CrowdFlex: Alpha

January 2023

D6.1 - Assessment of operational revenues across customer groups, technologies, and incentives, for the target technologies

Strategic Innovation Fund

ESO

ESO

Contents

1 Objectives and scope

CrowdFlex is a study to explore the role that domestic flexibility can play in helping solve various system challenges, accelerating the decarbonisation of the electricity grid. Previous work in CrowdFlex has identified the key focus areas of ESO and DSO system operability challenges that domestic flexibility could be instrumental in tackling. These have been developed into "trial services" to be explored in a large-scale consumer trial and are laid out in Table 1.

Table 1: "Trial services" relating to ESO and DSO system operability challenges.

System Operator	Trial Service	Local/National Response	System Need	Dispatch Notice	Response Duration
ESO	Balancing Mechanism	National	ESO Frequency	<1-hour	~30 mins
ESO	Thermal Constraint Management	Local	ESO Thermal	Day Ahead	<4 hours
ESO	Demand Flexibility Service[1]	National	ESO Adequacy	Day-Ahead	1-2 hours
DSO	Sustain-H	Local	DSO Constraint Management	Contract Stage	4 hours
DSO	LMA Secure	Local	DSO Constraint Management	Day Ahead	24 hours

While the key features of these system needs are well aligned to the capabilities of domestic flexibility, the extent to which domestic flexibility can address these system needs still requires clarification. Similarly, it is essential for CrowdFlex to quantify the system value arising from a customer providing flexibility, so that this can inform the level of financial incentives offered during the trial.

As such, D6.1 demonstrates the benefits to both the system and the consumer of domestic flexibility by operationally modelling low carbon domestic technologies, aggregated into a portfolio, participating in the flexibility services outlines in Table 1. We have done this initially in the context of a time-of-use (ToU) tariff, our first system intervention. This is because ToU adoption is the prevalent business-as-usual (BAU) method with which domestic consumers could capitalise on the flexible capacity within their homes, taking advantage of variable wholesale energy prices. We have then layered on top the further interventions that represent our "trial services" to understand the interactions between each service and the impact on the value generated. Specifically, the services modelled in this workstream are as follows in Table 2.

Table 2: Description of services included in operational modelling.

Service Included	Description
ToU tariff optimisation	Responding to a ToU tariff achieves savings by shifting demand to times when prices are low. We use our Flexible Asset Model (FAM) to optimise when to shift demand.
Balancing Mechanism	Making bids/offers to turn up/down demand compared to an original schedule generates revenue. We use our FAM to optimise when to make bids and offers, using the optimised ToU profile as the planned schedule.
Thermal Constraint Management	This analysis focuses on export constraints as a result of high wind generation in Scotland. Shifting demand to times when there is excess generation can generate revenue for households in Scotland through curtailment avoidance. This is calculated independently to the other services.

[1] Our proposal is that CrowdFlex does not attempt to design a service that provides demand turn down during system stress events, as the Demand Flexibility Service does, but to stack the other CrowdFlex trial services with the output of any evolved/future version of the DFS that runs in Winter 23/24.

DSO Sustain-H	Distribution Networks offer revenue for turning down demand in certain constrained locations during the evening peak window. The optimised profile for TOU and BM is used to find a revenue for this service without changing the profile further.
Not included	
Demand Flexibility Service	Demand Flexibility Service is separate from CrowdFlex. In a full trial CrowdFlex participants may stack CrowdFlex services with the DFS, however, the analysis on the value this could create has not been explored in this report.
DSO LMA Secure	The value of replacing LMAs is currently unclear as DSO's currently do not offer any value in exchange for scheduling storage heater load to avoid peaks on the network. However, the value and impact on the operational profile should be similar to DSO Sustain-H.

As per the recommendations from D5.1, the operational modelling has focused on two low carbon technologies, **electric vehicles (EVs)** and **heat pumps (HPs)**. This is due to their expected prevalence in the future power system and ability to shift demand flexibly. We have not modelled the additional flexibility that households can provide with white goods, despite the recommendation for their inclusion in CrowdFlex. This is because we expect the revenue per household available from flexible EV and HP operation to be dominant, and hence we focus on those technologies.

We have modelled the savings available by operating domestic heat pumps and electric vehicles flexibly in the GB power system in 2030.

2 Modelling approach and assumptions

2.1 Modelling approach

The determination of revenues available from flexible asset operation proceeds via two models:

- A Power System Model - determines hourly wholesale energy prices arising from GB generation capacities, baseline hourly national demand, hourly weather and variable renewable energy sources (VRES) output.
- A Flexible Asset Model – determines the optimal operational dispatch of flexible (residential) assets given these prices, while meeting the constraints of service delivery (house is heated to required temperature, EV is sufficiently charged for daily use, etc.).

2.1.1 Power System Model (ISDM)

Element Energy has its in-house Power System Model (PSM) which has been developed over a decade. The Integrated Supply-Demand Model (ISDM) was one of the first PSMs to recognise the system impact of Demand Response, and of the impact new residential electrification technologies will have on national energy demand. The model has been used in assignments for GB Government, Energy and Transport sector clients.

Similar to other PSMs, the model is run for a specific year, in this case 2030. It takes as input projections of hourly baseline electricity demand, generation capacities, and hourly weather data to determine hourly VRES generation. The model dispatches the generation fleet (with appropriate constraints) to form a least-cost generation stack for each hour.

Due to the potential impact that EV and HP demand can have on the system by 2030, ISDM is run with passive demand profiles as a baseline to determine costs and hourly electricity prices.

2.1.2 Flexible Asset Model (FAM)

In contrast to the system level modelling of ISDM, Flexible Asset Model (FAM) explores the opportunity for flexible residential assets to optimise daily electricity use. Hourly electricity prices are taken as inputs, and FAM optimises the time of consumption to minimise daily costs (maximise revenue) while meeting the constraints of each asset (the EV needs to be sufficiently charged, the HP needs to achieve the target heating temperature, etc.).

Starting with a projection of a baseline electricity demand profile (and costs), FAM proceeds in sequence through these steps:

- It optimises the demand profile based on wholesale electricity prices and DNO services - this reflects the optimal response based on a day-ahead perfect foresight of a ToU tariff and a DNO service (Sustain-H).
- With this optimised day-ahead profile, the hourly capacities are submitted to the Balancing Mechanism to optimise bid/offer spreads to generate additional revenues.
- A final run is undertaken to reflect the potential to respond to supply-driven events to turn assets up/down to avoid thermal constraints on the transmission network.

The operational optimisation reflects what can be achieved by an aggregator controlling a large number of flexible residential assets (where the aggregate capacity is large enough to participate in the above services). This ensures there is consistency between the asset modelling and the national system impact. To aid interpretation, the results of this portfolio optimisation is shown on a per-household level.

2.2 Model assumptions and key data

EV data

- EV baseline charging profiles are based on the Electric Nation Project (over 30,000 residential recharge events)[2]. This showed that in the passive case, most (but not all) charging events occurred overlapping with the evening peak in demand. This is consistent and appropriate for our assumptions.

[2] See Element Energy Report “Recharge the Future” for more details on how this data was used.

- 2030 EV Uptake from NG FES Consumer Transformation Scenario.

Heat pump data

- 2030 Air Source Heat Pump Uptake from CCC "Widespread Engagement" Scenario.
- The archetype for the dwelling is a Victorian semi-detached house with high levels of insulation.
- Heat pump demand profile based on hourly temperature from an average winter year and calibrated to annual demand.

Energy modelling assumptions

- 2030 gas cost based on BEIS 2021 Green book.
- 2030 capacities and annual baseline demand based on National Grid FES scenario.
- TOU Tariff from Element Energy modelling wholesale & network costs, equivalent to average household annual bill of a flat 18.7p/kWh tariff (using Elexon profile). Electricity costs are summarised in Table 3.
- Historic BM Price from 2018 (year with representative volatility) and 2022 (year with high volatility).

Table 3: Electricity costs for passive charging in GB, 2030.

Passive demand	EVs	HPs
Number of units	11.9 million[3]	4.7 million[4]
Annual average consumption per unit	2,044 kWh	4,908 kWh[5]
Annual average electricity cost at 18.7p/kWh[6]	£382	£917
Annual average electricity cost on TOU tariff[7] per unit (passive)	£550	£978

2.3 Balancing mechanism volatility

Due to the potential for BM revenues to dominate the annual savings/revenue stack, and recent volatility in prices in the BM market, we have run a baseline case and a sensitivity case. As shown below, in recent years, average bid/offer prices in the BM have been relatively stable until 2022 when tightness in the gas market (due to the war in Ukraine) resulted in unprecedented elevated volatility.

[3] 2030 EV Uptake from NG FES Consumer Transformation Scenario.
[4] 2030 Air Source Heat Pump Uptake from CCC Widespread Engagement Scenario.
[5] For a Victorian Semi-Detached house with high levels of insulation.
[6] BEIS Energy and Emissions Projections Annex-M Retail price (reference scenario), updated Dec 2020.
[7] TOU Tariff from Element modelled wholesale & network costs, equivalent to average household annual bill of a flat 18.7p/kWh tariff (using Elexon profile).

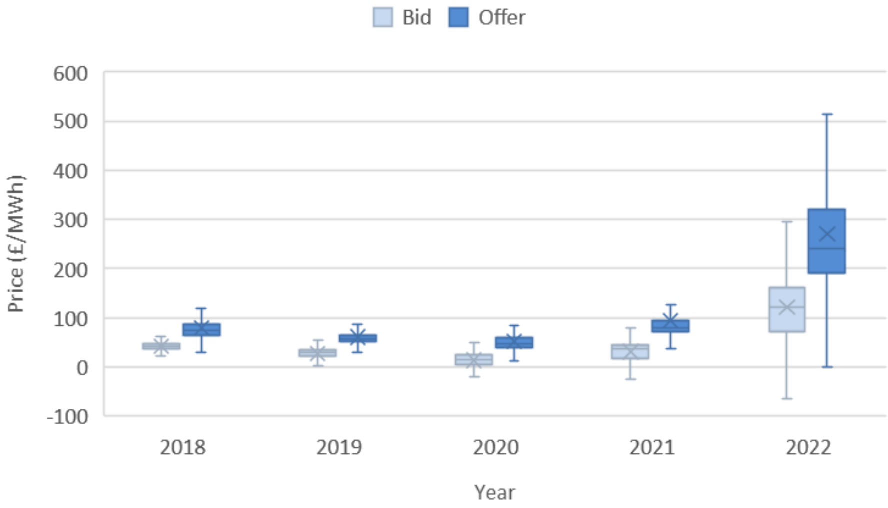

Figure 1: Balancing mechanism volatility 2018-2022.

Due to the volatility in BM prices, the value that domestic flexibility could generate from the BM varies significantly from year to year. As such, we have modelled the operation of domestic flexibility participating in the BM based on two reference years, 2018 and 2022. 2018 was a year in which the bid-offer spread was typical of the recent period, at £37/MWh. Whereas, due primarily to the dramatic increase in gas prices, the BM spread in 2022 was £148/MWh, a 4-fold increase on 2018.

By modelling both years, we can estimate the bounds of the potential value that participation in the BM can offer domestic consumers depending on whether it is a high and low spread year for the BM.

3 Total benefit of flexibility services

3.1 Revenues

The outputs of our modelling indicate that, for households with an EV and a HP, flexible operation with a TOU tariff and the stacking of all available CrowdFlex services can reduce annual electricity costs by 38-60%. This is from a £187-£307/year saving for EV owners (£69/year from ToU optimisation and £118-238/year from additional CrowdFlex services) and a £312-461/year saving for HP owners (£52/year from ToU optimisation and £260-409/year from CrowdFlex services). Full details of the revenue opportunities from domestic flexibility are broken down in Table 4, and illustrated in Figure 2 and Figure 3.

Table 4: Customer savings from service participation, by technology type. All savings are relative to a baseline customer on a flat tariff.

Revenue opportunity	EV (£/year)	HP (£/year)
Time of use savings	£69	£52
Revenue from Balancing Mechanism[8]	£23 - £143	£42 - £191
Increment from DSO turndown	£57	£140
ESO thermal constraint management	£38	£78
Total revenue opportunity	**£187-307**	**£312-461**

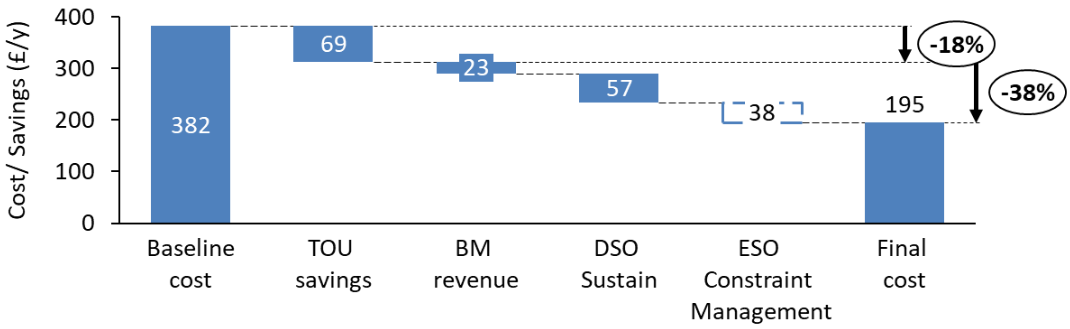

Figure 2: Baseline cost & available savings per year per EV.

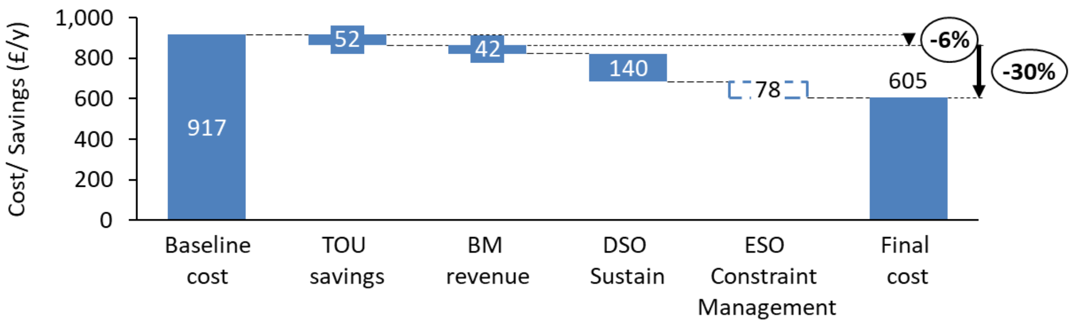

Figure 3: Baseline cost & available savings per year per HP.

[8] Variability is due to volatility. See section 2.3 for more details. The volatility of the BM is much more sensitive than the other services (although will be impacted by similar variables as Wholesale based ToU tariffs), therefore, it is the key sensitivity we have investigated in this report.

3.2 System benefits

The baseline for the analysis is that EVs and HPs are operated in passive mode, without concern for their impact on the grid. Passive electrification will, with near certainty, increase peak demands on the electricity system, increasing costs for all participants. Flexible operation works against the generation of new peaks.

The impact of flexible operation can be seen below. For EVs, there is close to a 10GW peak demand reduction when moving from passive to flexible EV charging. However, for HP operation, because of the limited thermal storage in the base case, there is no reduction in the peak (as we show below, peak HP loads can be reduced if dedicated thermal storage is also deployed). Overall, with flexible HP and EV deployed, ~10GW of peak demand reduction can be provided – more if dedicated thermal storage is deployed.

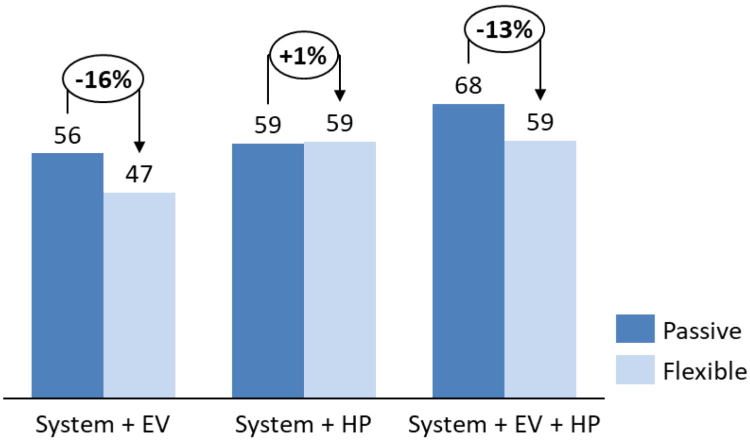

Figure 4: Change in system peak with introduction of EVs and HPs.

4 Time of use tariffs

4.1 Electric Vehicle charging

Switching to a time of use tariff with smart charging reduces charging costs by £69 per year when compared to passive charging, representing nearly a 20% reduction. This is achieved by moving most of the charging demand out of the evening peak and into the cheapest hours overnight. This is possible because the daily EV energy demand is small compared to the energy that can be added in the overnight charging window (typical charging at 7kW can be completed within 1-2 hours, compared to a 6-hour overnight window of lowest wholesale prices).

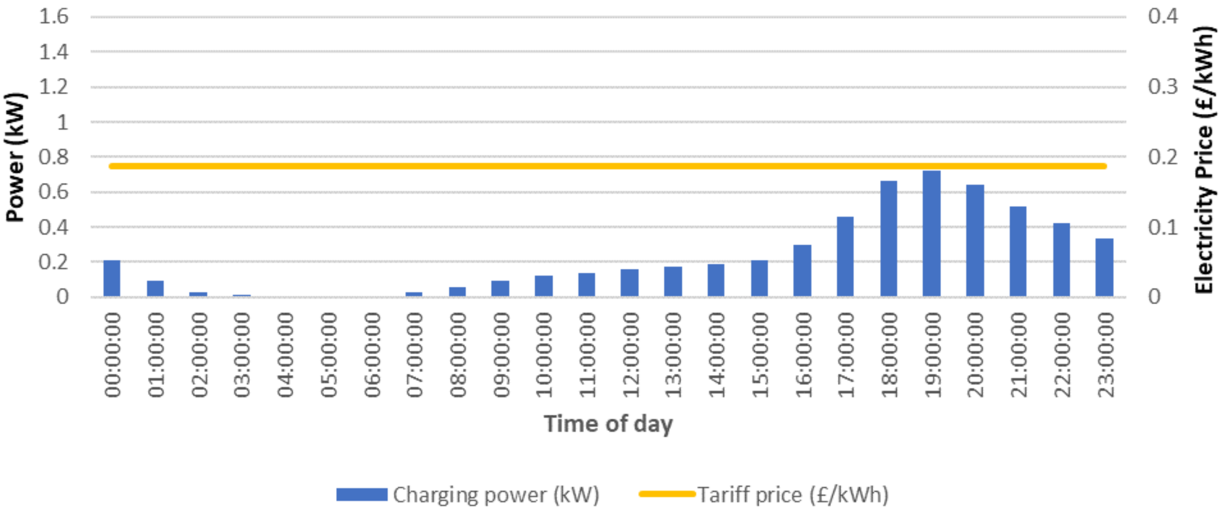

Figure 5: Passive EV electrical demand.

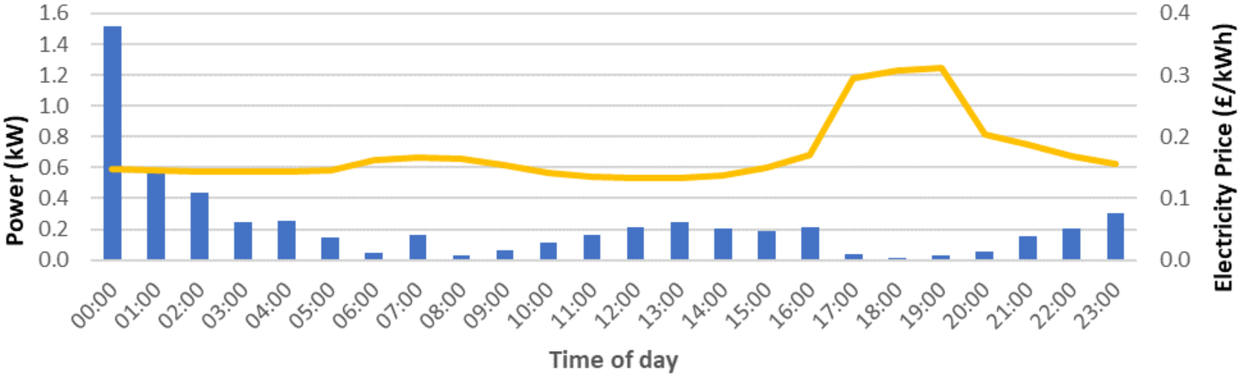

Figure 6: Flexible electrical demand responding to a time of use tariff.

Note that this represents the typical year-round behaviour. As the power system model includes variable renewable sources, there are times during the year where high levels of renewables output reduce wholesale prices outside of the overnight period, and the optimised modelling responds to this opportunity.

The midnight flexible EV demand is large but is limited by the optimisation algorithm to ensure no new peaks in aggregated demand are allowed (i.e., at this time, overall demand is still lower than the evening peak). The flat prices overnight show that this EV demand could be spread more evenly though the overnight period without any notable increase in costs. In our modelling, coupling of the supply side and demand models ensures that this feedback is represented.

4.2 Heat Pumps

Despite consuming approximately three-times the electricity that EVs consume (per household) the annual savings available to flexible HPs is lower compared to EVs. The reason for this is that there is much less flexibility available from HP operation in the base case modelling.

The baseline HP model assumes they are deployed in relatively thermally efficient houses, where some thermal energy can be stored in the fabric of the building. To move HP demand out of the peak periods (see below) would require the ability to shift demand by at least 3-4 hours. While EVs can (on the whole) achieve this, a HP with building fabric storage can only achieve a typical time shift of up to 3 hours – beyond this time, the internal temperature cools down below the required level. This means that, in flexible operation, HPs can respond to ToU tariffs but cannot move demand fully out of the peak periods. To do so would require more storage (see sensitivity study below).

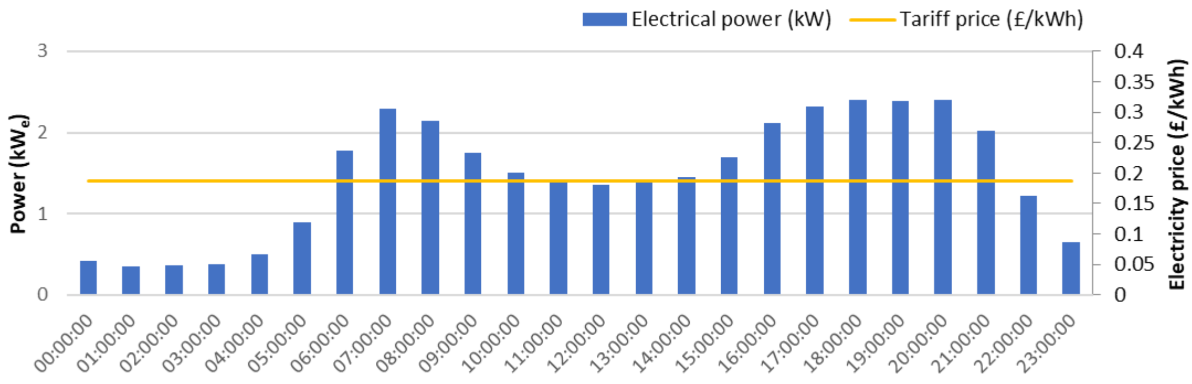

Figure 7: Passive HP electrical demand.

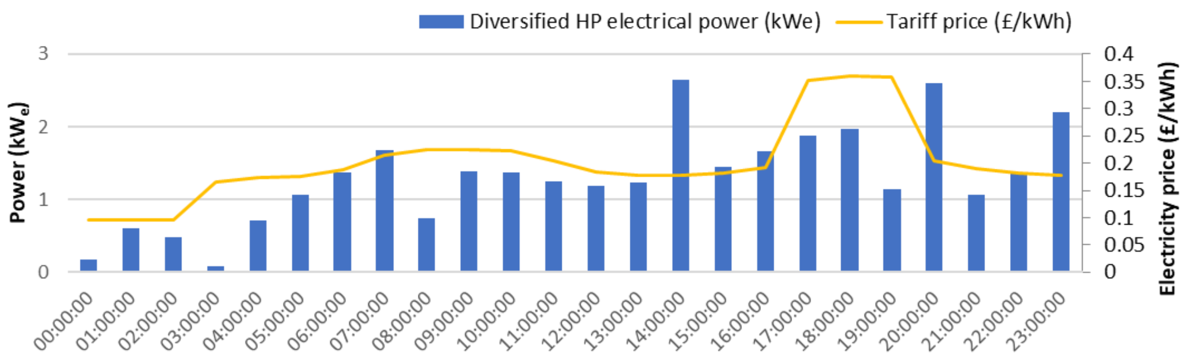

Figure 8: TOU responsive HP electrical demand using flexibility from building thermal mass.

A further point emerged from the modelling of the HP base case. As thermal energy is stored in the building fabric, the amount of thermal energy available is related to how cold it is outside. On a very cold day, the building will lose heat quickly, and so the amount of thermal energy that can be usefully stored is much lower. On a typical heating day, the fabric might permit 3 hours of demand shift, but on the coldest day, the time shift is less than one hour. This temperature dependent flexibility places an important limitation on flexible operation on the coldest days, i.e., at system peak. To avoid this, some form of additional energy storage would be required, and this is explored in the HP sensitivity study.

5 Balancing Mechanism

Our operational modelling of the BM enables flexible assets to make bid offers based on their baseline, which is their original demand profile following ToU tariff optimisation. The BM is a half-hourly system where bids and offers can be made in each half-hour period to buy or sell energy from/to the BM respectively. As described in section 2.3, we modelled two years of BM participation, a low spread year, 2018, and a high spread year, 2022, to assess the range of value that domestic flexibility could generate from the BM, dependent on the year. The results are broken down by EVs and HPs in the sections below.

Note that our modelling of BM participation assumes perfect foresight for the BM pricing in "real-time". This means that bids and offers are made equivalent to the system price, hence the outputs give the theoretical maximum savings possible for the reference year based on the assumptions used. However, our modelling does not assume perfect foresight in forecasting the BM in the day-ahead, hence the sequential optimisation of a day-ahead ToU tariff, and then BM participation in "real-time". BM revenues could be increased further with machine learning driven scheduling and co-optimisation of revenue streams.

5.1 EVs

EVs can generate between £23-£143/EV/year in additional savings (on top of ToU optimisation) from participation in the BM, provided EVs plug in on 80% of days. This value arises from making bids to turn up demand or making offers to turn down demand compared to the optimised charging schedule (dictated by a ToU tariff). Figure 9 illustrates an example day of EV participation in the BM in which both accepted bids and later offers are accepted, altering the original ToU optimised charging schedule to generate additional value for the consumer. The bid acceptance occurs in the two settlement periods occurring at 22:00 and 22:30, leading to a turn up in charging demand (illustrated by the positive light blue bar). The offer acceptance to turn down occurs in the three settlement periods between 04:30-06:00 (illustrated by the negative blue bars).

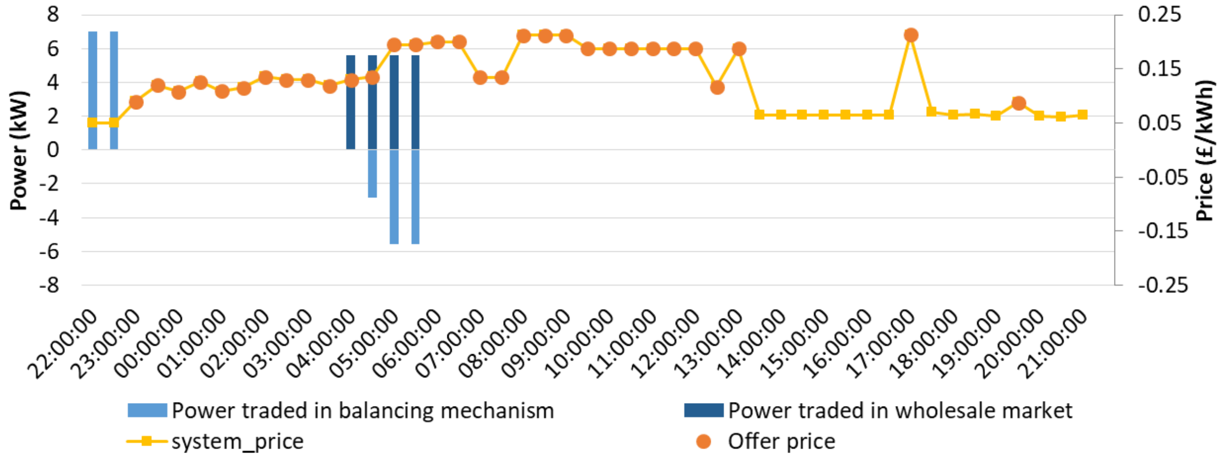

*Figure 9: Illustrative example of change in charging schedule for one EV due to BM trades. The **dark blue** bars represent the original charging demand, the **light blue** bars represent the change in charging demand due to BM participation. The **yellow** line illustrates the unit price of buying from the BM, while the **orange** points illustrate the unit price of selling to the BM (if available).*

5.2 HPs

The process for HPs is very similar, in that bids/offers are placed in the BM to turn the HP demand up or down based on its baseline demand of ToU tariff optimised operation. This is allowed by shifting times that a hot water cylinder is heated, and by allowing the building to under or overheat within acceptable limits, according to its thermal mass. Full details of the assumptions are given in Section 2.2. Given that, during the winter months, heat pumps operate over a much longer period per day than EV charging is required (although generally at a lower power output), the number of bid/offers accepted in the illustrative day in Figure 10 increases dramatically compared to the illustrative day in Figure 9.

Nevertheless, the annual value that can be generated from an average HP from BM participation is £42-£191/HP/year, based on participation in 218 and 2022 respectively. Note that this example demonstrates the capabilities of heat pumps without thermal storage. See Section 8 for the results of HP with thermal storage.

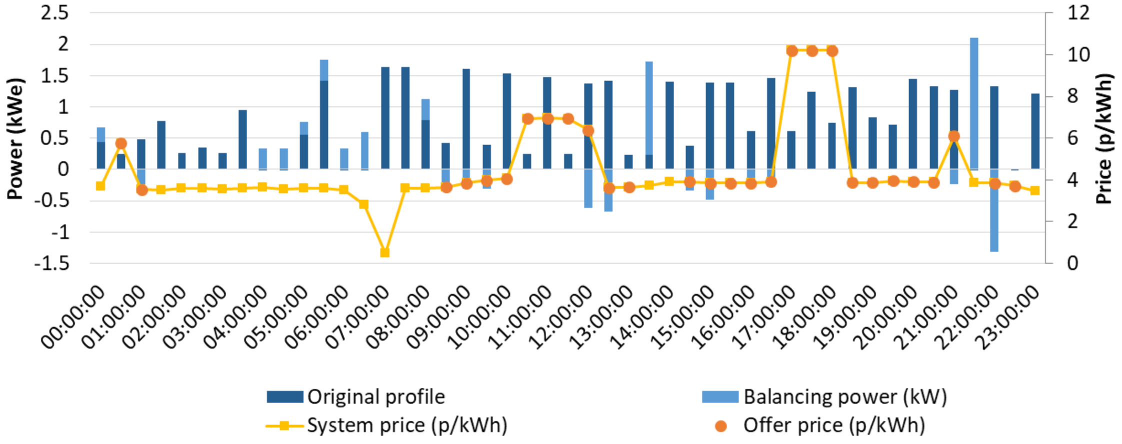

Figure 10: Illustrative example of change in charging schedule for one HP due to BM trades. The ***dark blue*** *bars represent the original charging demand, the* ***light blue*** *bars represent the change in charging demand due to BM participation. The* ***yellow*** *line illustrates the unit price of buying from the BM, while the* ***orange*** *points illustrate the unit price of selling to the BM (if available).*

6 Thermal Constraint Management

CrowdFlex seeks to investigate a locational service that turns up/turns down demand in response to thermal constraints on the transmission network. A key example of this, explored in more detail in this analysis, are thermal constraints as a result of high wind generation output in Scotland, creating a large export constraint between the Scotland-England border. The justification for this use case of domestic flexibility is described in detail in CrowdFlex deliverable D4.1. For the purposes of this analysis, we have focused on the revenue that could be generated by domestic flexibility in Scotland by turning up demand to avoid wind curtailment behind a thermal constraint. The data on the volume and cost of wind curtailment in Scotland to inform this analysis is based on ESO's Constraint Costs and Limits data[9]. The value generated from this procedure is based on payment for avoiding wind curtailment by turning up demand and in doing so, shifting demand out of other periods where thermal dispatchable generation is the marginal generation. This procedure is modelled to cost £174.12/MWh[10].

This service is calculated independently to the other services and therefore represents a theoretical maximum value that the service can achieve. Our operational modelling of EV and HP demand profile against the Scotland constraint profile suggests that, by participating in the Thermal Constraint Management service, EVs could generate an annual revenue of £38/EV/year, while HPs could generate significantly more - £78/HP/yr. This is because by shifting their space heating demand with a thermal mass, and their hot water demand with a hot water cylinder, HPs are able to reduce double the volume of curtailment as EV charging, as illustrated in Figure 11.

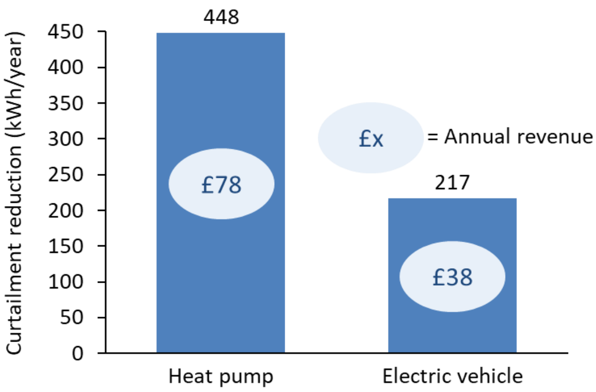

Figure 11: Curtailment reduction and annual revenue per household from Thermal Constraint Management.

[9] National Grid ESO, System Constraints – Constraint Costs and Limits, 2020/21.
[10] This is the combined cost of constraint payments to Scottish windfarms, and OCGT generation costs in England.

7 DSO services

7.1 DSO Sustain-H

For consumers in Constraint Management Zones (CMZs), DSO Services may be available for domestic flexibility to provide demand turn down during the evening peak to alleviate the constraint on the network. An example of this that will be investigated in CrowdFlex and explored in this analysis is NGED's product Sustain-H. The full details of this product are summarised in CrowdFlex deliverable D4.1; however, in essence, consumers are rewarded for reducing their demand on a routine basis (every weekday evening peak) for a given period. In the scenario explored in this modelling, the revenue potential was calculated with optimal turn-down power calculated between 16:00 and 20:00 between September and February, relative to the defined baseline of 7.2 kW (1.6 kW for EV and 5.6 kW for HP). This baseline is from the DSO planning assumptions and represents the diversified demand profiles over the winter peak demand, i.e., when the network will most likely be constrained during the contract period.

Given the baseline is based on the peak, even households exhibiting passive behaviour can generate significant value from DSO Sustain-H. This is because the average demand of a household after diversity on an average day is significantly less than the peak, resulting in a 5.3kW demand turn down on the baseline illustrated in Figure 12. We think that the use of a diversified demand set is appropriate for our modelling because, although DSO services are only available to a very small set of consumers who reside within CMZs, previous work by Low Carbon London suggests that only ~75 households are needed before a diversified profile becomes appropriate[11].

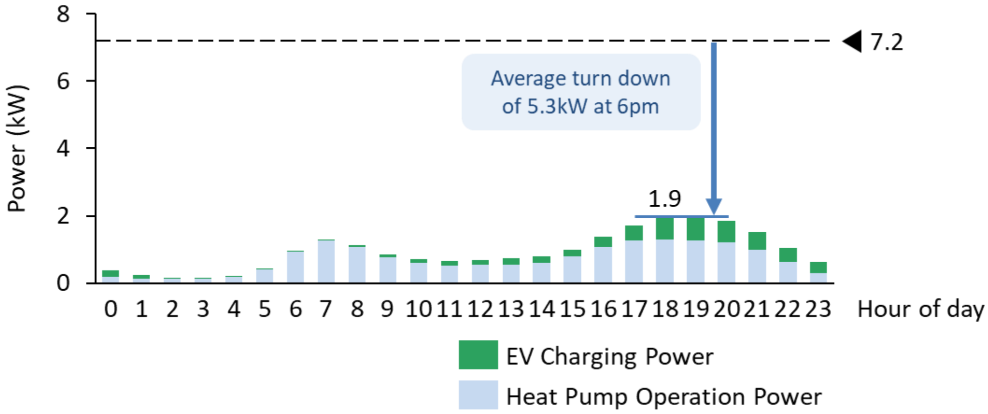

Figure 12: Average demand turn down achieved for households with passive behaviour participating in Sustain-H.

The demand turn down that can be generated in the delivery period can be significantly increased for a ToU optimised demand profile. For a household with both a HP and an EV, optimised to ToU, the average diversified profile demonstrates a turn down of 6.3kW (relative to the assumed baseline) during the evening peak (specifically at 18:00), illustrated in Figure 13. This would generate a revenue of £213/household/year (for households with a HP and an EV) just by responding to ToU tariff, and without explicitly chasing DSO revenues.

[11] Low Carbon London Learning Lab, Quantifying demand diversity of households, 2014.

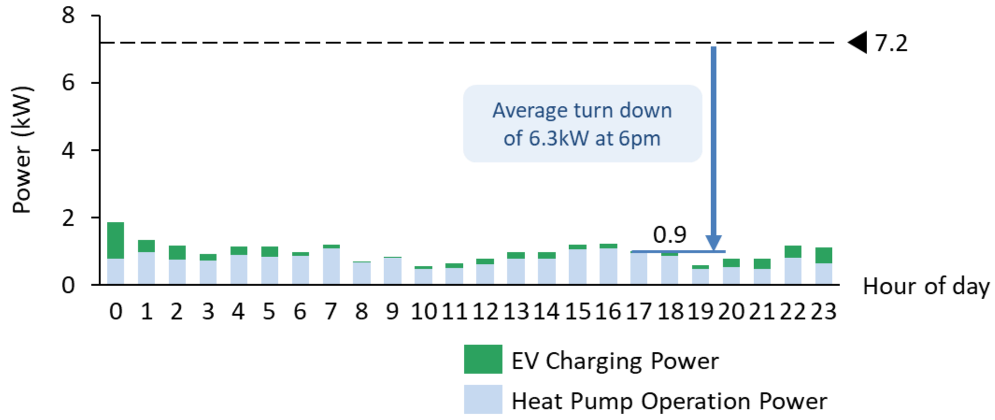

Figure 13: Average demand turn down achieved for households with ToU optimised behaviour participating in Sustain-H.

7.2 Stacking DSO Services with BM participation

Participation in the Balancing Mechanism can reduce the ability to participate in DSO constraint management. However, the adverse impact is slight compared to the additional BM revenues. As shown in the table, DSO service revenues are reduced by £16/household/year when the profile has been optimised for participation in the BM – this is lower than the BM revenues and significantly so when compared to BM revenues in a volatile year.

Table 5: DNO service revenues using different profiles

Profile	Turn down (kW)	% hours achieved	Annual revenue (£)	Additional revenue from baseline (£)
HP baseline	3.23kW	91%	£144	£0
HP flexible TOU	4.35kW	71%	£148	£4
HP flexible TOU and BM	4.66kW	51%	£140	-£4
EV baseline	0.88kW	100%	£42	£0
EV flexible TOU	1.60kW	84%	£64	£22
EV flexible TOU and BM	1.54kW	77%	£57	£15

8 HP sensitivity

As described above, storing thermal energy in the fabric (mainly walls) of a building is limited in terms of the thermal storage available, but also because the flexibility of the store reduces as the outside temperature drops. In this sensitivity, we add a dedicated thermal storage device that can store up to 3 hours of the full output of the heat pump. In practice, this translates to more than 3 hours of shift during a typical winter heating period. As can be seen in the graph below, this is sufficient for the flexible HP to completely avoid consumption during peak periods, including the peak day, which is a limit of the base case HP deployment.

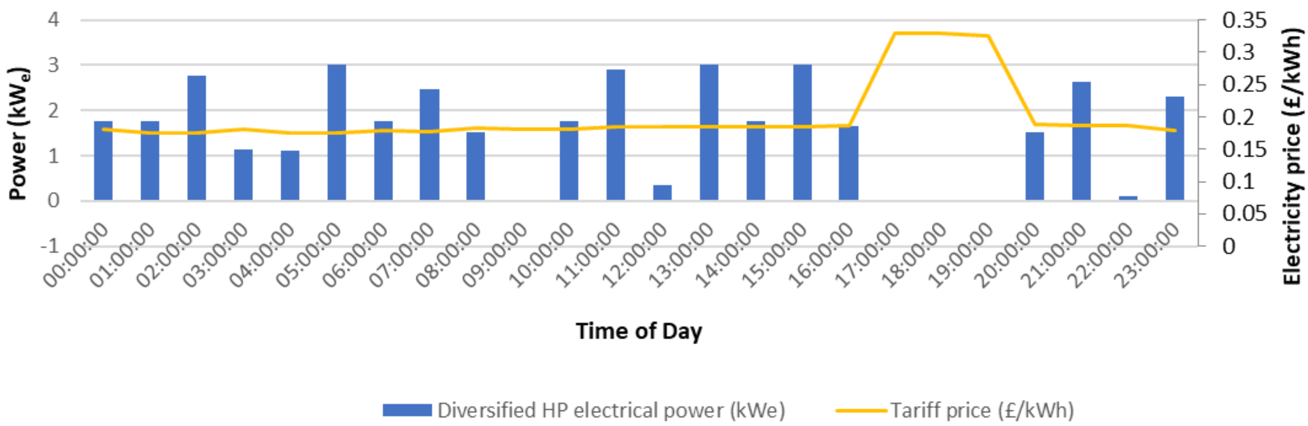

Figure 14: ToU responsive HP electrical demand with additional thermal storage for space heating.

The tables below summarise the positive impact that the dedicated thermal store can have on the revenue potential. Typically, there is a doubling or a tripling in savings or revenues available arising from the use of the dedicated thermal store. While an evaluation of the cost effectiveness of the thermal store is beyond the scope of this analysis, nevertheless, this does show that additional system savings add up to £100's per annum.

Table 6: DNO constraint service revenues.

	Turn down (kW)	% hours achieved	Annual revenue (£)	Additional revenue from baseline (£)
HP baseline	3.23kW	91%	£144	£0
HP flexible ToU and BM	4.66kW	62%	£140	-£4
HP flexible with additional thermal storage (ToU and BM)	5.50kW	77%	£203	£59

Table 7: Revenues with additional thermal storage.

Revenue opportunity	Annual revenue per HP (£/year)	Annual revenue per HP with additional thermal storage (£/year)
TOU tariff compared to baseline	£52	£151
Increment from BM[6]	£42 - £191	£62 - £280
Increment from DNO (2 kW turn-down)	£140	£203-£236

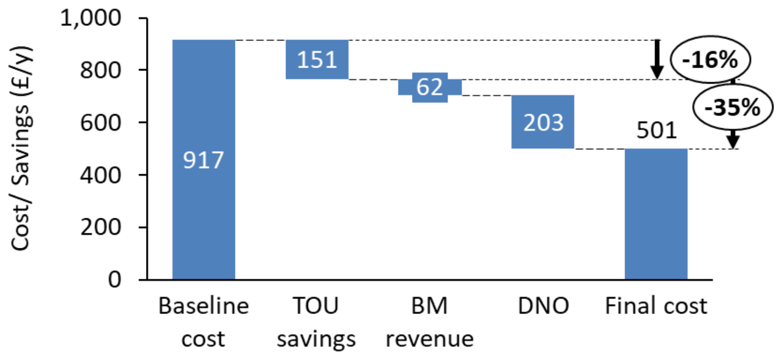

Figure 15: Total savings including additional thermal storage benefit

9 Summary and recommendations

- Flexibility can provide a **40-60% reduction in annual electricity bills** for operating an EV (>£180 saving) and a HP (>£300 saving).
- Time of use tariff: Despite its lower annual demand, the **EV has a much greater inherent capacity to move charging demand into cheap (overnight) periods, compared to the heat pump**, which can move away from, but not completely avoid, expensive times.
- Balancing Mechanism revenues can be as low as half the ToU savings, rising to 2-4 times as much as ToU savings, the main factor behind this being the level of volatility in the bids and offer prices. **In a volatile year, BM revenues can dominate the revenue/savings stack for both EV and HP**.
- **HPs can offer greater volumes of demand turn up than EVs, reducing the need to curtail wind generation during thermal constraints** on the transmission network, this results in a value of £78/HP/year for HPs and £38/EV/year for EVs.
- **Revenue from DSO service can be significant** due to the large turn down EVs and HPs are able to achieve, compared to the peak day baseline (even when consumption is already optimised to a ToU tariff). When stacked with the BM, the impact on DSO service revenues is less than the additional BM revenues.
- Annual modelling showed that **HPs can reduce demand during evening peaks throughout the heating season, apart from the peak day, when the flexibility drops with lower temperatures**.
- To provide flexibility during peak days, additional **thermal storage** is required.

Appendices

10 Appendix

10.1 Balancing mechanism revenues

Balancing mechanism revenues are limited by the scale of power available for cycling (< 1 kW), but EVs and HPs together can earn close to £65/year (using standard price volatility based on 2018 historic prices).

Category	BM Participation Metric	EV Results	HP Results
Frequency of cycling and average power	Total number of offers made in a year (and % coverage)	2,600 (15%)	3,400 (20%)
	Total number of bids made in a year	2,200	3,400
	Average bid power	0.3 kW	0.7 kW
	Average offer power	0.2 kW	0.7 kW
Average bid/ offer prices	Average bid price when bids are made to turn up demand	£39 / MW	£40 / MW
	Average offer price when offers are made to turn down demand	£74 / MW	£79 / MW
	Average bid price overall	£41 / MW	
	Average offer price overall	£79 / MW	
Bid/ offer spend and revenue	Total bid spend	£24	£49
	Total offer revenue	£47	£91
	Net BM savings	**£23**	**£42**
Competing revenues	Proportion of bids made during constraint window for DNO services	4%	11%