Multi Asset Demand Execution (MADE)

Closedown Report

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1. Executive Summary

The MADE (Multi Asset Demand Execution) project set out to explore the impact of multiple Low Carbon Technologies (LCTs) in the home on the electricity distribution network, and the potential for reducing this impact by coordinating the assets.

All scenarios for the transition to 2050 decarbonisation goals present a large proportion of UK homes heated by hybrid heat pumps, have solar PV panels generating electricity to use at home and export to the grid, a battery system installed to store the solar generation and also take advantage of cheap renewably-generated electricity from the grid, and the occupants will drive an EV (Electric Vehicle) which can be charged at home. The project aimed to replicate this combination of technologies for the first time and integrated within the home to make the most of the combined flexibility that these technologies have the potential to create and also orchestrated between homes to offer services to address local grid constraints.

The project was delivered in collaboration with PassivSystems who provided the heating technology, Everoze who undertook research and modelling, Delta EE who also undertook research and Imperial College who provided the electricity system analysis.

Following the analysis of the data collected during the project the following findings, learnings and benefits of coordinated control can be found.

Aggregated, optimised low carbon technologies

- Predictive LCT controls that can optimise and coordinate asset behaviour play a key role in delivering best value from the assets to the consumer as well as harmonising patterns of behaviour desired by the local and national electricity grid. The greater the level of coordination between the low carbon technologies, the greater the savings in consumer electricity costs.

- Time-varying tariffs can offer significant running cost benefits to consumers with MADE assets. This is in particular where the battery and heat pump are coordinated to store energy in the right balance between the battery and the thermal fabric of the building and then making the optimising for available PV generation.

- Even slight variations in tariff can introduce demand peaks, for example due to batteries delivering arbitrage. These peaks can easily be mitigated by a smart control system, at only a small incremental cost to the householder, as long as the provision of cheap electricity is not significantly reduced.

- Smart controls could effectively deliver both Secure and Dynamic Flexible Power services using the MADE assets, by pre-charging both the battery and the home in advance of the availability window. This though would needed to be tested.

Consumer benefits from smartly coordinated LCTs

- Domestic flexibility provides a notable value opportunity. The Phase 1 desktop modelling work by Everoze Consultants showed possible savings of up to £260 per annum, per household[1].

Local network benefits from aggregated, reactive LCTs

- Analysis by Imperial College [2] has shown that there is significant potential for coordinated control to deliver distribution network cost savings across different voltage levels and asset types, which can reach £200m to

[1] https://www.westernpower.co.uk/downloads-view-reciteme/231478

[2] https://www.westernpower.co.uk/downloads-view-reciteme/231487

£500m of avoided annualised reinforcement cost by 2035. These add to the savings enabled by smart asset control and help to offset some of the increased reinforcement spend needed to accommodate the significant load increase on the network.

- In collaboration with PassivSystems, Everoze[3] has identified that distribution networks can utilise the MADE concept by limiting loads to 33% of the 14 kW fuse limit at a property level without compromising household consumption behaviour and savings that can be achieved (based on half-hourly average loads). There is a notable potential for using residential consumers to manage peak loads on the network.

- The MADE concept offers material peak load shifting potential for the distribution network of between 35% and 40% reduction in peak loads on the network compared to optimised low carbon technologies optimised but in silo operation (based on half- hourly data).

Whole-system network benefits from peak load shifting

- Whole-system case studies run by Imperial College[4] demonstrate that there are opportunities to deliver significant cost savings by utilising distributed residential flexibility based on the MADE concept. The opportunities for cost savings increase with the level of uptake of the MADE flexible solution. From the Imperial College research, on the 2035 horizon, the net benefits of MADE (including the cost of enabling residential flexibility) could reach between £500m and £2.1bn per year, through allowing the electricity system to achieve the carbon target more cost-effectively, while at the same time reducing the need for high volumes of peaking generation capacity and distribution network reinforcements.

[3] https://www.westernpower.co.uk/downloads-view-reciteme/231478
[4] https://www.westernpower.co.uk/downloads-view-reciteme/231487

2. Scope and Objectives

When scoping this project, there was a clear understanding that in order to meet the UKs decarbonisation objectives, a large roll out of LCTs will be required. This requirement has solidified over the duration of the project with the commitment by the UK Government to achieve Net Zero by 2050 and the recent 10 point plan.

Several innovation trials have highlighted the possibilities for individual LCTs to provide flexibility to the DNO (Distribution Network Operator) such as Electric Nation, Freedom and Sola Bristol. However, each of these trials has looked at a single technology in isolation. As such DNOs do not have sufficient understanding as to how these technologies could interact and whether any potential flexibility is complementary, optimal, or counter-acting.

The research objective of this project was to better understand the feasibility of managing and aggregating multiple energy assets (EV, hybrid heating system and solar PV) affordably through the use of advanced algorithms to unlock value from energy markets. Through customer research we also evaluated consumer trust in these new technologies. This research specifically looked at greater levels of EV charging and heating system control, and designed appropriate user interfaces and information systems to help drive adoption.

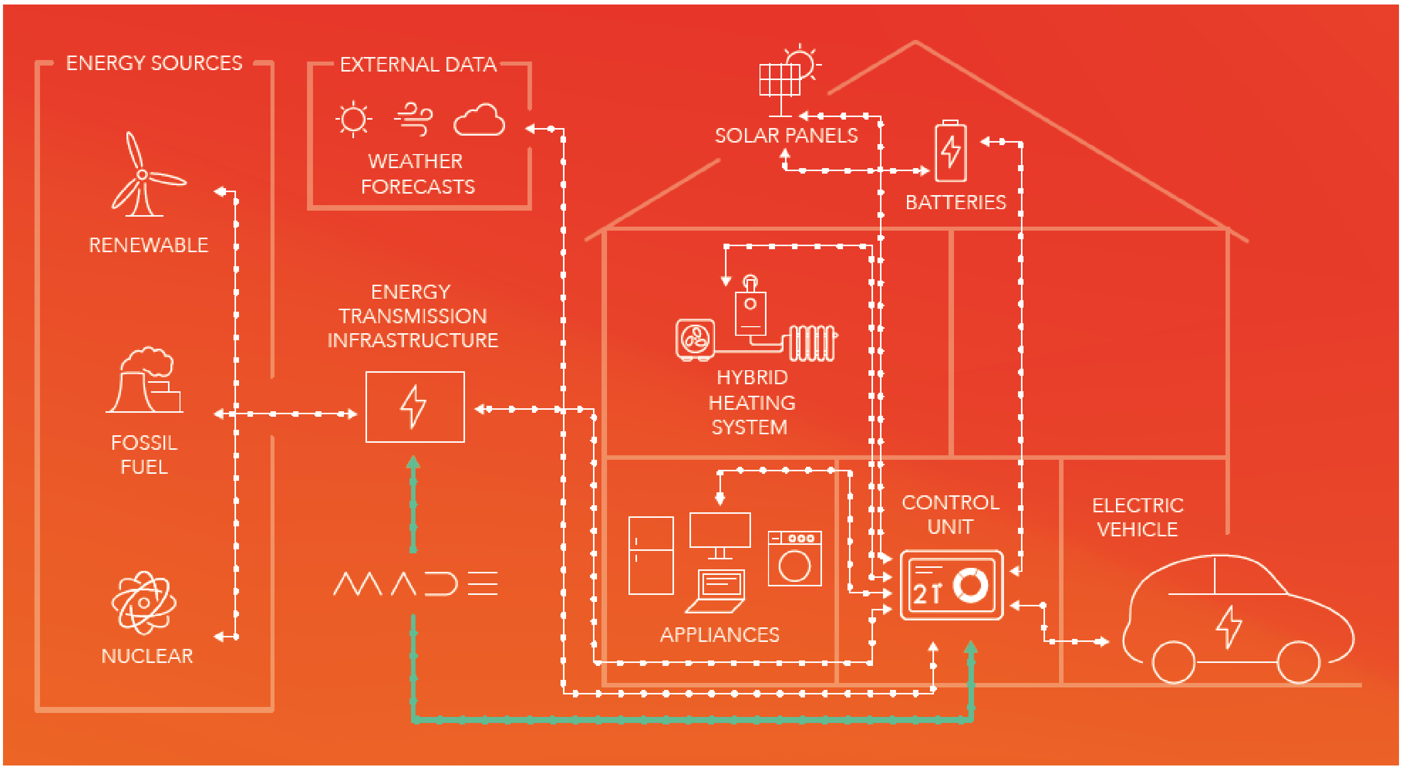

Figure 1: MADE overview

Based on the lessons learned from previous Network Innovation Allowance (NIA) projects, MADE carried out micro-economic and system-level analysis to extrapolate previous trial findings in order to:

- Built a microeconomic model for domestic multi-asset, multi-vector flexibility for the UK today. This identified the most attractive customer types; Identified the high potential service stacks; Quantified the value (£); Included a particular focus on DSO (Distribution System Operator) services.
- Understood how the combined operation of residential solar PV generation, heat pump systems and smart EV charging may provide benefits to the consumer;
- Assessed the whole-energy system benefits (including network infrastructure) and carbon benefits of large-scale deployment of the MADE concept;
- Considered conflicts and synergies between local community and national level objectives, in the context of the flexibility enabled by the MADE concept.

- Estimated consumer benefits of the MADE concept and inform the design of the market framework that would enable consumer to access the revenues that reflect the benefits delivered.

A five home technology trial in South Wales was used to validate the modelled learning.

The project was broken down into six work packages.

- **Work Package 1: Project Management**
  PassivSystems carried out the project management for the duration of the 18-month project to deliver the system design, development and technical feasibility installation.

- **Work Package 2: Problem definition, approach and trial design**
  The project consolidated existing information across partners, developing the customer, DSO, local network and national network proposition, a documented set of use cases, establishing data protection and data management protocols.

- **Work Package 3: Modelling: Consumer, Micro-Economic, Local and National GB Network**
  PassivSystems produced a high level control strategy, simulated the MADE concept (desktop exercise) and collaborated with Imperial College and Everoze to model the local network, national network and the microeconomics.

- **Work Package 4: Hybrid Heat Pump (HHP) /EV/PV Control & Aggregation Solution**
  PassivSystems designed and developed its smart control to enable optimisation (by cost or carbon) of the EV charge point, the electric heating asset and the rooftop PV generation. The included the PassivEnergy platform that aggregates demand across households and enables the demand flexibility to be traded with energy markets including the DSO.

- **Work Package 5: Technology Feasibility Trial (maximum of 5 homes)**
  PassivSystems delivered a five home technology trial, the field trial tested the technology deliverables and gather data on consumer EV charge and energy system outcomes.

- **Work Package 6: Technology, Customer and Network Analysis – Dissemination**
  The project partners delivered an interim and final report on consumer, energy system and business model outcomes. PassivSystems were responsible for sharing the findings of MADE publically during and after the project is complete.

The Project Objectives were to:

1. Use the ability of managing multiple energy assets (EVs, hybrid heating systems and solar PV) to switch between gas and electric load to provide fuel arbitrage and highly flexible demand response services.

2. Demonstrate the potential consumer, network, carbon and energy system benefits of large-scale deployment of in-home multi-energy assets with an aggregated demand response control system.

3. Gain insights into the means of balancing the interests of the consumer, supplier, and network operators when seeking to derive value from the demand flexibility.

3. Success Criteria

The project success criteria were to develop:

- A detailed understanding of technical feasibility of asset coordination (supported by a report and operational data)
- A detailed customer proposition for the MADE concept
- A detailed understanding of the customer benefits of the MADE concept (supported by a report and operational data)
- A detailed understanding of the impact of coordinated asset control on the distribution network (supported by a report and operational data)
- A detailed understanding of the whole system benefits of coordinated asset control on the distribution network (supported by a report)
- Dissemination of key results, findings and learning to policy makers, regulators, network operators and suppliers

4. Details of Work Carried Out

This section provides a brief summary of the key work carried out within the project. More detail can be found in the MADE Final Report as well as the project partner sub reports which are available on the WPD innovation website[5].

At a high level the work was split into two phases.

1. The first focussed on delivering modelling work that evaluated the feasibility and benefits of multi-asset co-ordination at a household, feeder and whole-system level, alongside customer engagement work.

2. The second focussed on a technical trial, with 5 homes having PassivSystems multi-asset control, a HHP, EV with smart charge point and PV with storage to trial the proposed demand flexibility services. The results of this trial were then used to refine the analysis from phase one.

4.1. Modelling

The key elements of modelling work are detailed in the sections below. More information is available in the various project learning reports which can be found on the WPD Innovation website.

4.1.1. Techno-economic modelling: Everoze

Everoze Consultants undertook techno-economic modelling to evaluate the feasibility and benefits of multi-asset co-ordinated delivery of flexibility at a domestic property level.

The full techno-economic modelling analysis report is available on the MADE page of the WPD website.

Approach

Following discussions between project partners, Delta-EE outlined three base customer types, defined by the type of property and household make-up, to be considered in the modelling. Three EV use cases and transport patterns with different intensity of EV use were also considered. The base customer types and the EV transport patterns were used to inform the seven modelling cases, which can be seen in Figure 2.

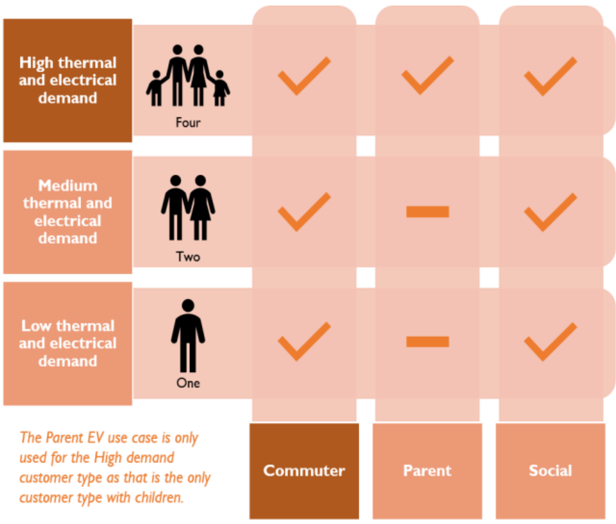

Figure 2: Seven modelling cases used in the domestic level techno-economic MADE modelling

Two different modelling scenarios were considered for each customer type-EV use case combination:

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[5] https://www.westernpower.co.uk/downloads-view-reciteme/231481

1. **Baseline Case** which includes a selection of Low Carbon Technology assets with no coordinated flexibility provision;
2. **Optimised Case** with the Low Carbon Technology assets operating in a coordinated manner (at a residential level) for flexibility provision.

Figure 3 details the assumptions made for each of the modelled energy assets in both the baseline and optimised cases.

	Solar PV	Heat pump	Battery	EV
BASELINE CASE	Included, installed kWp based on customer type	Included, ASHP loads optimised against price signals	Included, load-shifting using surplus solar	Included – unidirectional charger with smart charging
OPTIMISED CASE	Included, installed kWp based on customer type	Included, ASHP loads optimised against price signals	Included, load-shifting using surplus solar and pre-charging as well as ancillary service provision	Included – bidirectional charger with smart charging as well as V2H/V2G service provision

Figure 3: Asset operation assumptions in the baseline and optimised cases

The following revenue opportunities were utilised in the modelling:

- Peak Shifting.
- Firm Frequency Response (FFR)
- DSO Services

Results and Conclusions

The estimated flexibility value (£/household/year) accrued is shown in *Figure 4*. Modelled benefits or 'value' from providing flexibility were calculated as the savings in electricity costs and revenues from ancillary services, less any cost of additional electricity imports. This does exclude asset capital or operating costs and so 'value' does not imply life-cycle value. It should also be noted that DSO services are highly geographic and as such the revenues shown below will not be available in all areas. Additionally, price competition may reduce the value available from DSO services as widespread flexibility increases.

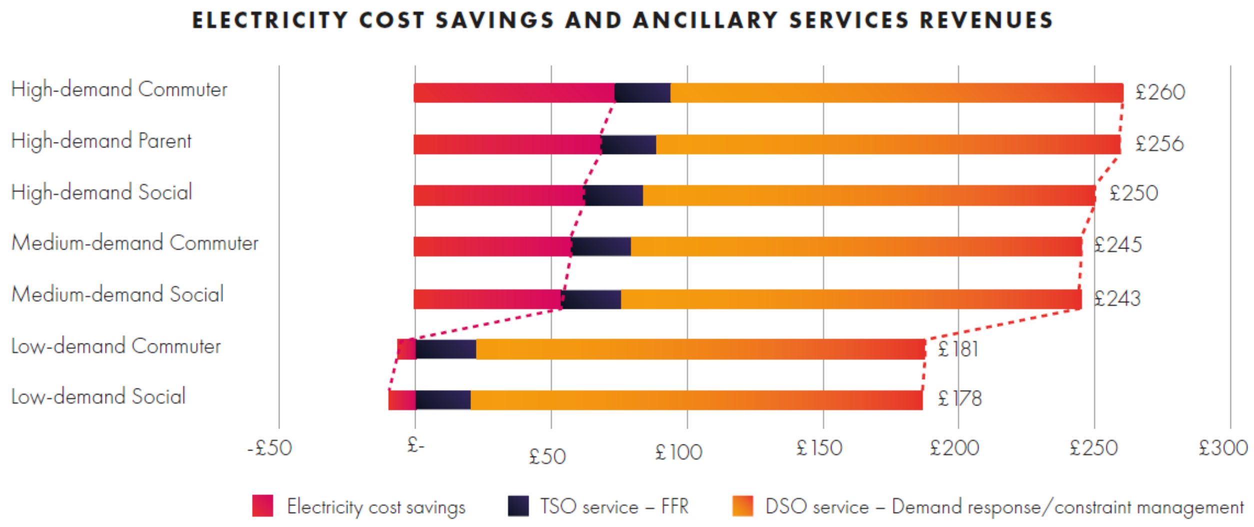


Figure 4: Estimated Flexibility Values for the considered property types/EV use cases

The estimated flexibility value as a percentage of household bill is shown below for each customer type.

Customer Type	Flexibility Value as a Percentage of Bill
High Demand, Commuter	18.6%
High Demand, Parent	21.1%
High Demand, Social	21.5%
Medium Demand, Commuter	21.0%
Medium Demand, Social	26.2%
Low Demand, Commuter	28.5%
Low Demand, Social	44.9%

Table 1: Estimated Flexibility Values as a percentage of household bill for the considered customer types

It should be noted that there is a high degree of variability in the DSO service revenues depending on the type of service and the cores delivery assumptions. Further sensitivity analysis around these numbers can be found in the full Everoze report[6].

Key findings from the modelling regarding electricity cost savings are as follows:

- **Value from peak shifting is sensitive to consumer type:** The property demand and consumption patterns, as well as surplus solar available at the property, have a high degree of sensitivity on cost savings that can be achieved.
- **Value from peak shifting tempered by additional energy imports for ancillary services:** The additional energy cost for providing services has a material effect of reducing the savings in energy costs from peak shifting. In some cases, this can be higher than the annual savings in energy costs.
- **Low demand/EV utilisation customer types are only attractive for DSO services:** The value opportunity from peak shifting and smart charging is low for customer types with low demand and low EV utilisation levels, and the value stack is heavily reliant on DSO services. For such customer types, if DSO service opportunities are not available, then there is little benefit from co-ordinated flexibility at the household level.

Key findings from the modelling regarding ancillary services are as follows:

- **Value from DSO services can be lucrative but is extremely locationally sensitive:** DSO services form a key part of the value stack but are subject to large variance in value depending the local network constraints and service need. WPD's SECURE service offers better value over the year compared to the DYNAMIC service; although the latter has a higher utilisation tariff, the likelihood of utilisation is lower. The right kind of DSO service opportunities appropriate for the domestic portfolio would need to be pursued, otherwise, revenues from DSO services are not attractive.
- **Co-ordinated flexibility can help maximise value from DSO service opportunities:** A household or a portfolio of assets being able to offer a higher volume with co-ordinated and combined flexibility from a suite of battery and EV would be able to maximise value.
- **FFR is a less attractive value proposition:** FFR is a small portion of the value stack, and so may not be worth pursuing given metering, testing and associated administration costs unless the entry requirements are streamlined.

[6] https://www.westernpower.co.uk/downloads-view-reciteme/231478

Following the trial, Everoze undertook a validation exercise comparing the modelling outputs for the trial home for the period compared with the real world trial data. These showed good alignment between modelled and real world operation.

4.1.2. Whole System Modelling: Imperial College London

Imperial College investigated the whole system impact of the MADE concept.

This was carried out using their Whole-electricity System Investment Model (WeSIM), a comprehensive system analysis model that is able to simultaneously balance long-term investment decisions against short-term operation decisions, across generation, transmission and distribution systems, in an integrated manner. WeSIM is summarised in Figure 5 below.

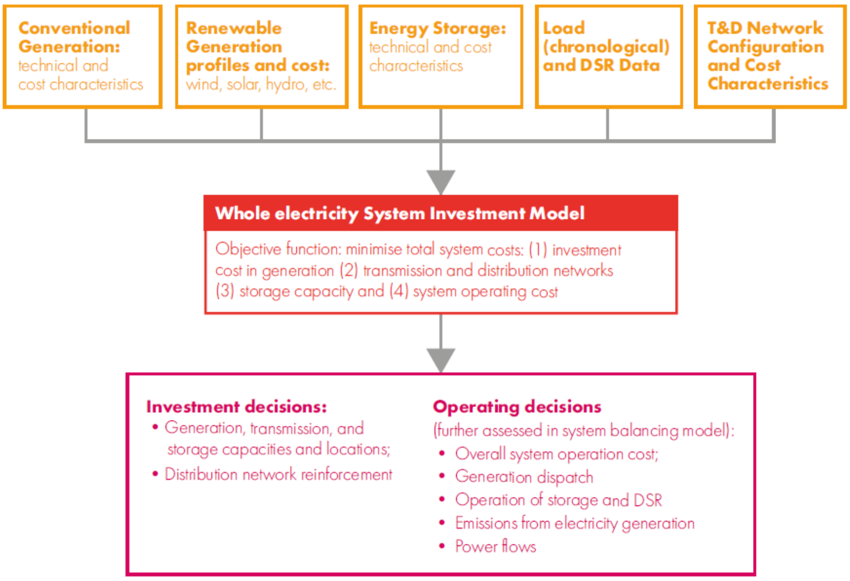


Figure 5: Whole electricity system Investment Model: Imperial College

The full whole-system network modelling analysis report is available on the Project MADE page of the WPD Innovation website.

Scenarios and key assumptions

Whole-system benefits of the Project MADE concept were quantified for four different levels of uptake of the MADE solution: 25%, 50%, 75% and 100% (relative to the number of eligible households). For each of the uptake levels the total system cost is compared to a counterfactual scenario that had a zero uptake of MADE concept but included some flexibility that would likely be provided even without a large-scale rollout of MADE or a similar solution for coordinated control of residential flexibility.

Due to the whole-system nature of Imperial College's modelling approach, the resulting benefits are disaggregated into components of cost savings, distinguishing between generation investment cost (both low-carbon and conventional), operating cost and distribution investment cost. The cost of enabling MADE is also included in total system cost and net benefit figures. Table 2 below defines the baseline scenario and MADE scenarios applied:

Asset	Baseline scenario: Optimised assets in silo operation	MADE scenario: Optimised assets with coordinated control (MADE)
Hybrid heat pump: 8 kW	✓	✓
PV generation: 4 kWp	✓	✓
Electric vehicle: 40 kWh battery with charger	✓	✓
Domestic battery with 5 kWh and 2.5 kW diversified peak output	✓	✓
Optimised asset controls	✓	✓
MADE concept: Coordinated control		✓

Table 2: Baseline Vs MADE assets

It should also be noted that the analysis is focused on the benefit accrued to the system, rather than the value that can be achieved by participants. Routes to market for many of the value streams do not currently exist.

Quantitative results

Total system cost across the five scenarios (counterfactual plus four MADE uptake scenarios) is shown in Figure 6. It should be noted that the figures for total system cost include the total cost of generation investment and operation cost, but only include the additional cost of reinforcement of distribution and transmission networks (i.e. do not include the cost of existing or fixed network assets). Also, the cost of enabling DSR outside MADE households is not included, although it would be the same across all scenarios and would therefore not affect the estimate of MADE system benefits. The cost of enabling MADE, i.e. the cost of smart control and residential battery storage is also included in the charts as a separate category. Total figures are reported using two sets of values, with and without including the cost of MADE.

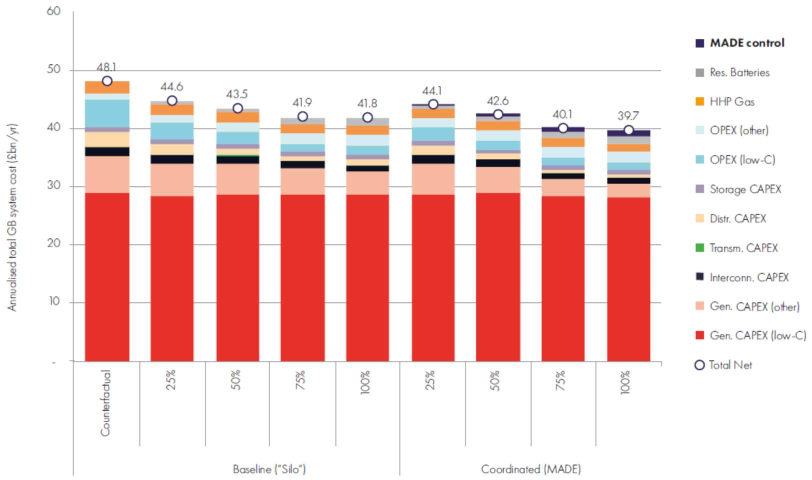


Figure 6: Total system cost across different MADE scenarios

The majority of the system cost is associated with investment in low-carbon generation, with sizeable components associated with conventional generation Capital Expenditure (CAPEX), generation Operational Expenditure (OPEX), interconnection CAPEX and distribution network reinforcement cost. It can be observed that, if the cost of enabling MADE is ignored, the total system cost reduces as the uptake level of MADE concept increases. This cost reduction is the fastest at low MADE uptake levels, whereas at high MADE penetrations there is limited incremental benefit of increasing the number of MADE households. Once the cost of MADE is included in the total system cost, however, the total cost flattens at higher MADE penetrations between 75% and 100%. This suggests that at high levels of uptake the incremental system benefits approximately drop to the level of incremental cost of enabling MADE.

To put the above total cost estimates into context, Imperial College's estimate for the total system cost in 2020 was around £27bn/yr. Total CAPEX of the existing asset base for both transmission and distribution, not included in the above figures, has been previously estimated at £2.2bn/yr. and £5.6bn/yr., respectively. Therefore, the system cost in our estimate for 2035 would be about £9-18bn/yr. higher. Of that increase, about £2.5bn/yr. in the baseline case is the additional distribution CAPEX, dropping to £0.6bn/yr. in the scenario with 100% MADE uptake. However, it should be noted that the demand assumed for 2020 was significantly lower due to far lower electrification levels for heat and transport.

System benefits of a large uptake of the MADE concept across the four scenarios can be found as differences between a given MADE uptake scenario and the relevant counterfactual (or baseline) scenarios, as shown in Figure 6 savings are reported as annual values, consisting of annual operating costs and annualised investment costs for different asset types. As in Figure 6, total system cost savings are quantified both as gross benefits (without including the cost of MADE) and as net benefits (reflecting the cost of enabling MADE).

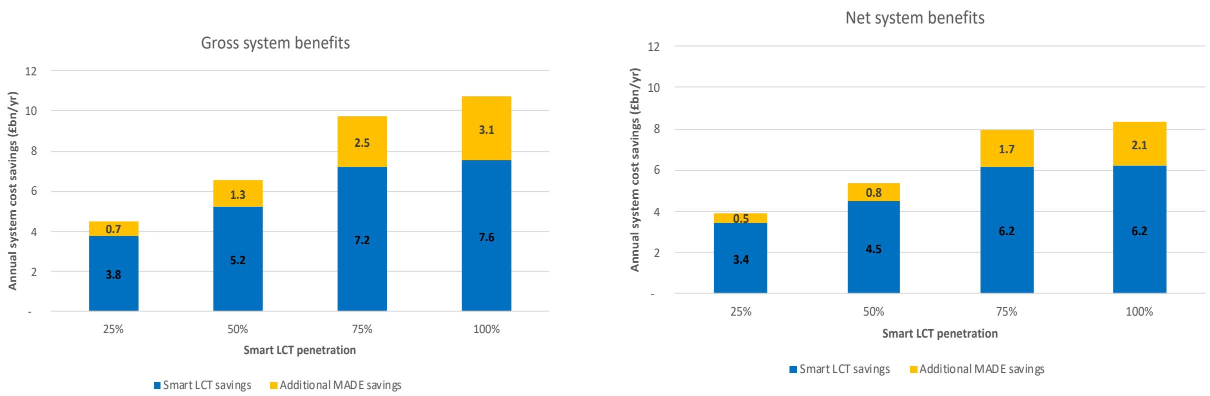


Figure 7: System cost savings by MADE concept: (a) Gross (b) Net

The results in Figure 7 show that in addition to smart LCT controls, the flexibility delivered via MADE solutions can achieve substantial system benefits in the order of billions of pounds per year, reaching £3.1bn per year in gross, £2.1bn in net benefits for full MADE penetration. It is also evident that the increase in benefits slows down as the MADE uptake increases, suggesting diminishing benefits of adding new MADE households to an already significant number of MADE-enabled homes. Net benefits of MADE are lower and become saturated at high penetration levels.

Key components of MADE-enabled cost savings include:

- Reduced investment cost of low-carbon generation: distributed flexibility allows cheaper sources of low-carbon electricity (e.g. wind or solar PV) to be integrated more efficiently, and therefore to displace other low-carbon sources (e.g. Carbon Capture and Storage (CCS)) while reaching the same carbon target;
- Reduced investment cost of conventional generation: flexible resources can be very effective at reducing peak demand and therefore greatly reduce the need to maintain a high volume of peaking generation capacity to secure a sufficient generation capacity margin and the resulting security of supply;
- Reduced investment cost of distribution networks: highly distributed flexible resources included in the MADE concept can help reduce the loading level of local distribution grids and therefore significantly decrease the requirements to reinforce distribution grids in order to cope with an increase in electricity demand;
- Reduced operating cost of low-carbon generation: as shown later, flexibility can also displace the output of low-carbon generation with relatively higher operating cost, such as CCS or biomass, which is then replaced by lower-cost generation such as wind generation.

4.1.3. Impact of MADE on the distribution Network: Imperial College

As shown in Imperial College's earlier studies, significant distribution network reinforcements could be needed to accommodate the rapid uptake of EVs and HHPs if these assets are not managed in a network-friendly way. Heat and transport electrification could increase the total cumulative expenditure required on distribution networks by up to £50bn by 2035 (or £1.8 billion per year in annualised terms). According to earlier analysis, the total replacement cost of the entire GB distribution network is estimated around £100bn, which makes the £50bn reinforcement cost quite material.

Utilising distributed flexibility, in particular using smart resources such as residential battery storage, EVs and HHPs, could significantly mitigate the impact of electrification of heat and transport on distribution network reinforcement cost. As illustrated in Figure 6 the additional cost of reinforcing GB distribution grids in the baseline scenario (i.e. without any uptake of MADE concept or smart LCT control) is estimated at £2.7bn/yr. It is worth stressing again that these are reinforcement costs that are additional to the CAPEX of the already installed asset base, which in the previous assessments has been estimated at around £5.6bn/yr. With smart LCTs deployed this drops to £1.1bn/yr, a saving of over £1.5bn/year.

When the coordinated control of the MADE concept is rolled out at 100% uptake level, the distribution network reinforcement cost drops to £0.6bn/yr, resulting in a further distribution CAPEX savings of £0.5bn/yr.

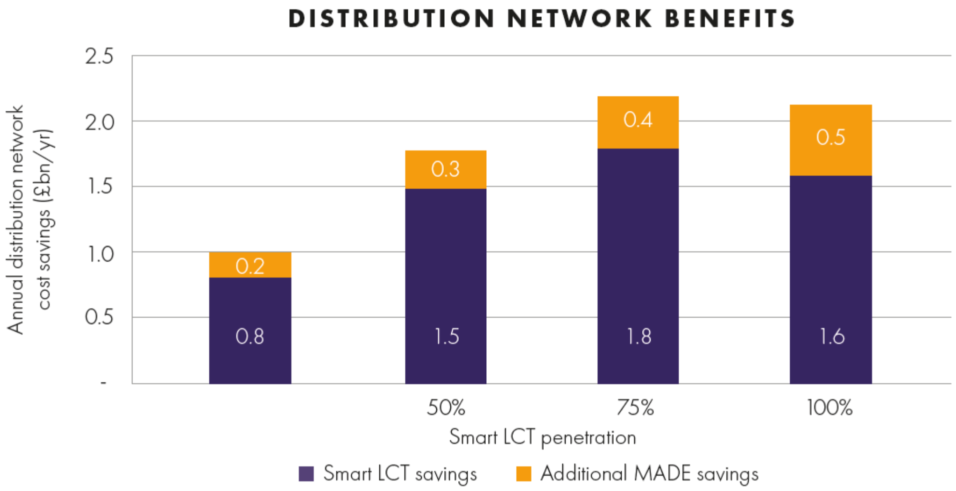


Figure 8. Breakdown of annualised savings in network reinforcement cost driven by MADE concept across voltage levels and network topologies

The results show that the total distribution network benefits of rolling out the MADE concept can reach up to £500m in terms of annualised reinforcement cost, with higher benefits achieved in LV than in HV networks. At higher MADE uptake levels the distribution network benefits tail off, with very limited additional benefits observed when moving from 75% to 100% penetration.

Within both LV and HV levels the predominant savings come from avoided reinforcement of semi urban networks, which are characterised by a relatively high number of customers, longer network lengths per customer than urban networks, and higher proportion of cables as opposed to overhead lines compared to rural networks. Significant savings also materialise in urban networks, while savings in rural networks are quite low, both due to lower specific network cost and a lower overall demand.

4.1.4. Business Models: Delta EE

The energy landscape is rapidly evolving and moving from the traditional centralised model (centralised transmission connected power generation) to one that is decentralised, more customer-centric and lower carbon. This transition is seeing more value being moved downstream and this is resulting in new ways for domestic customers to access these value streams.

As part of MADE, Delta-EE identified customer propositions for business models which could be developed following a large-scale deployment trial. These propositions are built upon a well-used framework for developing business models and customer propositions, and build on insight taken from studying similar business models.

These are summarised in the table below:

Table 3: Business Models

	Option 1: All inclusive	Option 2: Buying enhanced control	Option 3: Minimising peak demand
Technologies can include:	Heat pump, gas boiler, EV, Solar PV, Battery Storage, Smart controller hub.	Smart controller hub plus any combination of heat pump, Gas boiler, EV, Solar PV, Battery storage.	Heat pump, gas boiler, EV, Smart controller hub.
Purchase / ownership of tech	Leased at no upfront cost to customer.	Bought upfront by customer (or through finance arranged by customer).	Bought upfront by customer (or through finance arranged by customer).
Energy supply	Included within monthly fee.	Bought separately by customer.	Included but paid per unit energy used.
Contract	Monthly fee covers lease of technology, energy supply, MS&I. Approx. 5 years (could offer choice).	No monthly fee, no minimum contract length.	No monthly fee, no minimum contract length.
Customer value streams	Monthly fee which is an acceptable price to customer, easier budgeting, peace of mind.	Energy bills are reduced by smart control hub. Credit paid back from any DR revenue.	Cheap flat rate energy price (not being exposed to ToU variation).
Company value streams	Minimising cost of electricity through self consumption and buying at cheap times (company keeps costs savings), selling electricity to grid at peak times.	Sale of smart controller hub DR revenue from selling electricity back to gird at times of high demand.	Minimising peak power draw over home (no current value in this in the UK), Minimising cost of heating and charging EV via Dynamic ToU signals, DR Revenue – turning down demand.
Risks	Low for the customer, except for perception of entering a contract. Main risks taken on by company.	Low if the customer was seeking to buy these technologies already (but long payback period if all tech bought).	Low if the customer was seeking to buy these technologies already.
Target customer	Customers who seek low carbon heating and personal transport.	Customers who own or would like low carbon heating and personal transport.	Customers who are looking to buy low carbon heating and personal transport.
Most suitable provider	Energy Service Provider (could be energy supplier, manufacturer or other.	Controls company.	Energy supplier, DNO.

The full business models and consumer propositions report is available on the MADE page of the WPD Innovation website.

4.1.5. Customer Engagement: Delta EE

As part of MADE, Delta-EE also carried out customer research with 750 UK car owners. This exclusively commissioned customer research was carried out in order to better understand current views around EV ownership (and usage patterns) as well as third-party control of EV charging. The research was carried out via an online survey in May 2019, with a panel of UK adults which is close to representative of the broader UK population.

Depending on the technologies owned, survey respondents were directed to answer different sets of questions. The maximum number of questions answered by any respondent was 38.

The key findings from this survey were as follows:

- **EV Charging**. The most popular place for charging is at home. Most current EV owners charge their EVs for less than two hours per session. If forced to allow third-party control of their EV charging for the purposes of Vehicle to Grid (V2G), EV owners are willing to let their batteries discharge to a minimum level of 30%. EV owners are mostly very positive about the idea of having an app to help them control their charging.

- **Third-party control**. There was a lot of concern around third-party control of charging and heating systems across all groups. If third-party management of assets is to be accepted, people still want to feel as if they are ultimately in control at all times and that the third party is helping them save money.

- **EV and Solar PV owners are higher income and more engaged.** One of the apparent trends in the results is that the EV and solar PV owners tend to be between the ages of 25-49, are more engaged with switching their energy supplier, tend to have higher incomes (over £64k household income/year) and own their own homes. They also tend to live in detached homes, which are more likely to have their own driveway (for EV charging) and more roof space (for installing solar PV panels). The majority are also interested in installing a battery system. When asked about their attitude towards the environment, they tend to think that they are doing as much as they can to be environmentally friendly.

- **Those with electric heating are more engaged**. Of the survey respondents, 22% said electric heating was their main source of heating. A higher proportion of those with electric heating (including heat pumps) had low emission vehicles, particularly a fully electric car. Those with electric heating also switched suppliers more often than any other group.

- **The Laggards**. There was a group of respondents, about 10% of the total, who tended to be older (>50), drive petrol cars and not own solar PV. They were not as interested in being green and do not regularly switch energy suppliers. They also had little awareness of heat pumps or smart appliances or heating controls.

4.2. Trial

4.2.1. Technical trial deployment

The MADE project consisted of a small field trial of the technologies. The key aims of the technical trial were to:

- Improve understanding of the real world complexities of installing hybrid heat pumps, solar PV panels, batteries and electric vehicle (EV) chargers in homes together with the smart technology required to coordinate their operation;
- Demonstrate how coordinated control can be executed effectively within a real home and understand the benefits to the consumer;
- Collect data which can be used to validate the modelling results produced as part of the project.

The technical trial was designed to answer the following research questions:

- How does real-world overall household demand shape (and balance between the assets) change depending on time-of-use tariffs, level of asset coordination, and over the seasons?
- What happens to the peak demand as we move between each scenario?
- How can the demand shape be influenced by interventions?

4.2.2. Deployment summary

The MADE field trial involved five homes, each of which had all four low-carbon assets.

Table 4 provides details of the installations in each of these homes. Four of the heat pumps (and one EV) were pre-existing, reducing the need to install new assets under MADE.

Table 4: Summary of the installations in the field trial homes

Home	Heat pump	Fossil boiler	PV array	Battery	EV Charger	EV
1	5kW Samsung ASHP	LPG Combi	4.41kWp	Sonnen hybrid 5kWh	New Motion 32A	Nissan Leaf 30kWh
2	8kW MasterTherm ASHP	Gas system boiler	3.46kWp	Sonnen hybrid 5kWh	Alfen 32A	Hyundai Kona 64kWh
3	22kW MasterTherm GSHP	Oil system boiler	4.41kWp	Sonnen hybrid 5kWh	New Motion32A	Nissan Leaf 40kWh
4	9 kW Samsung ASHP	LPG system boiler	3.78kWp	Sonnen hybrid 5kWh	New Motion32A	Tesla Model 3 75kWh
5	9 kW Samsung ASHP	Oil system boiler	4.41kWp	Sonnen hybrid 5kWh	Alfen 32A	Nissan Leaf 40kWh

It should be noted that:

- **Hybrid heat pumps** consist of a legacy fossil fuel boiler supplemented by a heat pump, with their interaction controlled by a smart control system (see below). The system was configured to maximise heat pump utilisation wherever possible, in order to emulate a future decarbonised energy system.
- **Hot water** provision is from the fossil fuel boiler until the end of phase 4 of the trial, from phase 5 domestic hot water production was generated using a combination of a hybrid heat pump and/or smart immersion switch.
- **Hybrid batteries.** The Sonnen batteries were “hybrid” units which meant that there was a direct DC connection to the battery from the PV panels, utilising a shared inverter for PV export or battery discharge. As a consequence, PV generation is controllable (downwards) as the battery inverter can have its power limited.

4.2.3. Field trial design

The field trial was divided up into four phases, as outlined in Figure 9 which shows a summary of the trial plan. These four phases are as follows:

- Phase 1: Baseline - The focus was on gathering baseline data about household and asset electrical demand with the assets largely uncoordinated and hoped to capture some of the problematic scenarios caused by assets operating independently and synchronizing their activities on tariff transitions;
- Phase 2: In-home asset coordination - This phase involved automatic coordination of the operation of the hybrid heat pump with the battery and solar generation. It also included integrated control of the EV charge point (although largely manually driven);
- Phase 3: Full coordination including EV - This phase involved fully optimised integration of the EV charge point along with the other assets;
- Phase 4: Summertime - The last phase of the project explores the transition of the multi-asset system through late spring into summer as the availability of solar PV generation starts to dominate the picture/

The project aimed to explore a number of contrasting dimensions simultaneously:

- Time of use tariffs: which provide the first level of demand shaping through a straightforward mechanism which exists in today’s market and rewards the consumer directly. Testing involved three tariff patterns:
  (1) flat rate tariffs, set at 14p/kwh as a baseline;

(2) Cheap night-time tariffs like Octopus Go, an electricity tariff designed with EV users in mind. It offers an off-peak unit price of 5p/kWh between 12:30am and 4:30am, with a peak unit price of between 13-14p/kWh (13.8p/kWh for the MADE trial) outside of these hours, and;

(3) Octopus Agile, an electricity tariff with half-hourly varying energy prices, calculated from wholesale prices and the peak early-evening Distribution Use of System (DUoS) charges, and updated daily (day-ahead prices published the evening before). This captures the major national-scale and distribution-scale drivers which captures the major national-scale and distribution-scale drivers.

- Level of asset coordination: as the project progressed, the number of assets with operation coordinated by optimisation algorithms was increased;
- Seasonality: the interplay of the assets changes significantly over the seasons: in winter, heating is dominant over PV generation, but vice versa in summer;
- Interventions: to explore the flexibility of the system to respond to local network needs.

Month	Oct 19	Nov 19	Dec 19	Christmas period	Jan 20	Feb 20	Mar 20	Apr 20	May 20	Jun 20	Jul 20	Aug 20	Sep 20	Oct 20
Phase	Phase 1				Phase 2		Phase 3		Phase 4				Phase 5	
Tariff	Flat Rate	Economy 7	Octopus Agile		Octopus Agile	Octopus Go	Octopus Agile		Octopus Agile		Octopus Go	Octopus Agile	Flat Rate	Octopus Agile
Hybrid heat pump	Self-optimised against tariff				Coordinated optimisation: hybrid heat pump + solar battery		Coordinated optimisation: hybrid heat pump + solar + battery + EV smart charging					Coordinated optimisation: hybrid heat pump + solar + battery + EV smart charging + hot water		
Solar PV Battery	Automatic PV self-consumption and discharge													
Electric Vehicle	User behaviour		Charging deferral tests		Midnight charge deferral	Turn up and turn down								
Hot water	User behaviour				User behaviour									
Local grid interventions							Peak reduction and local grid signals	Secure and dynamic		Secure, dynamic and turn-up		Secure, dynamic and optional downward flexibility management (ODFM)		

Figure 9: Field trial intervention plan

4.2.4. Field trial results

This sections shows a single example of the type of control implemented. Full details of the field trial results are available in the full field trial analysis which is available on the MADE page of the WPD website[7].

[7] https://www.westernpower.co.uk/downloads-view-reciteme/231490

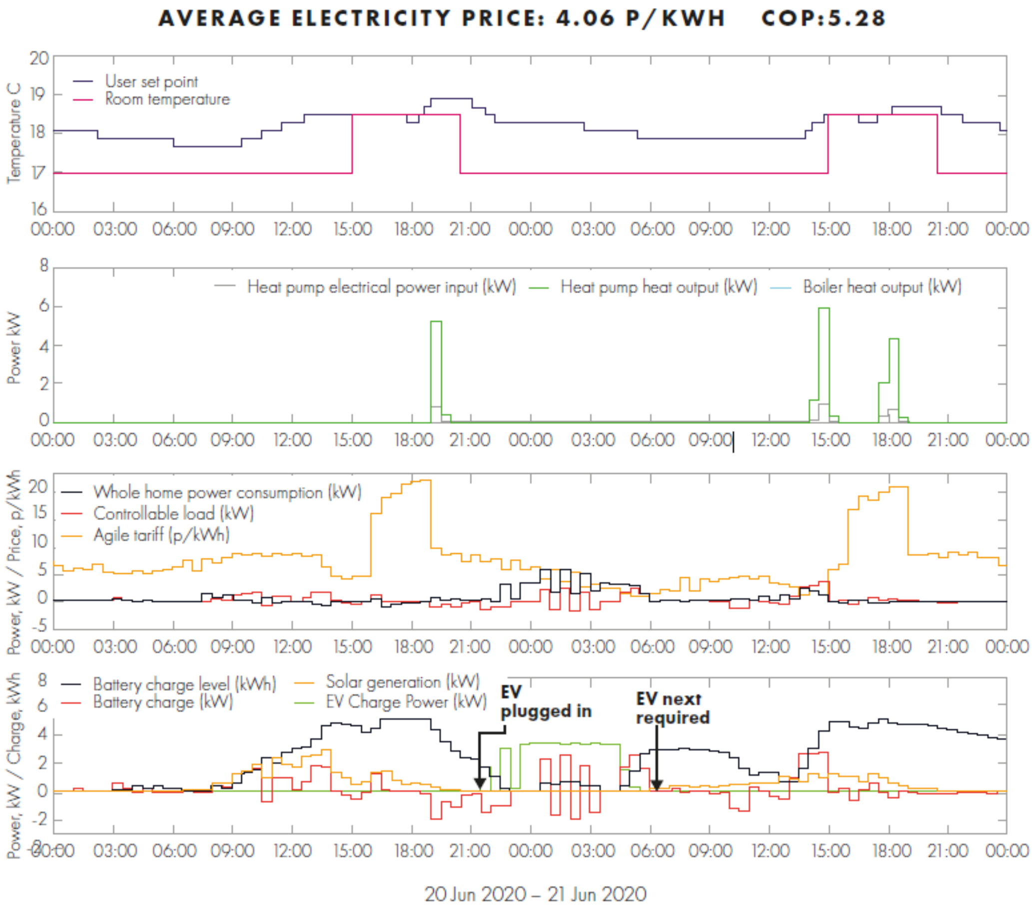


Figure *10* below shows typical operation under the coordinated control strategy implemented in Phase 3 of the trial, against the Octopus Agile tariff. The following can be observed from the figure:

- Room temperature is well maintained, with a minimum of 17.7°C (Celsius) and a maximum of 18.9°C across the two day period. For reference, the average external temperature was 15.3°C over this same period, with a high of 19.0°C and a low of 13.3°C.
    - On day one the home is sufficiently heated in advance of the evening set point due to a high external temperature and high solar irradiance, and thus no additional heating is required. After the evening Agile peak tariff period, the heat pump kicks in to ensure that thermal comfort is maintained for the duration of the evening.
    - Day two is less sunny with a lower external temperature, therefore the heat pump is used to bring the home up to the evening set point, with the bulk of this heating executed when the tariff is at 1.197p/kWh. Additional heating is required during the Agile peak tariff period; however, the required power is provided mainly by excess solar generation with some support from the battery when required to ensure the home remains off grid during this expensive tariff period.
- The EV is plugged in at 21:30 on day one, with the user requesting full charge by 06:30 the following morning. The maximum charge rate for this particular EV is 3.6kW.
- There is still some battery charge available when the EV is plugged in. As a result, the EV charges at a reduced rate in the first half hour interval to match the amount that the domestic battery can discharge, since the tariff is relatively expensive here compared to the rest of the night at 7.5p/kWh.
- Overnight the battery charges up during cheaper tariff periods and discharges during the more expensive tariff periods to offset EV charging, in order to maximise the consumption of cheap electricity.
- At 05:30 the EV reaches full charge in advance of the end time (a buffer is allowed due to the fact the true state of charge of the vehicle is not known). This is a good example of EV charging being delayed as late as possible to make use of cheap tariff periods while being confident that sufficient charge is being delivered.

- On day one the battery charges from excess solar generation, and discharges to meet excess household consumption.
- On day two there is not as much solar and there is higher demand from other uncontrollable loads within the home, therefore the battery discharges during the day. The battery then charges using electricity imported from the grid between 13:30 - 15:00 when the electricity price is between 1.1 - 2.1p/kWh to enable the home to be kept off grid overnight when the electricity price is notably higher.

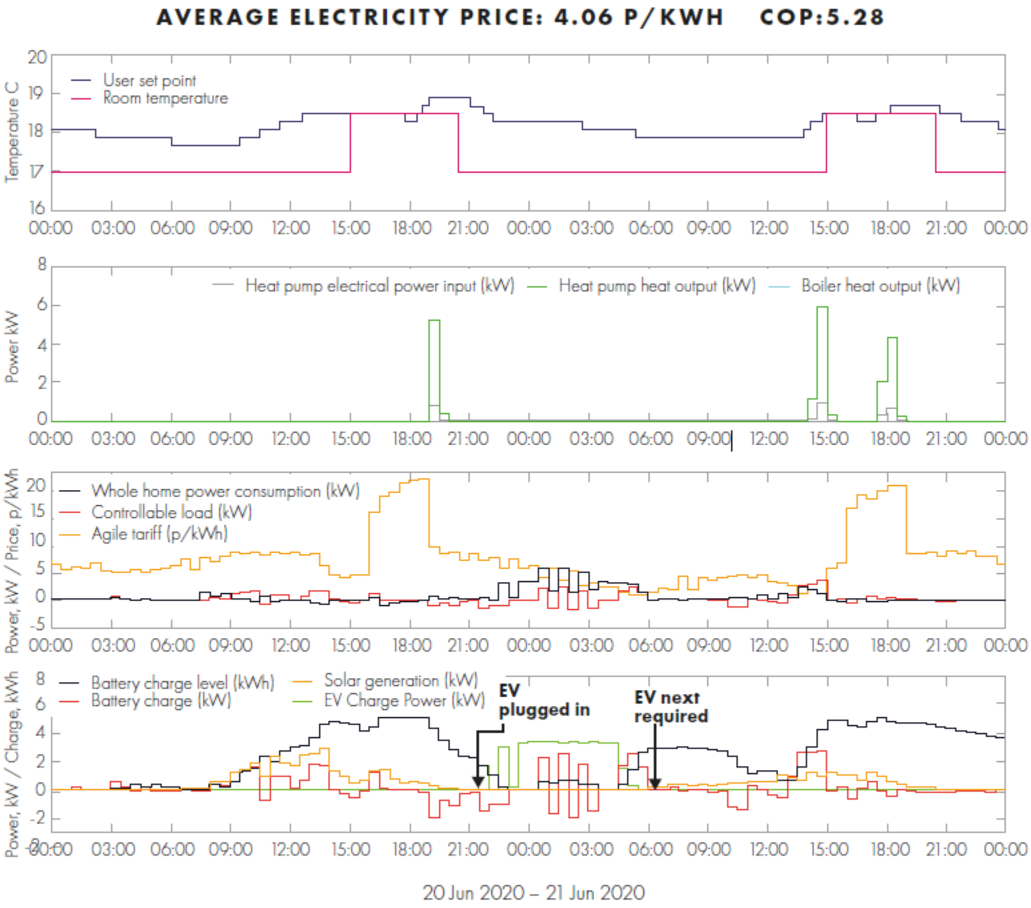


Figure 10: Fully coordinated control on the Octopus Agile tariff (Home 01, 20/06/2020 - 21/06/2020)

4.2.5. Interventions

Building from the response to tariffs, a number of direct DNO interventions were also trailed based on WPD's Flexible Power service. An example is shown below.

Figure 11 below shows a Secure style Flexible Power intervention from Phase 2 of the project, prior to EV coordination being implemented. Thus, in this example controllable load refers to heat pump and battery power. For this intervention, the home was given advance notice to minimise import (or maximise export) between 16:00 - 19:00, using the heat pump and battery.

The following can be observed from the figure:

- The home is overheated slightly in advance of the intervention period. This enables the set point to be met throughout the duration of the intervention period, without the need to run the heat pump during this time.
- The battery charges up in advance of the Flexible Power intervention period and then discharges over the intervention period, leading to negative overall controllable load.
- At this stage of the project, controllable load involved the heat pump and battery, but not the EV. On this day the EV was plugged in at 17:00 leading to a large increase of grid import, but the system could not yet shift

the load away from the Secure intervention period. This demonstrates a clear use case where fully coordinated control across all assets in the home would be advantageous.

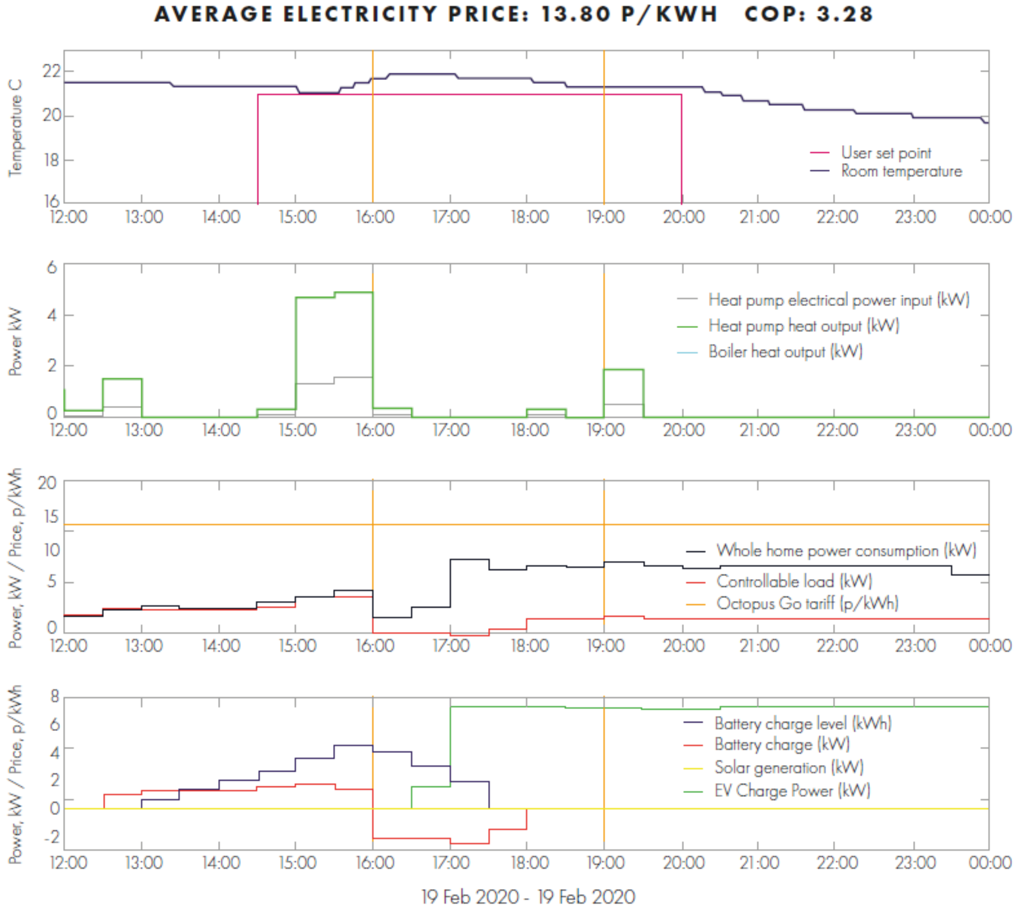


Figure 11: Smart controls can effectively deliver both Secure and Dynamic Flexible Power services using the MADE assets, by pre-charging both the battery and the home in advance of the availability window.

4.2.6. Simulations

The initial trial results presented real world examples of key behaviour patterns from the MADE project, and through this the benefits of coordinated control were illustrated. However, it is hard to produce clear comparisons between different scenarios (such as the level of asset coordination) because the real world always introduces significant amounts of uncontrollable variability. Comparisons could be carried out simultaneously between different houses, but this is not possible with such a small portfolio because each house is different; and comparisons between different days are confounded by factors such as temperature, solar irradiation and user behaviour. As a consequence, simulation work has been carried out to allow illustration of a more direct comparison between different control strategies. The results of this simulation work are presented in this section.

The approach was to execute multiple simulation runs with the same inputs, but to exercise different control strategies (such as the level of asset coordination) and provide insight into consumer cost savings.

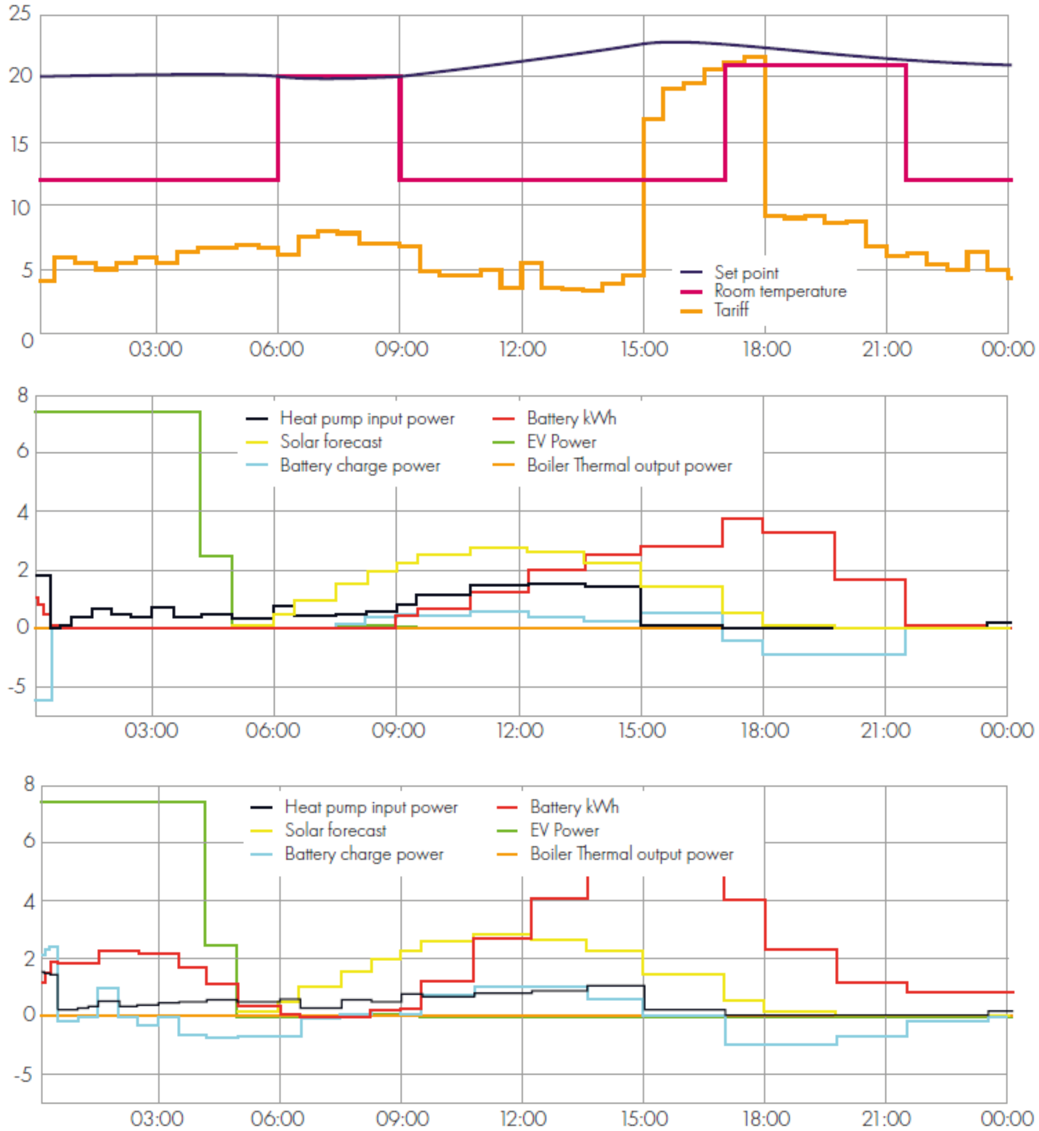
Simulations have been carried out for two different scenarios:

- **Day-ahead predictions with varying levels of asset control** these focus on the predictive optimisation calculation within the PassivSystems control system and contrast the different outputs that it produces for varying levels of asset coordination. The purpose of these simulation runs was to illustrate how asset demand shape changes with increasing levels of control.
- **Two day simulations runs with varying levels of asset control**: these cover optimisation over a longer time period and are more closely aligned with likely real world performance. The purpose of these simulation runs was to provide examples of consumer cost savings associated with increasing levels of control.

An example of the day ahead simulations is shown below.

A digital twin of MADE Home 5 was used to perform these optimisation calculations, for the 23rd April as of 00:00. On this day the house requires some heat from the hybrid heat pump, and we assume that the EV is assumed to require 30kWh of charge by 07:00, the battery is assumed to have 1kWh of charge at the start of the optimisation window and optimisation is performed against the Octopus Agile tariff.

Figure 12 below shows the optimisation output under the Phase 1, 2 & 3.



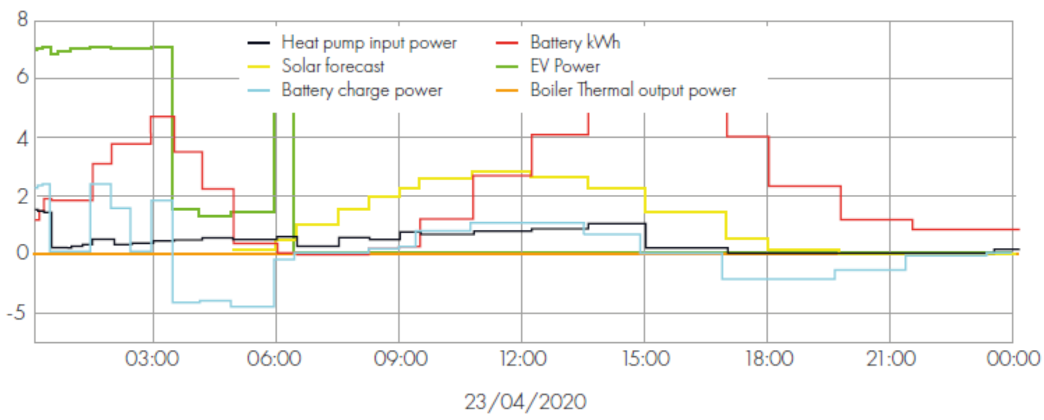


Figure 12: Smart controls can effectively deliver both Secure and Dynamic Flexible Power services using the MADE assets, by pre-charging both the battery and the home in advance of the availability window.

The following can be observed.

In Phase 1:

- The heat pump deliberately overheats the house during the middle of the day to make the most of free solar PV generation and to avoid having to run during the peak period but is unaware that the battery would have been able to store this energy more efficiently for later consumption. The house is heated to a maximum of 22.6°.
- The battery charges from excess solar and discharges to meet excess household load, but is not aware of the Agile pricing, so is not able to reduce the impact of the peak Agile period (it would have been more cost effective to fully charge the battery beforehand with grid import).
- No EV optimisation is performed, and thus the EV simply charges at full power at the start of the day. There is no coordination with the battery, therefore the only battery use during the EV charge session is when the battery discharges the 1kWh of charge it begins the day with as early as possible, despite the fact that this is actually the cheapest half hour period during the session.

In Phase 2:

- Coordination between the heat pump and battery means that less heat needs to be stored in the fabric of the home (relatively inefficient) and the battery can be used instead to store PV for later use (and avoiding the peak period). The home is heated to a maximum temperature of 22.0° vs 22.6° in the previous example, and the heat pump is able to run in the peak period utilising stored battery power. Note that the coordination algorithm decides to use both storage mediums operating in tandem as the most efficient strategy.
- The battery now charges between midnight and 3am to arbitrage the more expensive electricity between 3am and 6am.
- The EV still charges at full power at the start of the day.

In Phase 3:

- During the day, the heat pump and battery operate exactly the same as the previous example.
- The EV charge power is now optimised, with the EV charging during the cheapest overnight tariff periods.
- Under full coordination, the battery now charges more heavily in the first part of the night in order to be able to discharge 4am-7am to meet EV and heat pump load, avoiding the more expensive electricity at this time. During this more expensive period the EV charge rate (usual maximum 7.3kW) is reduced in line with the maximum battery discharge power (2.5kW) while being confident (through prediction) that the required EV charge level will be met in time.

5. Performance Compared to Original Aims, Objective and Success criteria

Table 5: Performance compared to Objectives

Objectives	Status
Use the ability of managing multiple energy assets (EVs, hybrid heating systems and solar PV) to switch between gas and electric load to provide fuel arbitrage and highly flexible demand response services.	**Complete:** This has been shown within the trial
Demonstrate the potential consumer, network, carbon and energy system benefits of large-scale deployment of in-home multi-energy assets with an aggregated demand response control system.	**Complete:** This has been shown in the revised modelling
Gain insights into the means of balancing the interests of the consumer, supplier, and network operators when seeking to derive value from the demand flexibility.	**Complete:** This has been shown in the revised modelling

Table 6: Performance compared to Success Criteria

Success Criteria	Status
A detailed understanding of technical feasibility of asset coordination (supported by a report and operational data).	**Complete:** This has been shown within the trial. The control strategy has been implemented and the results assessed.
A detailed customer proposition for the MADE concept.	**Complete:** the business modelling work in the first period highlighted the potential propositions for customers.
A detailed understanding of the customer benefits of the MADE concept (supported by a report and operational data).	**Complete:** the micro-economic model and analysis conducted by Everoze highlights the customer benefits of the project.
A detailed understanding of the impact of coordinated asset control on the distribution network (supported by a report and operational data).	**Complete:** This has been assessed by Imperial College London.
A detailed understanding of the whole system benefits of coordinated asset control on the distribution network (supported by a report).	**Complete:** This has been assessed by Imperial College London.
Dissemination of key results, findings and learning to policy makers, regulators, network operators and suppliers.	**Complete:** WPD, PassivSystems and the project partners have presented at a number of events and the project has been referenced in several publications.

6. Required Modifications to the Planned Approach during the Course of the Project

Following the impact of COVID 19 lockdown on asset usage patterns the timeframe of the field trial was extended to allow for more testing in a heating season. This additional time was accommodated within the existing project timescales and the change was managed in accordance with WPD Innovation change management procedures.

7. Project Costs

The project has progressed well against the budget and is currently tracking a slightly lower spend than expected. Table 7 summarises the details of the progress that has been made with respect to the project budget.

Table 7: Project Costs

Spend Area	Budget (£k)	Actual Spend (£k)	Variance to Budget(£k)	Variance to Budget %
WPD Project Management	£81,221	£75,850	-£5,371	-6%
PassivSystems costs	£1,357,000	£ 1,357,001	+£1	0%
Contingency	£116,825	£0	£0	0%
Partner Contribution	£100,000	£100,000		0%
TOTAL	**£1,655,046**	**£1,532,851**	£5,370	0%

8. Lessons Learnt for Future Projects

Throughout the project we have gained extensive learning about how coordinate control of LCTs and be implemented and the value it creates. This is detailed in the final project report and the accompanying sub reports and summarised below.

Capabilities of coordinated control

- Predictive LCT controls that can optimise and coordinate asset behaviour play a key role in delivering best value from the assets to the consumer as well as negotiating patterns of behaviour desired by the local and national electricity grid. The greater the level of coordination between the low carbon technologies, the greater the savings in consumer electricity costs.

- Time-varying tariffs can offer significant running cost benefits to consumers with MADE assets, particularly where the battery and heat pump can be coordinated to store energy in the right balance between the battery and the thermal fabric of the building and making the right decisions about waiting for available PV generation.

- Even slight variations in tariff can introduce demand peaks, for example due to batteries delivering arbitrage. These peaks can easily be mitigated by a smart control system, at only a small incremental cost to the householder, as long as the provision of cheap electricity is not significantly reduced.

- There are a number technical challenges associated with coordinating control of assets. These range from difficulties integrating with proprietary systems to subtleties like not triggering “sleep mode” on certain vehicles.

- Traditional control of heating comfort has focussed on hitting minimum temperature requirements. However with the advent of negative electricity pricing, maximum temperatures must all be considered to prevent the homes from overheating.

- Under certain price conditions, the batteries were doing two cycles a day:
  - Charge using very cheap overnight electricity, discharge to meet morning heating demand
  - Charge prior to Agile peak and discharge over peak

  This is an interesting learning given that batteries are typically designed with one cycle per day in mind.

- Smart controls can effectively deliver both Secure and Dynamic Flexible Power services using the MADE assets, by pre-charging both the battery and the home in advance of the availability window.

Benefits from coordinated LCT control

- It is important to be clear on baseline behaviour when looking to establish the value of the services. The value of coordinated control should not encompass the wider value of individual smart control, but focus on the net additional value of coordination.

- Domestic flexibility provides a notable value opportunity. The Phase 1 desktop modelling work by Everoze Consultants showed the potential for customers to save up to £260 per annum[8],. The technical trial completed in Phase 2 enabled Everoze to carry out some additional validation of this estimate. Further work would be required though in order to fully validate these savings and this could be part of a much larger roll out of this technology.

- Analysis by Imperial College[9] has shown that there is significant potential for coordinated control to deliver distribution network cost savings across different voltage levels and asset types, which can reach £200m to

[8] https://www.westernpower.co.uk/downloads-view-reciteme/231478

[9] https://www.westernpower.co.uk/downloads-view-reciteme/231487

£500m of avoided annualised reinforcement cost by 2035. These add to the savings enabled by smart asset control and help to offset some of the increased reinforcement spend needed to accommodate the significant load increase on the network.

- In collaboration with PassivSystems, Everoze has identified that distribution networks can utilise the MADE concept by limiting loads to 33% of the 14 kW fuse limit at a property level without compromising household consumption behaviour and savings that can be achieved (based on half-hourly average loads). There is a notable potential for using residential consumers to manage peak loads on the network.

- The MADE concept offers material peak load shifting potential for the distribution network of between 35% and 40% reduction in peak loads on the network compared to optimised low carbon technologies optimised but in silo operation (based on half- hourly data).

- Whole-system case studies run by Imperial College demonstrate that there are opportunities to deliver significant cost savings by utilising distributed residential flexibility based on the MADE concept. The opportunities for cost savings increase with the level of uptake of the MADE flexible solution.

9. Dissemination

Throughout the project, the project team have strived to share learning from the project as it became available. A summary of some of the key stakeholders and events are listed below.

The Project had a poster disseminated at the CIRED 2020 workshop in, Berlin. The project partners have also presented MADE on a number of different occasions between April 2020 and September 2020. The aim was to create learning opportunities for many key external stakeholders, particularly the wider DNO community, electricity suppliers, charitable bodies, and third sector organisations. Below is a list the key of events and organisations to whom we have disseminated:

- Quarterly project briefings to BEIS Science & Innovation and Heat Policy Teams;
- Briefing for Jonathan Brearley the Chief Executive of Ofgem;
- Direct engagement with UK Power Networks, Scottish and Southern Networks & Northern Powergrid;
- National Grid ESO Innovation team;
- University College London;
- Policy Connect;
- Energy Systems Catapult;
- Elexon
- Cardiff University & Exeter University
- InnovateUK;
- Welsh & Scottish Governments;
- Flexibility First Forum;
- EnergyUK; members of the Retail, Generation, and Strategic Policy and Public Affairs teams.
- British Standards Institute;
- Scottish Renewables Conference
- International Energy Agency
- Policy UK
- Westminster Forum;

Project Partners have also disseminated to organisers that could deploy the technology commercially, to help introduce new revenue streams, develop new consumer propositions and support future housing developments. The following organisers have received presentations from MADE project partners:

- Shell Energy
- So Energy
- EDF Energy
- Octopus Energy
- Tonik Energy
- Barratt Homes PLC
- Sero Homes
- Unite Students

The project was referenced in the EnergyUK**;** Barriers to Flexibility Delivering the potential benefits of a smart flexible energy system in the transition to net zero report.

Finally, we also undertook dissemination to wider audiences through WPD innovation events (Balancing Act and Innovation Showcase), Project specific webinars (interim and final results) as well as industry conferences (Solar Storage Live).

10. The Outcomes of the Project

The MADE project has shown that there is significant additional value extracted through the coordination of multiple LCTs within a single premise. Both at a system wide level, and at a single property level there are tangible benefits, including de-risking the distribution network from unpredictable demand when assets are coordinated rather than operating individually.

Following a market assessment by Delta-EE and supplemented by National Grid ESO's Future Energy Scenarios (FES) it is evident that the deployment of low carbon technologies will grow rapidly out to 2050. Strong growth in the sales of all low carbon technologies is expected in the medium to long-term. Under almost any scenario the number of air source heat pumps and hybrid heating systems installed in UK homes will be well into the millions by 2030. The uptake of EVs will also be rapid from the late 2020 in to the early 2030s with over 10 million on the roads by the mid-2030s in all scenarios. Domestic solar PV installations will also see a significant increase with anywhere from 2 to 5 times more installations than today by 2050. The MADE project has demonstrated that by optimising these technologies in mature market conditions it will support to maximise value and limit network and system impacts.

Predictive controls are a key enabling technology for all of the above benefits of tariff optimisation and asset coordination. Under the MADE project PassivSystems has trialled a sophisticated control system uniquely able to make the right quantitative trade-offs to underpin the complex decisions in controlling multiple low carbon assets simultaneously.

The modelling has demonstrated that current wholesale cost profiles and network charges, savings from peak shifting is a smaller component of the overall value stack compared to ancillary services revenues. The property demand and consumption patterns, as well as surplus solar available at the property, have a high degree of sensitivity on cost savings that can be achieved.

The additional energy cost for providing ancillary services has a material effect of reducing the savings in energy costs from peak shifting. In some cases, this can be higher than the annual savings in energy costs, however this is more than offset by the additional revenue generated

The value opportunity from peak shifting and smart charging is low for customer types with low demand and low EV utilisation levels, and the value stack is heavily reliant on DSO services. For such customer types, if DSO service opportunities are not available, then there is little benefit from co-ordinated domestic flexibility at the household level. Moreover, if the EV is available for most of the time during the evening peak period, then with the EV by itself performing peak-shifting, a domestic battery would not be needed for such Low Demand consumer types (unless DSO services are available and pursued).

In collaboration with PassivSystems, Everoze has identified that distribution networks can utilise the MADE concept by limiting loads to 33% of the 14 kW fuse limit at a property level without compromising household consumption behaviour and savings that can be achieved (based on half-hourly average loads). There is a notable potential for using residential consumers to manage peak loads on the network.

The MADE concept offers material peak load shifting potential for the distribution network of between 35 and 40% reduction in peak loads on the network compared to optimised low carbon technologies optimised but in silo operation (based on half- hourly data).

Imperial College has assessed the opportunities to deliver whole-system cost savings by utilising distributed flexibility based on the MADE concept are significant and increase with the level of uptake of the MADE flexible solution. In the 2035 horizon with an ambitious carbon target and high uptake of EVs and HHPs the gross benefits could reach £3.1bn per year, through allowing the electricity system to achieve the carbon target more cost-effectively, while at the same time reducing the need for high volumes of peaking generation capacity and distribution network reinforcements. The highest achievable net benefits, after deducting the cost of enabling residential flexibility through MADE, are lower (£2.1bn per year).

The net benefit is still considerable despite moderate levels of flexibility already being present in the system in the form of demand side response, large-scale battery storage and interconnectors. There is also a significant potential for distributed flexibility to deliver distribution network cost savings across different voltage levels and asset types, which can reach £200m to £500m of avoided annualised reinforcement cost.

With clear value available, Delta-EE identified customer propositions for business models which could be deployed in the short to medium term and long term. These propositions are built upon a well-used framework for developing business models and customer propositions and build on insight taken from studying similar business models. The propositions identified by Delta-ee are as follows:

1. All Inclusive: All energy services (heating, personal transport and other energy needs) provided for a single monthly fee.

2. Buying Enhanced Control: Company optimises energy demand across technologies and pays income to customer.

3. Minimising Peak Demands: Balancing electricity demand over the home to reduce peak demand, in return for a cheaper tariff.

To validate the modelling activities of the MADE concept, PassivSystems successfully completed a 12-month technical field trial, with five homes having multiple LCTs operating through one consumer interface.

Predictive controls that can optimise and coordinate asset behaviour play a key role in delivering best value from the assets to the consumer as well as negotiating patterns of behaviour desired by the local and national electricity grid. The greater the level of coordination between the low carbon assets, the greater the savings in consumer electricity costs.

Time-varying tariffs can offer significant running cost benefits to consumers with MADE assets, particularly where the battery and heat pump can be coordinated to store energy in the right balance between the battery and the thermal fabric of the building and making the right decisions about waiting for available PV generation.

Even slight variations in tariff can introduce demand peaks, e.g. due to batteries delivering arbitrage. These peaks can easily be mitigated by a smart control system, at only a small incremental cost to the householder, as long as the provision of cheap electricity is not significantly reduced.

Smart controls can effectively deliver both Secure and Dynamic Flexible Power services using the MADE assets, by pre-charging both the battery and the home in advance of the availability window.

With advanced controls it is expected that this flexibility and the associated benefits can be obtained without affecting customer comfort. This is essential if wide scale acceptance of advanced control of LCTs is to be achieved.

11. Data Access Details

Anonymised site data will be available to share in accordance with WPD's data sharing policy *www.westernpower.co.uk/Innovation/Contact-us-and-more/Project-Data.aspx)*

12. Intellectual Property Rights

The table below presents a complete list of all IPR generated within the project from all project partners.

Table 8: Intellectual Property Generated

IPR	Category	Owner
Battery storage forecasting tool	Relevant Foreground	PassivSystems
Delta EE feeder level monitoring report	Relevant Foreground	Delta EE
Delta EE business model report	Relevant Foreground	Delta EE
Delta EE customer survey results	Relevant Foreground	Delta EE
Imperial whole system value report	Relevant Foreground	Imperial College London
Passiv Systems modelling report	Relevant Foreground	PassivSystems
Project Interim report	Relevant Foreground	PassivSystems
Everoze report	Relevant Foreground	Everoze
Field trial plan	Relevant Foreground	PassivSystems
Technical specification	Relevant Foreground	PassivSystems
Software high level design	Relevant Foreground	PassivSystems
Customer engagement report	Relevant Foreground	PassivSystems
Interim trial results report	Relevant Foreground	PassivSystems
Updated Conflicts and Synergies Reports	Relevant Foreground	Imperial College
Revise Proposition Framework	Relevant Foreground	PassivSystems
Technical Field Trial data analysis report	Relevant Foreground	PassivSystems
Revised Whole Energy System benefits report	Relevant Foreground	Imperial College
Revised Techno-economic report	Relevant Foreground	Everoze

13. Planned Implementation

The MADE project has successfully achieved its core objectives of highlighting the potential value of coordinated control. We have disseminated the learning with potential providers who could help roll this out. However to do this a few key elements need to be in place.

Further access to Time of Use Tariffs: The project has shown a clear ability for assets to optimise against ToU tariffs, and the benefits that can be achieved through this. However, the penetration of current ToU tariffs remains low. Domestic level banded tariffs have been available from DNO's for a number of years now. In addition, following the acceptance of DCP 268, from 2021, all DUoS tariffs will include time bands. The roll out of smart metering and half-hourly settlement are crucial to making this more widespread, exposing suppliers, and then their customers to more cost reflective price signals. These processes are both underway, this project highlights some of the benefits they would unlock and highlight the need for them to progress swiftly.

- **LCT interoperability standards:** There is clear evidence that coordinated control of assets can provide significant value. However, the process of providing this control is not straightforward. Significant time and effort was needed within the project to integrate with proprietary control systems. Clear standards would ease the control across and between assets. Work is already underway on within the British Standard Institute (BSI). As part of PAS 1878. The findings of the project are being fed into this work to highlight the value, as well as the practical challenges.

- **Clear incentives for the adoption of LCTs:** There already exists a wide range of flexible technologies that could deliver customer cost and carbon savings whist also helping manage the wider system. These include electric vehicles, smart hybrid heat pumps, heat pumps, solar PV, batteries and smart EV/V2G chargers that could all be providing services at this time if the right signals and instructions were being administered. Harnessing the potential of these technologies is critical to ensuring green energy supply isn't unnecessarily wasted. Clear incentives are needed to ensure sufficient volume of LCTs are deployed to help hit Net Zero. These could be under many forms but need to be clear and investable. Ensuring that assets are installed with the option to be flexible is essential to make sure that consumers can easily access the value that can be generated.

- **Clear economic and investable business models:** As highlighted in Section 14, it is essential that any business models developed go beyond asset installation (as highlighted above) and include the potential for coordinated control. It is expected that these will need to be quite diverse to help target various segments of the market based on key factors such as access to capital as well as appetite for control.

Also as we have gathered more learning about the feasibility of such controls a number of potential follow up work has been identified.

- **Large scale trial of optimised LCTs and coordinated control:** To date the MADE trial has focussed on the small-scale demonstration of the concept. This provides interesting insight but would be enhanced by a larger scale field trial and/or more extensive simulation work to understand the quantitative impact of MADE assets on household demand shape and running costs, and their statistical variability. With such variation in UK housing stock, customer requirements, and even weather patterns, a larger, a longer trial would help understand the potential variability. The MADE project focused on hybrid heat pumps and no other a heating appliance. Exploring the potential of the next generation of heat pumps and storage heaters may deliver further value from the MADE low-carbon assets. The MADE project was also limited by the relative immaturity of EV and charge point connectivity. Exploring the potential of the next generation of V2G charge points could deliver further value from the MADE low-carbon assets.

- **Leaving no customers behind:** Further work is needed to understand how accessible the MADE concept is to customers in vulnerable situations, or who suffer from fuel poverty. Considering the potential benefits to such customers, collaboration with local authorities, registered social landlords, distribution networks and Ofgem may be needed to ensure everyone can benefit. Elements such as business models need to be further developed as well as education and support to understand how to maximise the benefits. Utilising frameworks such as the Centre for Sustainable Energy's Smart and Fair Framework could help us understand the accessibility of the proposition as well as any potential mitigations that could widen access.

- **LCT forecast tool:** There is a need amongst the local and national networks to ensure optimal network planning, asset dispatch and manage uncertainties. Current models do not adequately consider LCT optimisation, homes having multiple LCTs, coordinated LCTs and limited heat appliance profiles. The next step is to calibrate existing models or develop a new model to consider a more granular home electricity profiles that adopts stochastic portfolio view, probes energy service and mobility requirements in greater detail, considers market trends (e.g. LCT sale forecasting and ToU adoption) and better assess predictability of consumer behaviour further. As control systems develop, and markets signals become more developed our understanding of how LCTs will operate, and the potential impacts on the network will need to evolve. Static profiles are unlikely to provide sufficient detail.

- **Improved understanding of connected LCTs:** DNO and industry knowledge of assets connected to the distribution network is improving with new developments such as the embedded capacity register and innovation projects such as LCT Detection. It is important that DNO's better understand what is connected to the network, but also to understand how they might operate. Understanding the technical capability as well as likelihood to flex is important. As shown control systems and tariffs have a very large impact on asset operation and developing better understanding of this could provide significant value.

- **Review the connection process for domestic LCTs:** The connection process for multiple LCTs is far from straightforward and often uses unlikely assumptions on asset operation. Where systems can be shown to reliably limit import or export capabilities these should be considered in the assessment of maximum demands both from the installer and the DNO. A review of control systems such as the one tested, with standards such as G100 could allow for this.

14. Contact

Further details on replicating the project can be made available from the following points of contact:

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Glossary

Abbreviation	Term	Definition
BSI	British Standards Institute	BSI is the national standards body for the UK. They produce technical standards on a wide range of products and services. They also supply certification and standards related services to businesses.
CAPEX	Capital Expenditure	The money an organisation or corporate entity spends to buy, maintain, or improve its fixed assets such as buildings, vehicles, equipment or land.
CCS	Carbon Capture and Storage	CCS is the process of capturing carbon dioxide (CO_2) formed during power generation and industrial processes and storing it so that it is not emitted into the atmosphere.
FFR	Firm Frequency Response	A service provided to National Grid which uses assets to quickly reduce demand or increase generation to help balance the grid and avoid power outages
HHP	Hybrid Heat Pump	HHP is a heating system that combines two sources of providing Heat: a Heat Pump (normally Air or Ground Source) and the other is a traditional gas or oil boiler.
LCT	Low Carbon Technology	Any device or solution used to reduce carbon emissions, examples include heat pumps, solar PV and energy storage systems
OPEX	Operational Expenditure	An operating expense is an ongoing cost for running a product, business or system.
WeSIM	Whole-electricity System Investment Model	WeSIM is a comprehensive electricity system analysis model developed by Imperial College.

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