other side of the constraint to increase generation to meet overall demand and ensure system balance. As well as the high cost, typically these additional generators are thermal, such as Combined Cycle Gas Turbines (CCGTs), and therefore significantly increase carbon emissions for the system.

In addition to these services, ESO has already developed and deployed the **Demand Flexibility Service (DFS)** in November 2022. This is part of several measures to ensure system security over the winter months. DFS also helps to ‘prove’ the potential of domestic and non-domestic demand flexibility as a ‘live’ service, with ESO committed to implementing at least 12 trials and undertake analysis and reporting of results. Work Package 4 recommends that CrowdFlex: Beta work with DFS as part of its trial services.

Work Package 4 of CrowdFlex: Alpha has also recommended two DNO services that should be considered in CrowdFlex: Beta. These include:

- Provision of the National Grid Electricity Distribution (NGED) **Sustain-H** service in Constraint Management Zones (CMZs).
- Provision of the **LMA Secure** service to ensure diversity of heat demand for SSEN in historic Load Managed Areas (LMAs).

The five services recommended for CrowdFlex: Beta differ in their geographic coverage. The ESO trial services cover larger geographical regions (e.g., national for BM and DFS, regional for thermal constraint management), while the DNO services are more localised to CMZs or LMAs. The key requirement from all of these services is a reliable understanding of the potential of residential demand flexibility to serve system needs.

1.2 Challenges to deployment of domestic flexibility

Demand flexibility has the potential to play a major role in transforming the energy system. As a nascent resource, interviews with subject matter experts (SMEs) have helped identify two main issues facing deployment of domestic demand flexibility to meet system needs:

1. **Uncertainty of response**

   Relative to the industrial and commercial sectors, domestic consumers have higher variability in electricity use over the day. Domestic electricity demand depends on micro-level behavioural patterns (e.g., appliance use, EV charging, and heating and cooking schedules for homes with electrified heating and cooking) that, when aggregated, cause electricity demand profiles to change significantly over the day. Moreover, many of these individual profiles can change at the same time, creating systemic demand peaks. This situation is especially notable from large changes caused by one-off occurrences like TV pickups around sporting events.[3] In addition, the potential variability in flexibility response is itself an open question that needs to be investigated more.

2. **Additional resources needed in the control room**

   As described in Work Package 1 (D1.2), the current paradigm for grid services is based on deterministic models using single point-estimates. It also provides a framework on how using probabilistic forecasts can be beneficial for the system by reducing derating of domestic flexibility as an asset. However, to make this resource usable, decisions would need to be taken about how probabilistic forecasts are displayed in the control room.

[3] https://www.nationalgrideso.com/news/euro-2020-and-tv-pick-effect

To address these concerns, CrowdFlex is developing a model of domestic demand flexibility that will be used to generate a probability distribution of demand response based on input parameters, such as incentive level, notice period, geographic (DNO) region, etc.

This model will help to reduce uncertainty by providing upper and lower bounds around expected demand response, based on a probabilistic forecast. The model could show, for example, pre-specified percentiles of the demand response distribution with the lower percentile (e.g., 5th percentile) indicating the amount of 'firm' flexibility response that can be provided at a given time and place.

2 Use case

The use case of relevance to CrowdFlex is the expected response of domestic consumers during flexibility events. This involves two-way communication between actual response by consumers *during* flexibility events and modelling to develop and validate estimated consumer response *in advance of* events based on pre-specified input parameters.

It should be noted that the use case considers the value generated by a model of flexibility, rather than the CrowdFlex trial itself; costs and benefits are therefore considered primarily from the electricity system's perspective. While consumers participating in CrowdFlex facilitate validation and improvement of expected responses, they don't accrue direct benefits from the model, unlike financial or non-financial benefits from participation in the trial itself.

The key components of the use case and a potential route to market after CrowdFlex: Beta is laid out in the table below.

Table 1:Use case for expected demand response model and route to market

Title	**Expected response during flexibility events**
Actors	CrowdFlex consortium members
Basic flow (trials)	1. CrowdFlex consortium members build models of expected domestic flexibility from their customers' electricity consumption data, based on existing consumption profiles and performance in previous flexibility events. 2. Predictions from the model are sent to ESO. 3. ESO works with consortium partners to decide how to configure flexibility events (timing and frequency of events). 4. Data on actual demand response by consumers during events is received by CrowdFlex consortium members. 5. Differences between forecasted and actual flexibility responses are utilised to refine forecasts and model build. 6. Predictions from the updated model are sent to ESO.
Route to market and use flow after CrowdFlex trials	1. Service providers own and calibrate or retrain their domestic response estimation models on their respective schedules. 2. ESO observes probabilistic estimates of demand response, potentially disaggregated by geographical DNO region in the control room. 3. ESO uses information on aggregate demand and weather forecasts to decide when to call upon flexibility response in a geographically targeted manner and potentially close to real time. 4. Service providers bid for levels of flexibility (turn up or turn down) that they can provide based on their own forecasting models and submit the same to ESO. 5. ESO decides which bids to accept based on bid value and system needs.

3 Aim

This document provides a guiding framework for a cost-benefit analysis (CBA) of a model of domestic demand flexibility that will be developed during CrowdFlex: Beta. Specifically, the model is expected to provide an expectation (probability distribution) of the magnitude of consumers' turn up / turn down response during a flexibility event based on pre-specified input parameters outlined earlier.

The document follows Strategic Innovation Fund (SIF) guidelines on components of a CBA, and is meant to be estimated, validated, and iterated over time. The model specification is being developed in D8.2 of Work Package 8.

Importantly, it should be kept in mind that since modelled estimates of large-scale demand flexibility is a novel use case, the costs and benefits are uncertain and require empirical validation.

However, through interviews with subject matter experts (SMEs), it is clear that such a model would generate high value to the system, in both the short and long run, and necessitate relatively lower costs for implementation.

4 Counterfactual

A CBA of a novel demand side flexibility prediction model needs to be compared against the counterfactual where services operate business-as-usual, with no probabilistic model of demand side flexibility. When considering the value generated by the model and building a cost-benefit analysis for it, there is not yet a direct comparison that can be made to the value generated by an alternative system-level domestic flexibility model since no such model is currently in use.

A cost-benefit ratio that is more favourable than 1:1 would, therefore, be sufficient and the actual ratio is expected to be much lower from an initial consideration of potential components of costs and benefits that are reasonably estimable, as described below.

5 Costs

The model would necessitate additional costs in terms of:

5.1 Information resources and data monitoring/maintenance

ESO will need to invest in resources for communication and harmonisation of data from suppliers/aggregators to utilise information on estimated demand flexibility. This cost can be mitigated if models are supplier-specific and outputs are provided in a harmonised open-access manner, such as through the VirtualES framework.[4] Participants would also incur costs of building and maintaining demand forecasting models, including human resource costs (e.g., data scientists, software engineers, etc.) and computing capabilities.

5.2 Additional actions and resources required in the ESO control room to implement the model

The model developed through CrowdFlex: Beta can be utilised in the ESO control room to give operators updated predictions on the potential of demand flexibility. This can reduce the cost of additional actions and resources required in the control room. Decisions taken by the operators may need to be fed through a dedicated unit in the control room, such as the Distributed Resource Desk.[5]

ESO has submitted its RIIO-2 Business Plan 2 assessment for consideration.[6] In this document, control centre operation expenses (Role 1) are requested at £67.8 million, and IT and telecoms capital expenditure is requested at £241.8 million over the April 2023 - March 2025 period (see Table 16). Assuming that using the domestic flexibility model accounts for 1% of this category of expenditures, the above costs to the ESO should be approximately £2.42 million over 2 years, i.e., **£1.21 million per year on average**.

With the speculative assumption that all participants employ a total of 50 additional personnel at an average salary of £50,000 per year for model delivery and maintenance[7], and incur additional investment in computing resources of £1 million per year, the overall cost of utilising the model would be around **£4.71 million per year** (£1.21 million + £2.5 million + £1 million).

[4] https://www.nationalgrideso.com/future-energy/virtual-energy-system

[5] National Grid adds 'Distributed Resource Desk' to control room to boost flexibility | Current News (current-news.co.uk)

[6] RIIO-2 Business Plan 2 Draft Determinations - Available here.

[7] https://www.glassdoor.co.uk/Salaries/energy-modeler-salary-SRCH_KO0,14.htm

6 Benefits

Better predictions of demand flexibility generate benefits through several channels outlined below:

6.1 Improved domestic flexibility capacity through reduced derating

In the circumstance where domestic flexibility becomes a business-as-usual function, the primary short-term benefit of better models of demand flexibility would be a reduction in underutilised flexibility capacity. With better forecasting models, the standard deviation of expected demand response would be reduced, increasing confidence in the ESO's ability to use demand flexibility to substitute for additional generation reserve requirements to meet electricity demand, especially at peak times.

A probabilistic model of domestic flexibility can allow control room engineers to utilise a larger information set while making risk-based decisions on how and where to engage domestic flexibility. This could be useful in many instances. For example, suppose a cold snap in one part of the country necessitates a response from the control room. A probabilistic demand flexibility forecast would allow engineers to evaluate the potential demand flexibility that consumers can provide during such an event.

The key difference from a deterministic forecast is that probabilistic values can be assigned to levels of flexibility provision. Depending on the control room's risk appetite, they may decide that the probability of provision of the required level of demand turn-down in a different region during the cold snap is not high enough to justify deploying flexibility and an increase in generation is the right response. Optimisation of responses in this manner reduces constraint management and balancing mechanism costs.

Probabilistic forecast models can generate value to the system by estimating the likelihood of provision of different levels of energy. For example, a reduction in the standard deviation of day-ahead estimates of demand response valued at a rate similar to average wholesale price in the day-ahead market from April 2021 to November 2022 would indicate an average value of £178.60 per MWh reduction in the standard deviation, conceptualised as an increase in 'firm' flexibility provision, with a maximum of £363.71 per MWh (August 2022) and a minimum of £69.38 per MWh (April 2021).[8] A 1 unit reduction in the standard deviation of expected demand response (say from 3 GW to 2 GW around a mean of 10 GW), would generate a value of £178.60*1,000 = £178,600 per GWh. Since this value flows from a reduction in uncertainty of estimated demand response, it is expected to be higher initially and reduce in future as the estimates get better (and uncertainty reduces incrementally) over time. **A value of £0.50 million per year can be generated through this channel**, since the initial phases will be most valuable to increase confidence in the demand response estimation.

6.2 Reducing carbon intensity of electricity generation by utilising domestic flexibility instead of fossil fuel-based power to manage thermal constraints

A significant benefit provided by increasing the accuracy of demand flexibility forecasts is to enable a reduction in the carbon intensity of electricity generation. This is facilitated by substituting away from fossil fuel based 'peaking plants' (CCGT, for example) in favour of more renewable energy generation and/or demand curtailment. Using assessments from IPCC AR5, this would have a large impact on marginal emissions, to the order of 760 gCO_2eq per kWh or 370 gCO_2eq per kWh for CCGT technologies.[9] At the level of current UK BEIS recommendation on the cost of carbon[10] of $£_{2020}$ 250 per tonne of CO_2, this translates to benefits of approximately $£_{2020}$ 0.19 per kWh for coal-based generation and $£_{2020}$ 0.09 per kWh for CCGT. Assuming that domestic flexibility can replace 10 GWh of CCGT, this translates to a social value of $£_{2020}$ 0.09 * 10^7 **= $£_{2020}$ 0.90 million per year**.

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[8] Wholesale market indicators data available here.

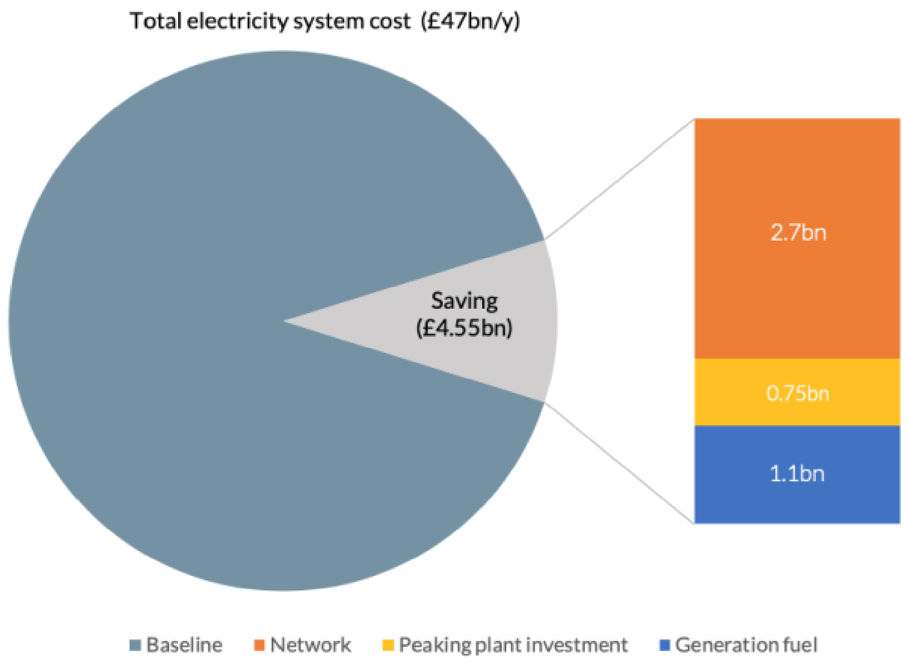
[9] Direct emissions by fuel source available here.

[10] 'Valuation of greenhouse gas emissions: for policy appraisal and evaluation', Policy paper, BEIS, 2021. Available here.

6.3 Reduced operational expenditures of existing services (e.g., balancing mechanism or thermal constraint management)

Most of the constraint management costs paid by ESO are in the form of payments to suppliers to reduce or increase their output.[11] Accurate estimates of demand flexibility will allow the operator to utilise flexibility as an alternative to paying suppliers to change output. For instance, when weather forecasts indicate a period of high potential wind power generation, forecasted demand flexibility can provide an estimate of how much domestic consumers in Scotland may be able to turn up their use resulting in lower required curtailment of wind generation.

A report by Project LEO (Local Energy Oxfordshire) estimates that demand flexibility (both domestic and non-domestic) can reduce system costs by £4.55 billion per year when projected out to 2050. The savings are generated through avoided increase in network capacity (~£2.7 billion per year), reduced peaking generation capacity requirement (~£0.75 billion per year), and reduced curtailment of renewable energy sources (~£1.1 billion per year).[12]



Source: Figure from Project LEO report on Modelling the GB Flexibility Market

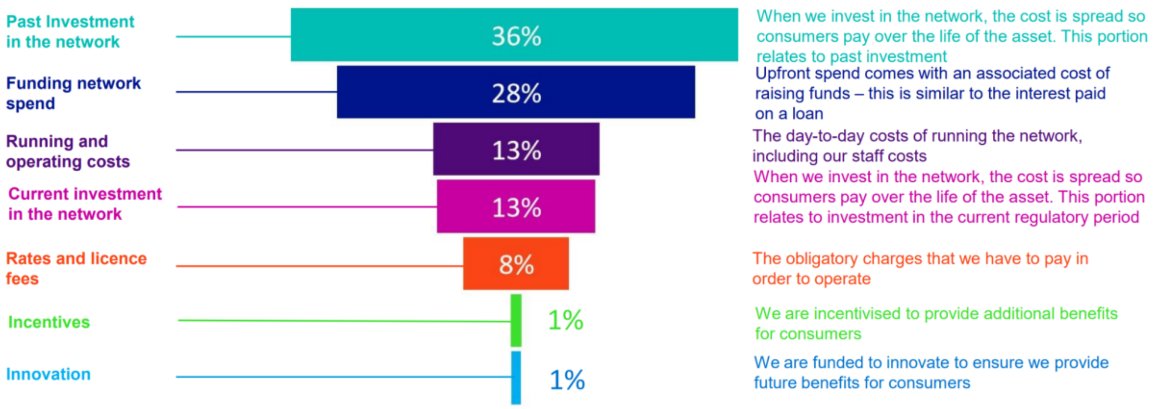
6.4 For consumers, use of demand flexibility can reduce the network cost component of electricity tariffs

Lower operational costs for ESO imply that the costs passed on to end users also reduce, resulting in lower electricity bills. Transmission and distribution charges are recovered from households as a share of their electricity bills. Approximately 3% of an average household's electricity bill is paid toward transmission costs, amounting to £20 per household per year. However, in an accounting sense, the purely financial benefits to consumers are a pass-through of benefits of reduced operating costs described above, and hence should not be 'double counted' in the CBA.

[11] Monthly Balancing System Summary Reports. Available here.

[12] Modelling the GB Flexibility Market, Part 1, 2020. Available here.

Electricity Transmission: how the £20 is made up



Source: Understanding the consumer bill, December 2021, report accessible here.

7 Summary of CBA

Table 2: Summary of costs and benefits of demand response forecasting model

<table>
<tr><th></th><th>Component</th><th>Value</th></tr>
<tr><td rowspan="2">Costs</td><td>Information resources and data monitoring/maintenance.</td><td>Approximately £2.5 million per year for human resources, and £1 million per year for computing and data monitoring/maintenance capacity for all CrowdFlex participants.</td></tr>
<tr><td>Additional resources required in the ESO control room.</td><td>Approximately £1.21 million per year for ESO (1% of control room operation expenses estimated in RIIO-2).</td></tr>
<tr><td rowspan="4">Benefits</td><td>Reduced derating of domestic flexibility as an asset.</td><td>£0.5 million per year through reductions in standard deviation of estimated demand response.</td></tr>
<tr><td>Reduced network operation expenditure - balancing mechanism costs.</td><td rowspan="2">System costs currently at £1.3 billion per year, expected to rise to £47 billion per year by 2050 in BAU. Flexibility is projected to reduce approximately 10% of these costs (£4.55 billion by 2050). This is total flexibility, and if domestic flexibility accounts for a third of this amount (similar to the sectoral share of total electricity use), the projected savings would be approximately £1.36 billion per year by 2050.</td></tr>
<tr><td>Reduced network operation expenditure - thermal constraint management costs.</td></tr>
<tr><td>Reduced carbon emissions from fossil fuel-based electricity generation.</td><td>Using the UK-recommended cost of carbon estimates, turning down CCGT generation generates benefits of £$_{2020}$ 0.09 per kWh of CCGT replacement. Assuming replacement of 10 GWh of CCGT, this translates to roughly £$_{2020}$ 0.9 million per year.</td></tr>
</table>

The overall implication of these components and indicative quantification is that the benefits from this model would potentially outweigh the costs associated with implementing it by orders of magnitude in the long term.

If the costs of building and utilising the model are at or lower than £5 million per year, the model of demand flexibility implies a **cost-benefit ratio of 1:3,** assuming

1. System costs are reduced by a conservative estimate of 1% in the short term (£13 million out of £1.3 billion per year),
2. Additional value is generated through reduced derating of domestic flexibility (£0.5 million per year), and
3. Lower carbon emissions from non-deployment of CCGT power plants are valued at the social cost of avoided carbon dioxide emissions (£0.9 million per year).

However, given the nascency of use of the model, estimates of costs and benefits would need to be validated and CBA re-evaluated as the trial evolves.

8 Recommendations

The use case of expected domestic demand flexibility will be developed through CrowdFlex: Beta. We therefore recommend that ESO work with CrowdFlex consortium members and design trials for CrowdFlex: Beta that:

- Utilise existing data on electricity demand by time-of-day disaggregated by geographical region, and technology type and response (manual vs automated) to build model(s) of expected demand response at a high temporal and spatial resolution. The model(s) will be aligned with Trial Service 1 only (scheduled manual interventions to manage contingencies).
- Share data on expected responses with ESO and DNO control rooms at DNO-region level and, where possible, disaggregate by response type.
- Schedule and implement demand response events that incentivise customers for flexibility provision.
- Use this actual demand response data to calibrate and re-train the models of expected demand response.
- Undertake repeated refreshes of the cost-benefit analysis to quantify and understand benefits to the system and consumers.
- Finalise a demand response forecasting model through repeated trials over the period of CrowdFlex: Beta. The aim will be to quantify and minimise differences between modelled estimates and actual domestic demand response.

After the CrowdFlex: Beta trials, the calibrated demand response model should be utilised by ESO as a ‘business-as-usual’ service that indicates the potential demand turn up or turn down that can be provided by domestic consumers based on input parameters that are pre-specified by the ESO (such as region, or time of day, or notice period). With the final product, ESO should also:

- Record ongoing expenditure on human resources and control room operations specific to utilising the model.
- Record as and when generation capacity and long-term investment plans are revised due to utilisation of demand flexibility response.
- Re-evaluate CBA components with updated actual figures and recalculate cost-benefit ratios every two to three years.