WPD INNOVATION

MADE

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SIX MONTHLY PROGRESS REPORT
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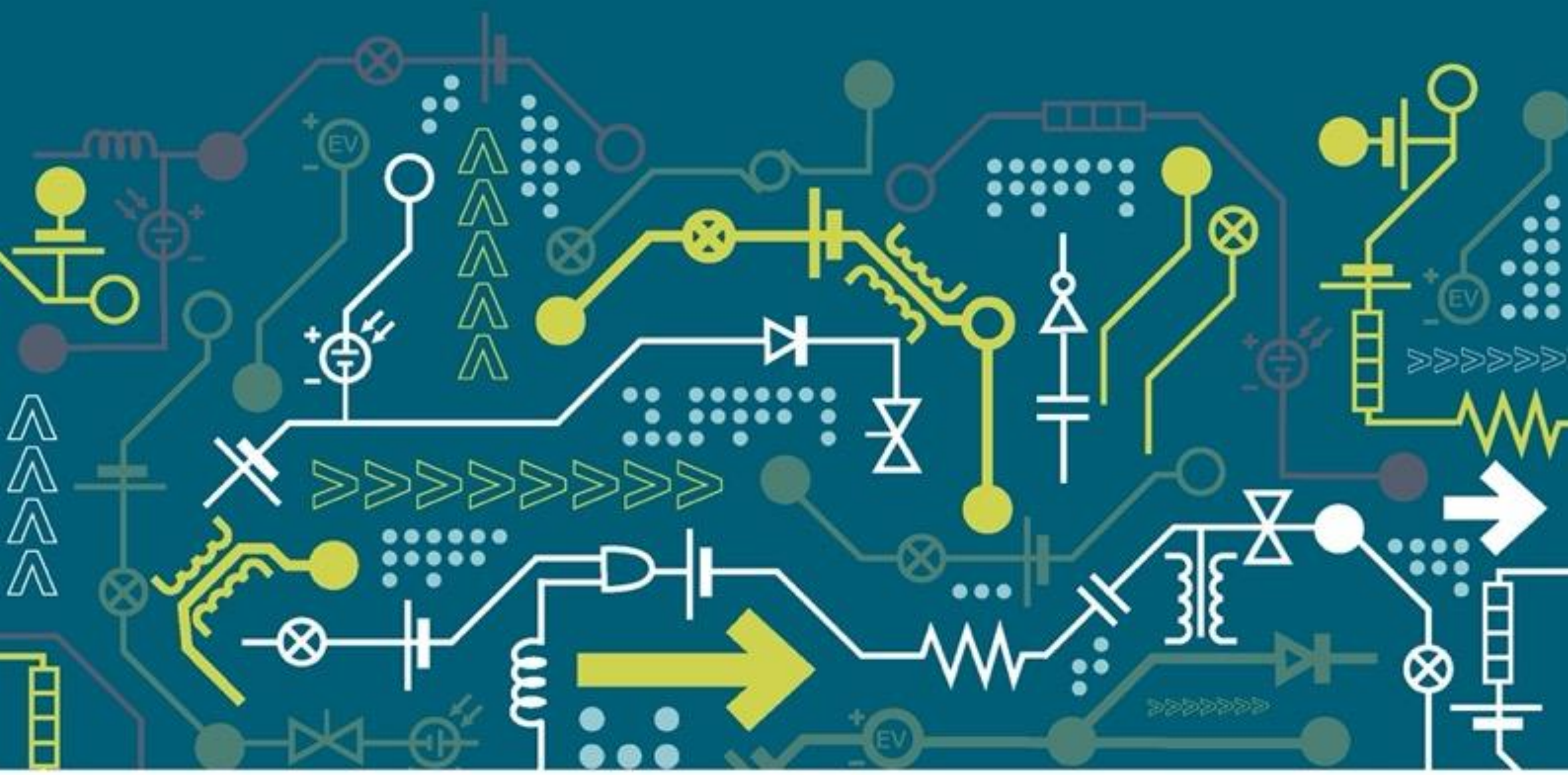

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1 Executive Summary

The Multi Asset Demand Execution (MADE) project is funded through Ofgem's Network Innovation Allowance (NIA). MADE was registered in March 2019 and will be complete by October 2020.

The MADE project investigates the network, consumer and broader energy system implications of high-volume deployments of the combination of:

- Domestic Electric Vehicle (EV) charging;
- Hybrid heating systems (domestic gas boiler and air-source heat pump) or Heat Pump (HP) heating systems; and
- Solar photovoltaic (PV) generation and battery storage.

The research objective is to better understand the feasibility of managing and aggregating multiple Low Carbon Technology (LCT) assets affordably through the use of advanced algorithms to unlock value from energy markets.

MADE is a £1.6m project, delivered by PassivSystems with a five-home technology trial in based in South Wales and the South West.

This report details progress of the project, focusing on the last six months, October 2019 to March 2020.

1.1 Business Case

Previous Distribution Network Operator (DNO) trials[1] have highlighted the significant potential value of flexibility from LCT loads (My Electric Avenue highlighted up to £2.2bn of reinforcement avoidance by 2050 and Freedom highlighted £300 million of reinforcement deferral in South Wales alone by 2050). This trial will evaluate the potential interactions between the various value streams to understand the total savings possible.

Based on a future homeowner that has a conventional heat pump and a conventional EV charger, PassivSystems estimate that one LV (Low Voltage) feeder (at a cost of approximately £40k) would be required for every four homes, a cost of £9,279 per home.

As shown in the trials mentioned above, this cost can be reduced significantly though the use of inherent asset flexibility (smart EV charging & hybrid heating systems). By utilising this flexibility, PassivSystems estimate that one feeder would be required for every 14 homes, at a cost of 2,900 per home.

An integrated optimised approach with supplemented PV and battery storage (the MADE method) could produce significant savings, PassivSystems estimates that one feeder would be required for every 39 homes, at a cost of £1,531 per home. This would help reduce network reinforcements; in addition, a hybrid solution can also respond to constraint signals and prevent Distribution Use of System (DUoS) charges.

Financial benefit = base cost – method cost.

Financial benefit = £2,900 - 1,531 = £ 1,369 per household.

Whilst the speed of deployment will vary on a regional basis, the deployment of LCTs is expected to grow significantly across GB. As such the learning will be replicable across all GB.

To achieve the optimised control of LCTs, new hardware and software is required. With economies of scale, the hardware cost to roll out an automated multiple asset control that will integrate with the

[1] For Example Electric Nation (http://www.westernpower.co.uk/projects/electric-nation), Sola Bristol (https://www.westernpower.co.uk/projects/sola-bristol), Freedom (https://www.westernpower.co.uk/projects/freedom) & My Electric Avenue (www.myelectricavenue.info).

majority of LCTs will be £100. In addition, an annual service fee of £30 - £50 will maintain and continually optimise to market conditions. This equates to a Net Present Value (NPV) of approx. £500 - 756 over a 25-year lifetime. However, these costs will provide significant additional benefits beyond DNO reinforcement avoidance which should help cover a significant portion of the costs.

1.2 Project Progress

This is the third progress report. It covers progress from April 2020 to the end of September 2020.

This reporting period has focussed on the continuation of the field trial, and the re-run of the relevant analysis. Phase four (summer running) of the trial was successfully completed and learning has fed into updated analysis from Imperial College and Everoze. PassivSystems have also conducted extensive analysis on the trial results including simulating similar days under different control methodologies to demonstrate the value created.

The period was also marked by the management of COVID 19 restrictions across the UK which had an impact on the trial.
Whilst some homes of key workers continued as normal, unsurprisingly lockdown created noticeably different energy usage for some participants, primarily around reduced EV mileage. To mitigate this, we have extended the project and re-ran interventions in September.

The next reporting period will focus on the closure of the project and suitable knowledge dissemination.

1.3 Project Delivery Structure

1.3.1 Project Review Group

The MADE Project Review Group meets on a bi-annual basis. The role of the Project Review Group is to:

- Ensure the project is aligned with organisational strategy;
- Ensure the project makes good use of assets;
- Assist with resolving strategic level issues and risks;
- Approve or reject changes to the project with a high impact on timelines and budget;
- Assess project progress and report on project to senior management and higher authorities;
- Provide advice and guidance on business issues facing the project;
- Use influence and authority to assist the project in achieving its outcomes;
- Review and approve final project deliverables; and
- Perform reviews at agreed stage boundaries.

1.3.2 Project Resource

Using existing relationships from the Freedom project, we have formed a project team led by PassivSystems to deliver the MADE project. This includes: Wales and West Utilities, Imperial College, Everoze and Delta EE.

The project partners are all experts in their field and are managed by PassivSystems. Everoze, Imperial College London and Delta EE act as subcontractors to PassivSystems, whilst Wales and West Utilities act as an advisor.

passivSYSTEMS — PassivSystems - Project management, home energy management system, PV optimisation and demand aggregation modelling.

WALES&WEST UTILITIES — Wales & West Utilities - Gas distribution network requirements, measurement and modelling.

everoze — Everoze – micro-economic energy modelling, commercial modelling.

Imperial College London

Imperial College – Data analysis and a whole-system assessment on the future GB electricity systems.

DELTA Energy & Environment

Delta-EE – Customer research and Business Modelling.

1.4 Procurement

There were no additional contracts placed within this reporting period.

During the initial reporting period contracts were placed with PassivSystems for the delivery of the project. PassivSystems have in turn placed contracts with the partners acting as subcontractors.

1.5 Project Risks

A proactive role in ensuring effective risk management for MADE is taken. This ensures that processes have been put in place to review whether risks still exist, whether new risks have arisen, whether the likelihood and impact of risks have changed, reporting of significant changes that will affect risk priorities and deliver assurance of the effectiveness of control.

Contained within Section 7 of this report are the current top risks associated with successfully delivering MADE as captured in our Risk Register. Section 7.2 provides an update on the most prominent risks identified in the previous reporting period. The project has had a total of 35 risks logged and there are currently 18 live project risks.

1.6 Project Learning and Dissemination

The project partners have continued to capture MADE lessons learned, key results, the energy system impact and next steps. Through project governance the project partners have collaborated to analyse, review and share key outputs which are logged and are to be presented in the project final report and end of project lessons learned workshop.

The desktop modelling and simulation analysis had gained interest from variety of key energy sector stakeholders with follow up dissemination presentations requested. The last six months have provided key outputs from the real-world technical trial, which has exceeded the early desktop modelling and simulations results and expectations. The MADE project consortium has been in a position to disseminate real-world coordinated control performance, the impact and benefits.

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 is 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;
- 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.

A key next step has been to disseminate 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
- EDF Energy
- Octopus Energy
- Tonik Energy
- Barratt Homes PLC
- Sero Homes
- Unite Students

The project partners are currently updating the dissemination plan in preparation for the final project report, key outputs and next steps. The next reporting period will focus heavily on disseminating the learning.

2 Project Manager's Report

2.1 Project Background

Following the publication of the Committee on Climate Change (CCC) report promoting hybrid heating systems as a "low regret" option, we need to consider the network implications of CCC's call for ten million hybrid heating system installations across GB by 2035. Many of these installations will be in homes that have also adopted EVs. Understanding the interplay between these two primary drivers of electrification is essential to plan future network developments. The third factor that the project will explore is the impact of domestic solar PV and storage installations on these. During the same timescale as hybrids and EVs are being adopted, solar PV costs will fall to a level that makes subsidy free installation an economic reality for homes that wish to save on the cost of their grid supplied electricity.

Several innovation trials have highlighted the possibilities for individual LCTs to provide flexibility: EV - Electric Nation[2], HP - Freedom[3], PV and Storage - Sola Bristol[4]. However, each of these investigations has looked at a single technology type in isolation. Currently we do not have sufficient understandings on how such systems may interact and whether the flexibility is complementary, optimal, or counter-acting.

The research objective is 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 will also evaluate consumer trust in new technology that is taking greater levels of EV charging, heating system control, and design appropriate user interfaces and information systems to help drive adoption.

Based on the lessons learned from previous NIA trials MADE will carry out micro-economic and system-level analysis to extrapolate previous trial findings in order to:

- Build a microeconomic model for domestic multi-asset, multi-vector flexibility for GB today, this will: Identify the most attractive customer types; Identify the high potential service stacks; Quantify the value (£); Include a particular focus on Distribution System Operator (DSO) services;

- Understand how the combined operation of residential solar PV generation, heat pump systems and smart EV charging may provide benefits to the consumer;

- Assess the whole-energy system benefits (including network infrastructure) and carbon benefits of large-scale deployment of the MADE concept;

- Consider conflicts and synergies between local community and national level objectives, in the context of the flexibility enabled by the MADE concept; and

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[2] The Electric Nation project aimed to enable DNOs to identify which parts of their network are likely to be affected by EV uptake, and whether EV demand control services are a cost effective solution to avoiding or deferring reinforcement on vulnerable parts of their networks. The project has deployed Smart Chargers to understand how and when people charge their EV's, and has trialled solutions such as smart charging and Time of Use tariffs. The results from these trials were used to develop a network assessment tool to predict where plug-in electric vehicle uptake may cause network problems.

[3] FREEDOM, in partnership with Wales and West Utilities installed 75 hybrid heat pumps within domestic properties in South Wales. The hybrid heat pumps used electricity when there was sufficient capacity on the system to do so and switched to gas at the point the capacity on the electricity system had been reached. This project demonstrated the value of a hybrid solution to avoid the need to reinforce the electricity network whilst supporting a significant decarbonisation.

[4] The Sola Bristol installed 2kW of battery storage in domestic lofts alongside PV solar panels. The PV panels were directly connected to the battery to store excess solar energy. Five commercial buildings were also tested. The project highlighted the

- Estimate 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 and the South West will be used to validate the modelled learning.

The project runs for 21 months and has been broken down into six work packages.

Work Package 1: Project Management
PassivSystems will complete the project management for the duration of the project to deliver the system design, development and technical feasibility installation. The project management will use PassivSystems' project management processes and will oversee the flow of development work through PassivSystems' agile Kanban processes.

Work Package 2: Problem definition, approach and trial design
The project delivers the consolidation of existing information across partners, development of the customer, DNO, 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 will produce a high-level control strategy, simulate the MADE concept (desktop exercise) and collaborate with Imperial College and Everoze to model the local network, national network and the microeconomics. All partners will apply advanced big-data techniques to analyse and quantify the success of different approaches, considering demographic parameters, consumer flexibility, different loading conditions, different generation periods, time of application of different prices etc. The system-wide benefits of a large-scale rollout of the MADE concept, considering both local and national level infrastructure will be assessed. This will be enabled by advanced modelling approaches developed by Imperial College, that identify system solutions that deliver secure and cost-efficient energy supply while respecting national decarbonisation targets.

Work Package 4: ASHP/EV/PV Control & Aggregation Solution
PassivSystems will design and develop its smart control to enable optimisation (by cost or carbon) of the EV charge point, the electric heating asset and the rooftop PV generation. They will include the PassivEnergy platform that aggregates demand across households and enables the demand flexibility to be traded with energy markets including the DSO. PassivSystems will develop its existing aggregation platform to ensure each vehicle has enough charge for the next trip (based on consumer preferences) before calculating how much remaining capacity to sell to grid and/or support domestic heating (via heat pump, hybrid heating system, or hot water tank immersion). The controls will also manage the heat and transport assets and maximise the self-consumption of rooftop solar PV through a coordinated control strategy.

Work Package 5: Technology Feasibility Trial (maximum of five homes)
PassivSystems will deliver a five-home technology trial; the field trial will test 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 will deliver an interim and final report on consumer, energy system and business model outcomes. PassivSystems will be responsible for sharing the findings of MADE publically during and after the project is complete.

2.2 Project Progress

2.2.1 Work Package 1: Project Management

Progress within this reporting period
This work package runs for the duration of the project and looks to ensure the project is running smoothly and is progressing adequately. This also looks to track and manage risks to maximise the change of successful delivery. Key elements of this are mentioned in Sections 3-7.

Next steps
This work package will continue for the duration of the project.

2.2.2 Work Package 2: Problem definition, approach and trial design

This Work Package was completed in the first reporting period.

2.2.3 Work Package 3: Modelling: Consumer, Micro-Economic, Local and National GB

This Work Package was completed in the first reporting period.

2.2.4 Work Package 4: ASHP/EV/PV Control & Aggregation Solution

Progress within this reporting period
Following the last reporting period, the main work in this work package was to maintain the control system and tweak as necessary. A few minor issues arose such as the response to very negative pricing as well as the management of overheating. These were all dealt with swiftly.

Next steps
PassivSystems has completed the control development and any refinement work. This work package in now complete.

2.2.5 Work Package 5: Technology Feasibility Trial (maximum of five homes)

Progress within this reporting period

This work package built from the work in the previous reporting period and continued to operate the five home trial. With Phases 1 & 2 complete, this reporting period went beyond non-coordinated control, and control of just the in-home assets, to control all the LCTs as well as understand Summer operation (Phases 3 & 4). Additional Simulation work was also carried out to understand the value of different levels of control on similar days.

It is should be highlighted that the COVID-19 pandemic hit during Phase 3 of the field trial. This caused some disruption to the trial, particularly due to significantly reduced EV use during national lockdown. As a result, some of the interventions planned during this phase of the field trial were delayed, and thus some of the key examples of fully coordination control were conducted slightly later in the year resulting in lower heating demand than originally anticipated.

Some highlights of the operation of phases 3 and 4 are detailed below.

Phase 3 Overview: Full coordination including EV

The control strategy for each asset during Phase 3 was as follows:

- **Hybrid heat pump:** use was optimised against the tariff, coordinated with solar generation and battery availability as well as EV demand. The hybrid heat pump controls were configured with a high price for the fossil fuel boiler in order to reflect the future scenario of substantial decarbonisation, which enabled a high proportion of the heat demand to be provided by the heat pump.
- **Battery:** the battery was optimised against the tariff, coordinated with solar generation and hybrid heat pump use as well as EV and baseload electricity demand. Where possible, the system utilised Sonnen's internal control mode for matching demand on a minute by minute basis, overriding when excess charging or discharging was required. This enabled load shifting through pre-charging the battery during cheap tariff periods.
- **EV:** During this phase, EV charging control was fully automated. Charging was controlled using Passiv's EV control algorithm, based on user information inputted via the Passiv app. Upon plugging in, EV users were asked to enter the current state of charge of their vehicle, the desired state of charge, and the time they required it to be charged by. Based on this information, the EV

was then charged at the most beneficial time within the flexibility given (i.e. ensuring it was recharged when required), coordinated with all other energy assets in the home to minimise consumer costs whilst also honouring any constraints that may be in place.

During this phase, homes were optimised to two different tariffs:

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

Phase 3: Octopus Go tariff

Figure 1 shows typical operation under the coordinated control strategy implemented in Phase 3 of the trial, against the Octopus Go tariff. The following can be observed from the figure:

- There is high demand during the cheap overnight tariff periods with the battery, and EV where plugged in, charging during this time.
- The battery undergoes a full charge during the cheap overnight tariff period. The battery then discharges over the course of the day, with some excess solar stored battery where available.
- Room temperature is well maintained, with a minimum of 17.7° and a maximum of 18.6° across the period shown in the figure. There is little demand for heating, and heat pump demand is partially met by the battery which was charged during the cheap overnight and times of excess solar. Due to high external temperatures in June and thus little demand for heat, no heating occurs during the cheap overnight period however during a Winter scenario the heat pump would be expected to make use of the cheap rate in addition to the battery and EV.
- The EV is plugged in at 16:00 on day one, with the user requesting full charge by 06:30 the following morning. It should be noted that the maximum charge rate for this particular EV is 3.6kW. Since the battery is empty upon the EV being plugged in, charging is delayed until the cheap overnight tariff period where the EV then begins to charge at full rate. However the EV cannot draw sufficient charge to meet the user's request in this period alone, therefore some charging must take place after the cheap tariff period as well. Coordination between the EV and the battery has enabled the power supplied by the domestic battery (previously charged on the cheap rate) to the EV to be maximised: the EV charge rate was reduced to match the battery power capacity between 05:00 and 06:30 (with the confidence from the predictive control that a fully charged EV would still be achieved). Thus this allows the home to stay virtually off-grid whilst the EV charge session completes, reducing the cost of charging the EV.
- The EV is plugged in at 15:00 on day two, with the user requesting full charge by 06:30 the following morning again. Day two has a greater amount of solar generation, and thus the battery still holds a fair amount of charge during the early evening (whereas it was empty on day one). Thus EV charging can commence in advance of the cheap overnight tariff period, freeing up space in the battery so that it can charge a greater amount during the cheap overnight period. Once the tariff becomes cheap, the EV power is increased to full rate and by the end of this period the EV is essentially fully charged. As the EV charging is de-rated towards the end of the charge session a small amount of power is drawn outside of the cheap tariff period. Again, the battery discharges to match the EV power in order to prevent the need to import electricity at the higher rate.

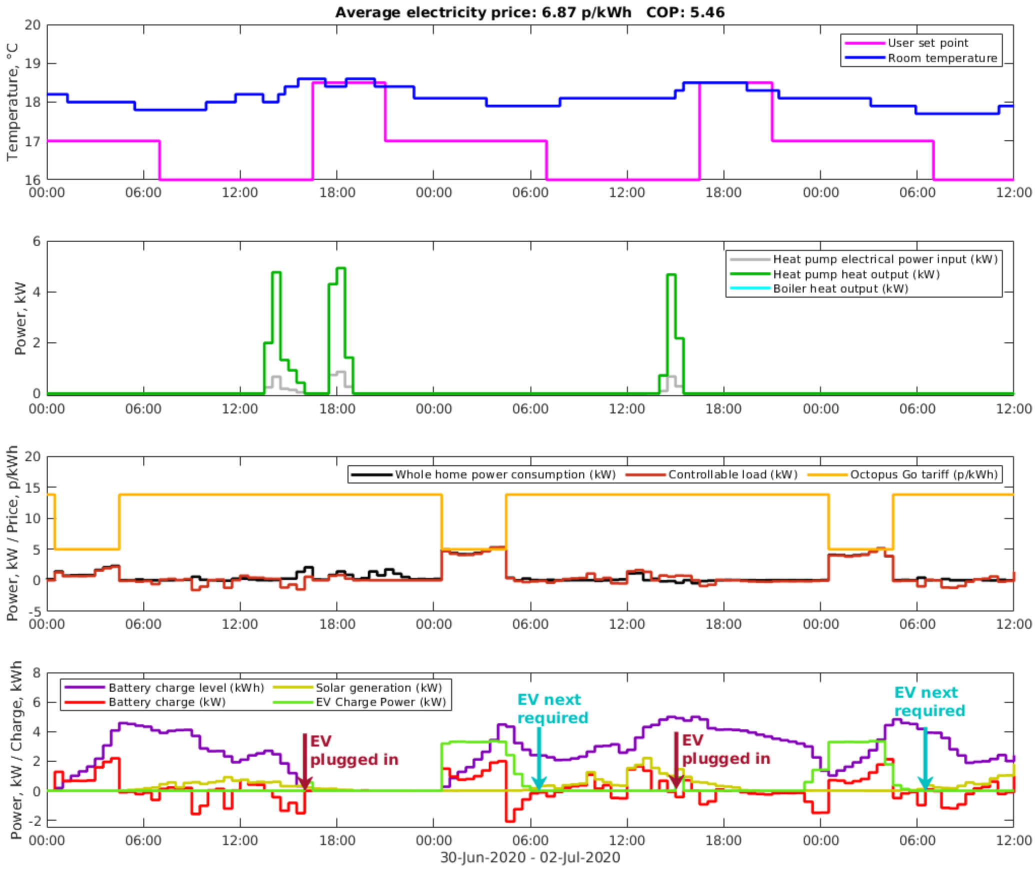


Figure 1: Fully coordinated control on the Octopus Go tariff (Home 1, 30/06/2020 - 01/07/2020)

Phase 3: Agile tariff

Figure 2 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° and a maximum of 18.9° across the two day period. For reference, the average external temperature was 15.3° over this same period, with a high of 19.0° and a low of 13.3°.
    - 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. This demonstrates an advantage of coordination between the EV and the battery.

- 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.

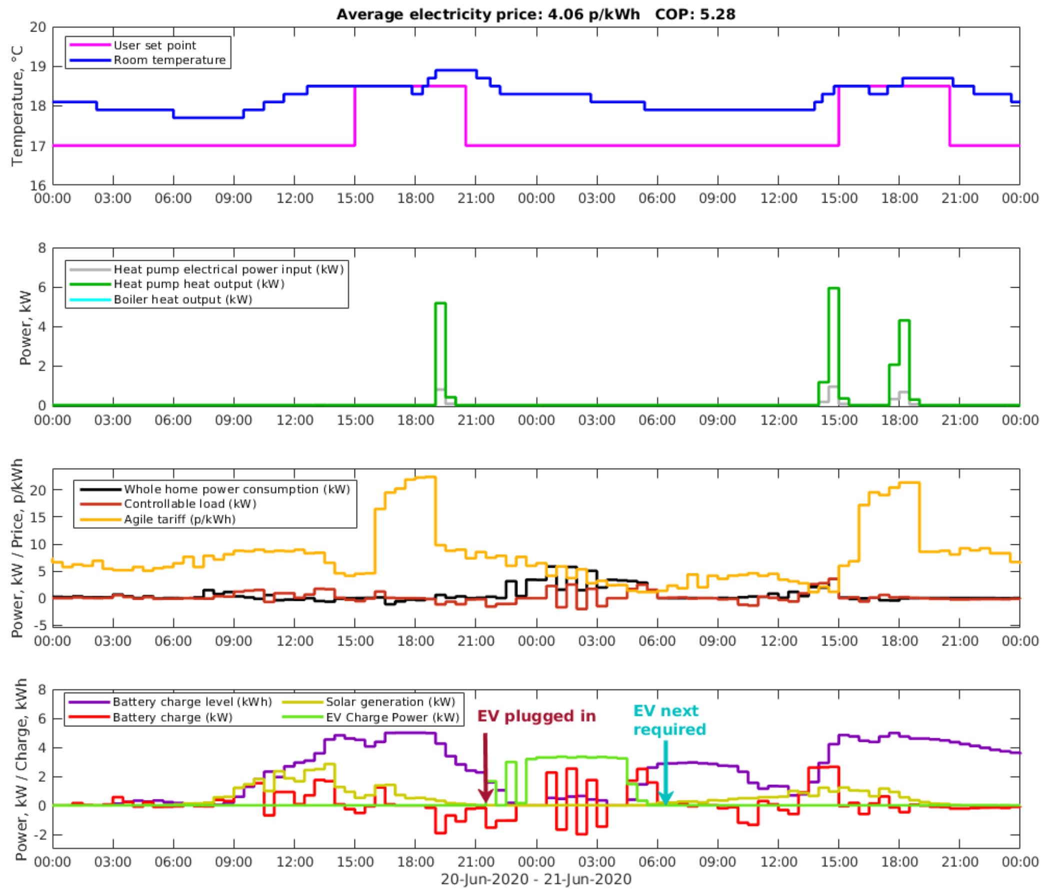


Figure 2: Fully coordinated control on the Octopus Agile tariff (Home 01, 20/06/2020 - 21/06/2020)

Figure 3below shows an example of coordinated control where EV charging was optimised to match solar generation, as well as a trade-off made against time-varying Octopus Agile pricing. The following can be observed from the figure:

- No heating was required on this day.
- The EV was plugged in at 10:40 with a full charge requested by 16:00 the same day.
    - At the start of the charge session, the EV charges at a reduced rate which closely matches solar generation, providing a nice example of asset coordination. The battery provides an active role as well, dynamically compensating for the variations in solar generation and household load.

- Towards the end of the charge session, electricity is required from the grid in addition to the solar generation in order to charge the EV to the required level. This is primarily done during cheaper tariff periods, with the battery also charging during these periods before discharging during the more expensive periods, demonstrating coordination again.
- The EV is fully charged by 16:00, as required. The battery charges prior to 16:00 in order to (successfully) keep the home off grid during the Agile peak tariff period.

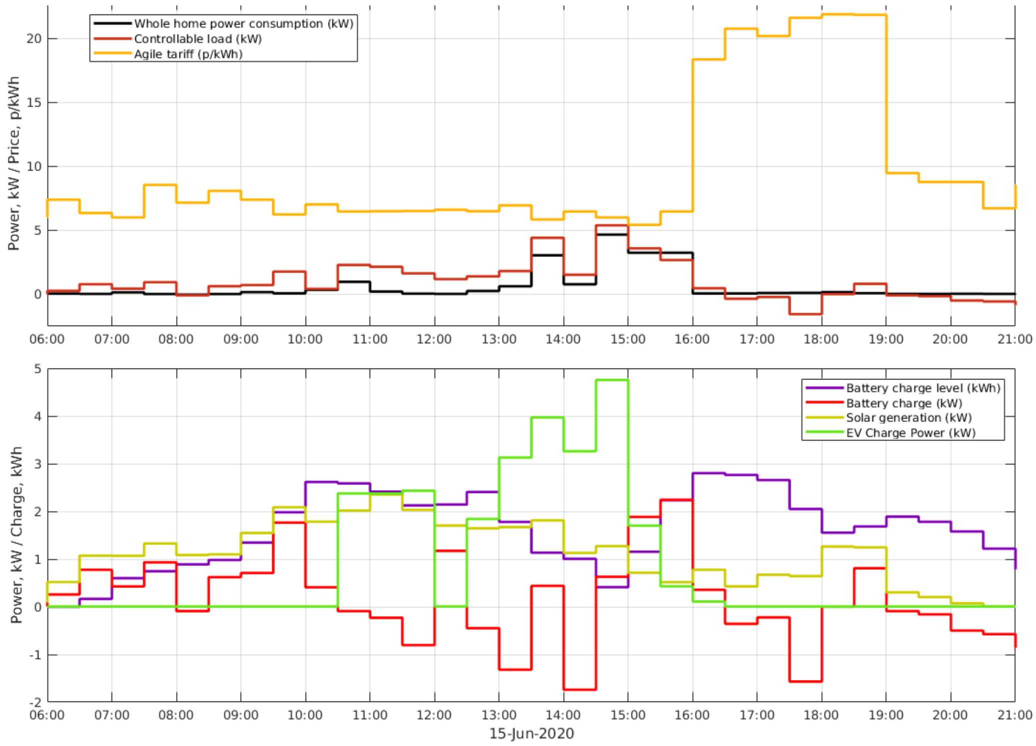


Figure 3: EV, Solar and Battery Coordination (Home 05, 15/06/2020)

Phase 4 Overview: Summertime

Phase 4 of the trial involved investigation into how coordinated asset behaviour changed in summertime conditions, when solar PV generation was dominant over heating demand. During this phase, homes were optimised to Octopus Agile (dynamic wholesale plus peak) tariff and the Octopus Go (cheap overnight) tariffs.

A key issue that arose during this phase was the overheating of homes when incentivised by high excess solar or negative electricity prices. Note we use the term “overheating” to specifically mean that caused by deliberate running of the heat pump for financial gain etc., rather than its more common meaning of homes being warmer than desired due to summertime solar gains without heating running (although of course there is an overlap as solar gains give less room for heat pump running).

Phase 4: Agile tariff

Figure 4 shows an example of typical summertime operation, with high external temperatures and high solar generation, under the Octopus Agile tariff. The combination of solar PV and battery keeps the home completely off-grid over almost all of this period, with significant net export of electricity as well. The following can be observed from the figure:

- There is no heating demand. The home stays well above set point without the need for use of the heat pump or boiler.
- High solar PV generation has moved the system back from two cycles a day (observed previously) to one cycle a day, as the system recognises that free solar is advantageous over cheap night time electricity rates.

- Under summertime conditions, it can be seen from Figure 3.15 that the battery has moved to one cycle per day. This cycle involves charging during the day from excess solar and then discharging over the course of the evening, keeping the home virtually off grid during this time.
- The change in cycle pattern is driven largely by two factors. The first is that the control algorithm can recognize the cost advantage of charging from free solar is more beneficial than charging from the grid, even with cheap overnight rates. It therefore decides to save battery capacity for the upcoming solar, demonstrating a cost benefit of coordination between the battery and solar. The second driver is the absence of morning heating demand (or indeed other electrical demand to discharge the battery), thus the battery is not required to harness cheap overnight electricity in order to prevent import required for heating once the tariff becomes more expensive. This coordination between the battery and heat pump allows for more efficient operation of the battery, which again results in cost savings for the householder.

* The household imports only 4.76kWh of electricity over the three day period, but exports 34.8kWh of electricity in the same period. The percentage of household electricity consumption supplied by solar PV generation (and subsequent battery discharge) was as follows:
    - Day 1: 79%
    - Day 2: 90%
    - Day 3: 95%

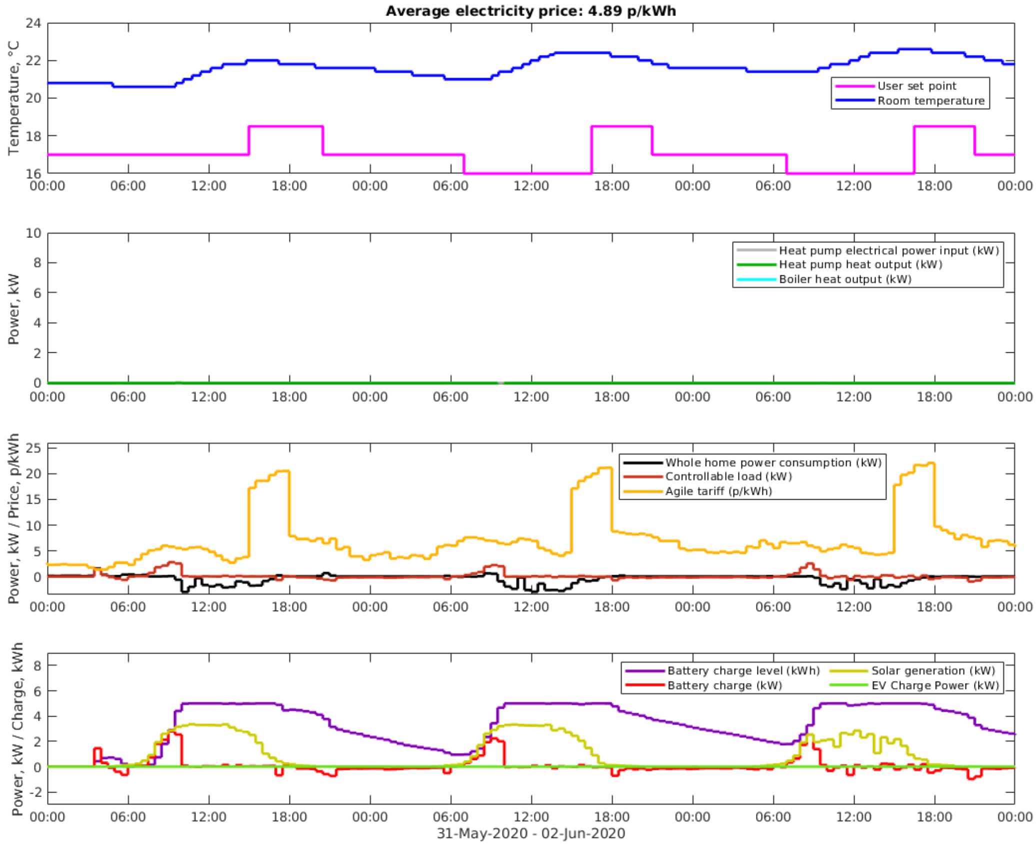


Figure 4: Summertime operation on Octopus Agile tariff (Home 1, 31/05/20 - 02/06/20)

Figure 5 below shows the average daily whole home power import profile over a one week period with high external temperatures and high solar generation on the Octopus Agile tariff for all five MADE homes. The average external temperature in this period was 16.5°C; an average of 20.4°C during the day (09:00 - 21:00) and 12.7°C overnight (21:00 - 09:00). Controllable load refers to heat pump plus domestic battery plus EV charging. The following can be observed from the figure:

* There is a good amount of solar generation across the MADE portfolio in the week considered.

- There is no heating demand during this summer period (nor any negative Agile pricing to incentivise demand).
- There was some EV charging activity but only on a few occasions (so the average power values shown here are not very meaningful).
- Homes tend to draw from the grid overnight and export to the grid during the day. Most of the homes tend to charge the battery using excess solar from 06:00, and then start to export around 10:00 when the batteries become full.
    - One of the homes (Home 2) has a particularly low household consumption, therefore the battery typically accumulates charge from excess solar on previous days and the export transition happens earlier in this home at around 08:00.
- The battery discharges over the course of the evening to offset demand with ‘free’ stored solar power. As solar generation continues across the Agile peak tariff period, the battery discharge during this time is lower than the Phase 2 example.
- Whole home power import remains low (or negative) throughout the day.

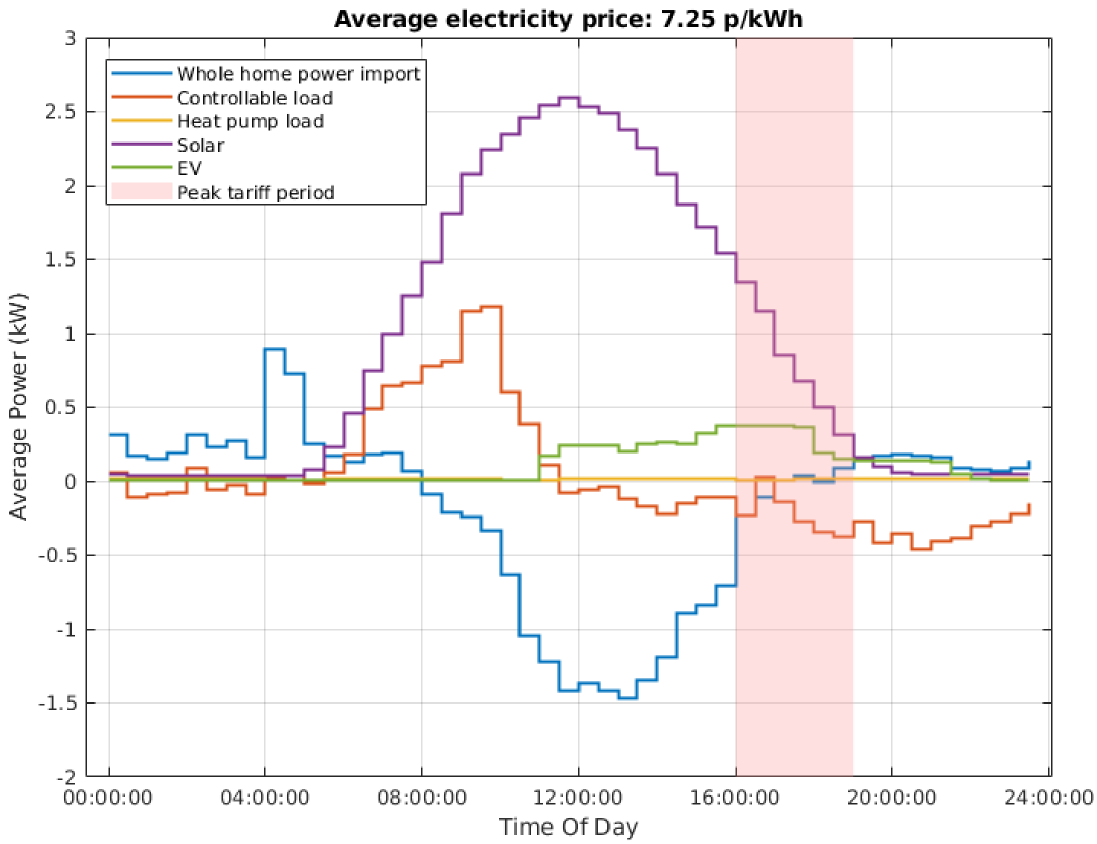


Figure 5: Average load profiles for summertime operation on Octopus Agile tariff (All homes, 25/05/2020 - 01/06/2020). Controllable load refers to heat pump plus domestic battery plus EV charge. Whole home power import = import from (/export to) the grid.

Phase 4: Octopus Go tariff

Figure 6 shows an example of typical summertime operation, with high external temperatures and high solar generation, under the Octopus Go tariff. The combination of solar PV and the battery holding excess for the evening keeps the home completely off-grid over almost all of this period, with significant net export of electricity, and little need for the cheap overnight electricity.

The following can be observed from the figure:

- There is no heating demand. The home stays well above set point without the need for use of the heat pump or boiler.
- The battery does a small amount of charging during the cheap overnight tariff period to meet early morning demand before solar kicks in. However the system recognises that that free solar is advantageous over cheap night time electricity rates.

- The household imports only 4.3kWh of electricity over the three day period, but exports 22.6kWh of electricity in the same period.

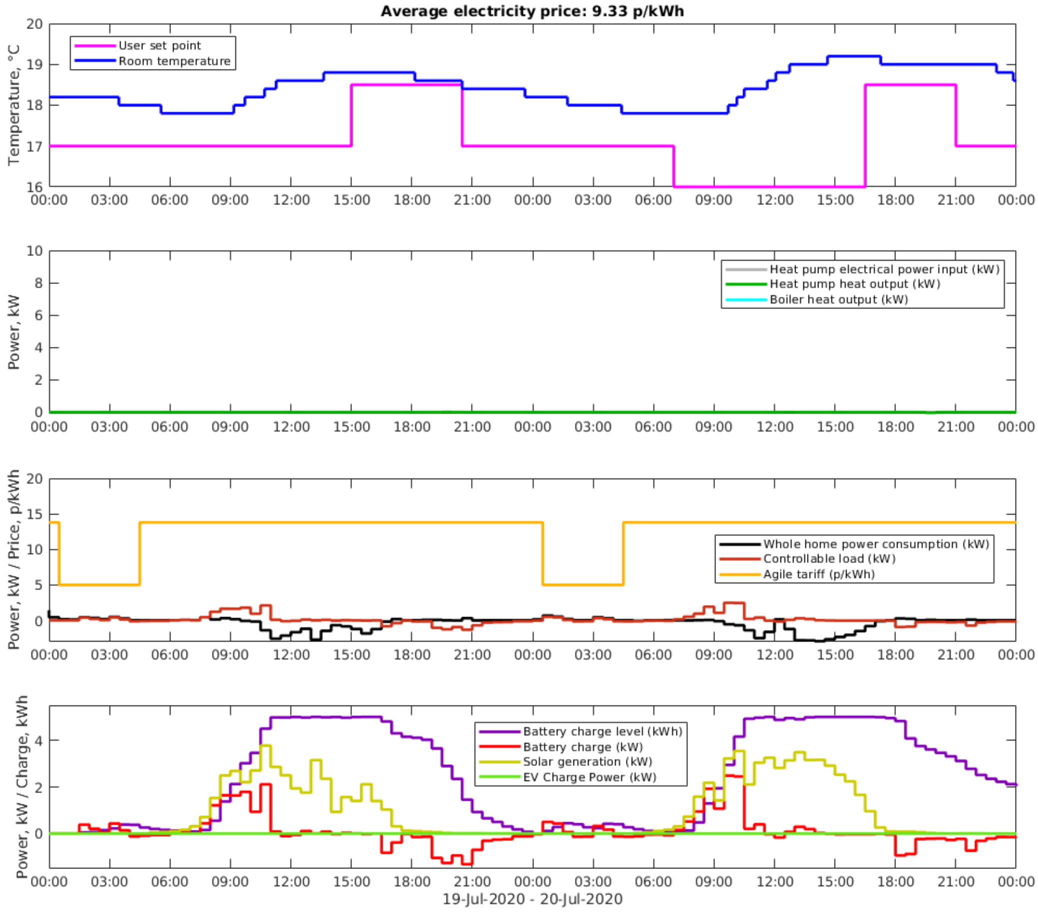


Figure 6: Summertime operation on Octopus Go tariff (Home 1, 19/07/20 - 20/07/20)

Figure 7: below shows the average daily whole home power import profile over a one week period with high external temperatures and high solar generation on the Octopus Go tariff for all five MADE homes. The average external temperature in this period was 15.3°C; an average of 17.4°C during the day (09:00 - 21:00) and 13.4°C overnight (21:00 - 09:00). Controllable load refers to heat pump plus domestic battery plus EV charging. The following can be observed from the figure:

- There is a good amount of solar generation across the MADE portfolio in the week considered.
- There is no heating demand during summer, as expected.
- Homes tend to draw from the grid during the cheap overnight tariff period and export to the grid during the day. Homes tend to charge the battery using excess solar from 06:00, and then start to export around 10:00 when the batteries become full. Some additional battery charging takes place during the cheap overnight tariff period.
- The battery discharges over the course of the evening to offset demand with ‘free’ stored solar power.

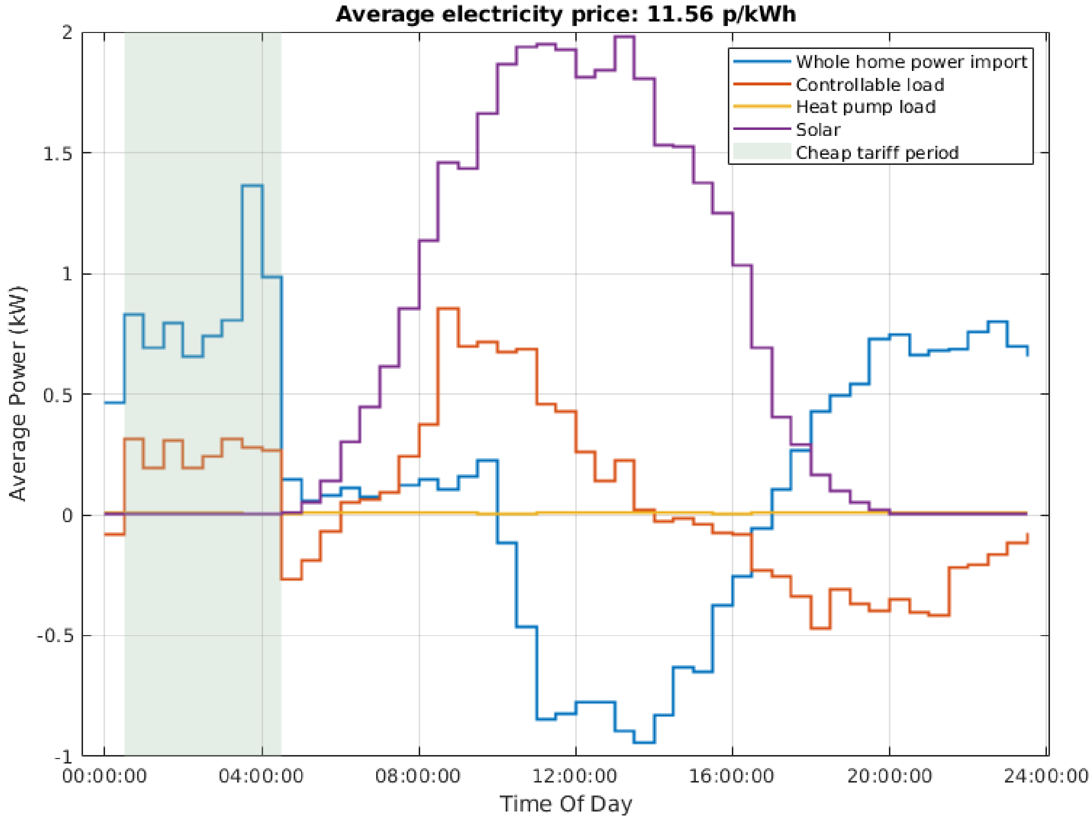


Figure 7: Average load profiles for summertime operation on Octopus Go tariff (All homes, 17/07/2020 - 23/07/2020). Controllable load refers to heat pump plus domestic battery plus EV charge. Whole home power import = import from (/export to) the grid.

Supporting simulation results

The work above 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). The simulation outputs were then analysed to provide insight into consumer cost savings, the impact of Flexible Power interventions, or the level of reduction of ToU tariff peaks.

Simulations have been carried out for different scenarios:

- **Day-ahead predictions with varying levels of asset control**: these focus on the predictive optimisation calculation within the Passiv controls 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.

Note that:

- Savings figures are still anecdotal as they apply only to the individual days analysed and should not be extrapolated to annual figures, but they will give a broad indication of the savings possible.

- Some randomisation is still present in the simulations (particularly for solar irradiation and electrical baseload) which gives some underlying variability.

Benefits of coordination - Optimisation output

This section of the report outlines how the optimisation output changes with increased layers of control. 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 8 below shows the optimisation output under the Phase 1 (baseline) control strategy (where the heat pump is coordinated with PV but not the battery or EV).
The following can be observed from the figure:

- 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.

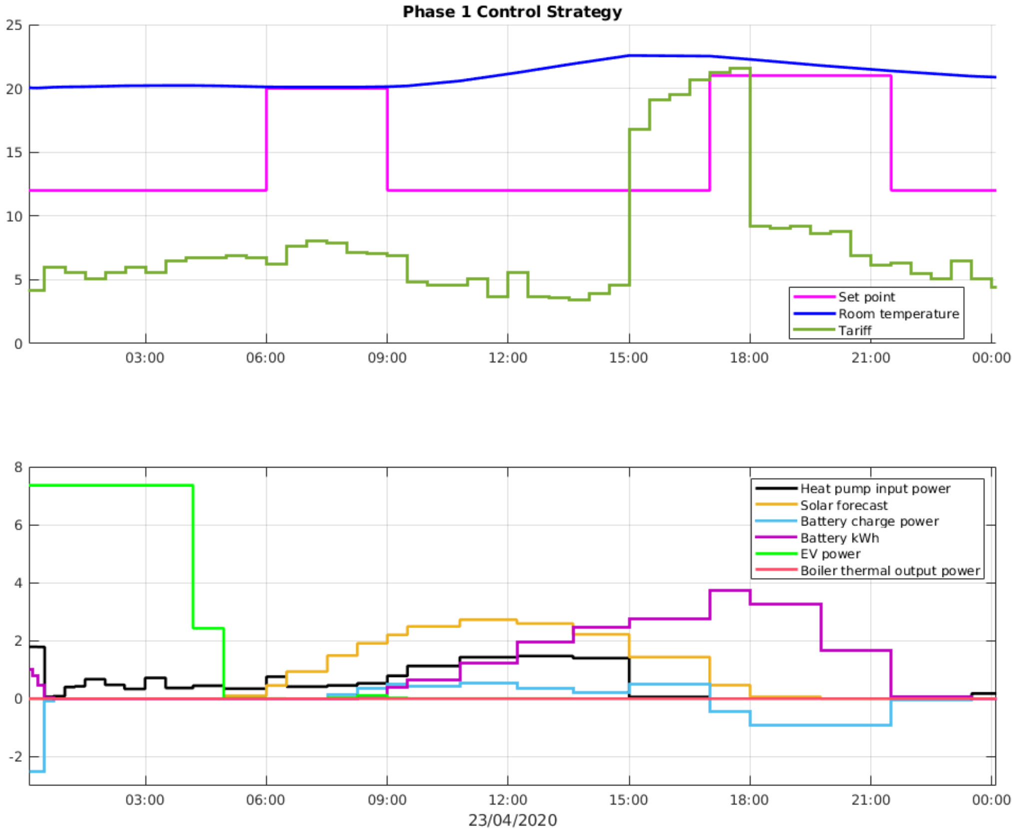


Figure 8: Optimisation output under Phase 1 control (Digital twin of Home 5, 23/04/2020)

Figure 9 shows the optimisation output under the Phase 2 control strategy where heat pump operation is coordinated with PV and battery but not yet the EV. The following can be observed from the figure:

- 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.

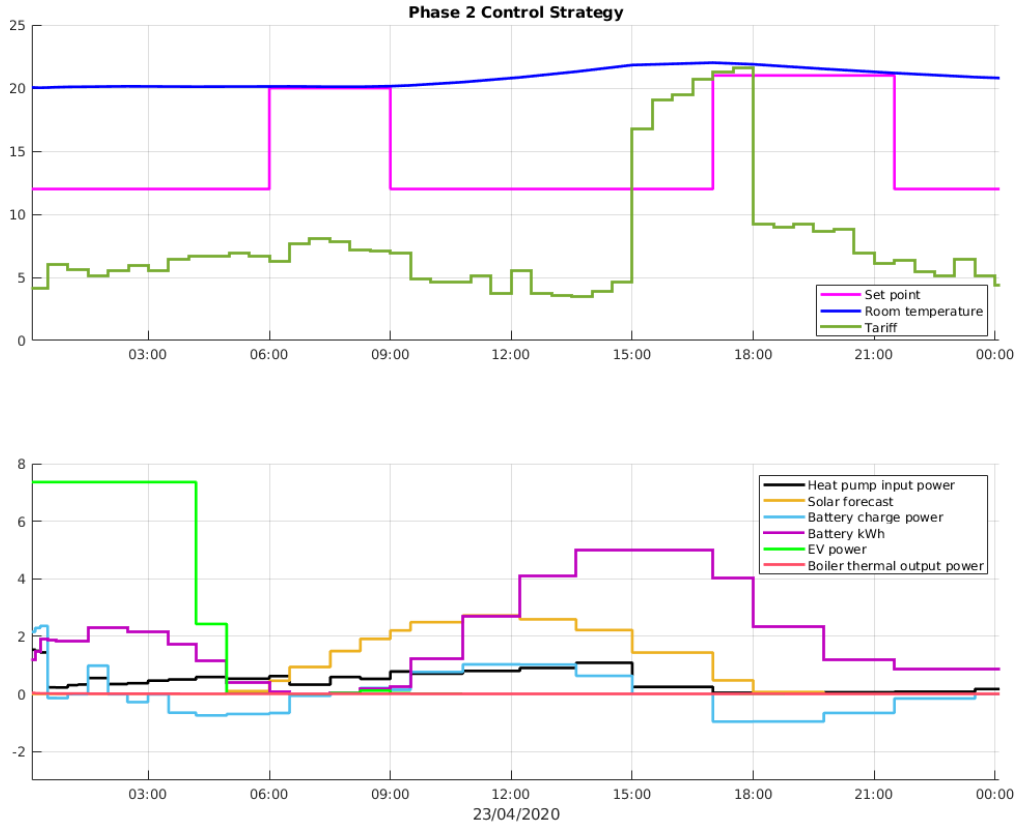


Figure 9: Optimisation output under Phase 2 control (Digital twin of Home 5, 23/04/2020)

Figure 10 shows the optimisation output under the Phase 3 control strategy where all assets including the EV charger are coordinated. The following can be observed from the figure:

- 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.

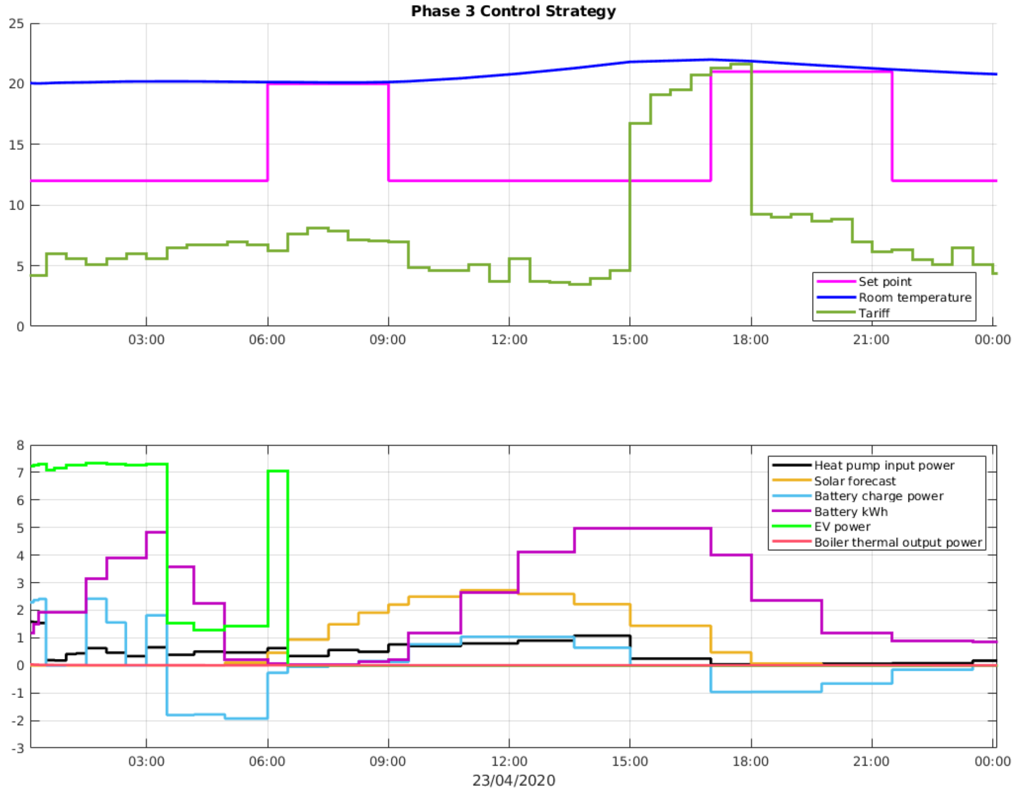


Figure 10; Optimisation output under Phase 3 control (Digital twin of Home 5, 23/04/2020)

Benefits of coordination - Full simulation runs

This section presents the results of using a digital twin of one of the MADE homes to investigate the benefits of asset coordination. These simulations used more detailed modelling than the previous section and were run over a longer time period (2 days). Comparative evaluations were made of householder running costs as the level of asset coordination within the home increases.

- The digital twin was of MADE Home 2;
- The home was assumed to be on the Octopus Agile tariff;
- The EV is assumed to be plugged in at 18:00 on the first day, requiring a full charge by 07:00 the following morning;
- Simulations were run for Winter, March, and Summer scenarios;
- A maximum room temperature increase of 2°C was assumed for heating.

Winter, March and Summer simulation runs were performed with both uncontrolled and smart EV charging. In the uncontrolled case the EV was assumed to charge as soon as it was plugged in, whereas in the smart case the EV charging was assumed to be delayed until midnight.

Table 1 shows the total cost over the two day period considered for each of these simulation runs.

	Winter	**March**	**Summer**
Baseline Control	8.76	5.82	4.21
Baseline Control, Smart EV Charging	6.92	4.09	3.21
Phase 2 Control	8.00	5.26	4.05
Phase 2 Control, Smart EV Charging	6.21	3.95	3.12
Phase 3 Control	5.95	3.72	2.92

Table 1: Total electricity cost on the Octopus Agile tariff across a two day period under various control strategies (£)

In Summary

- There is value in full coordination between all assets in the home, throughout the year. These results indicated that there may be more value from full coordination during the Winter than during the Summer however the variation is small and this may simply be due to the tariff on the particular days selected or due to randomisation in the simulation runs.
- There is notable value from EV charging control, particularly during the Winter simulation runs.
- There is much less benefit from Phase 2 control over Phase 1 control during the summer. This is expected largely due to the fact that there is unlikely to be heating demand during the summer and so there is no benefit to coordination between the heat pump and battery. This is also expected since during the summer the battery is generally fully charged entirely using free solar and thus this will happen whether or not additional demand is expected in the evening.

Next steps

The final interventions are being carried out. These were the ones delayed due to COVID and will filter into the final analysis.

2.2.6 Work Package 6: Technology, Customer and Network Analysis – Dissemination

Progress within this reporting period

During this reporting period, Work Package 6 focussed on the re- run of previous analysis, building on the output of the trial.

For example, In Imperial's previous modelling they quantified high-level system benefits of rolling out the MADE solution at the national level for several future system scenarios. Whole-system case studies presented in that report showed significant opportunities to deliver cost savings by utilising distributed flexibility based on the MADE concept.

This high-level assessment, however, did not take into account the specific features of distributed flexible resources deployed and trialled in MADE project, such as the actual sizes of battery storage, EV characteristics, installed power of solar PV and HP parameters for participating households (it rather used generic high-level assumptions for these parameters). Therefore, further analysis was conducted to provide a more detailed assessment of system-level benefits of large-scale uptake of the MADE concept, as well as put those in the context of likely cost required to enable flexibility from the assets included in MADE portfolio of residential flexibility.

System benefit of MADE concept

Whole-system benefits of MADE concept are quantified for four different levels of uptake of 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. In that respect, two counterfactual scenarios were considered, in order to estimate both upper and lower bounds of the system value of MADE:

- *Upper bound estimate*: counterfactual (baseline) scenario included flexibility in the form of 5 GW of large-scale battery storage connected to high-voltage distribution grids, and a moderate uptake of smart domestic appliances and flexible industrial and commercial (I&C) demand;
- *Lower bound estimate*: same baseline scenario as for the upper bound estimate but also including a high uptake of smart EV charging (but no V2G).

Any cost reduction achieved by deploying the MADE concept is interpreted as gross system benefit of MADE solution (not accounting for the cost of installing or deploying smart control or additional battery storage). This is expressed both as aggregate total benefits as well as benefit per participating MADE household, for both upper and lower bounds. The benefits are then combined with the estimated cost of enabling MADE to determine the net system benefits, both in aggregate terms and per participating household.

Assumptions on the number of households:

According to the latest data from the Office for National Statistics, there are 28.535 million dwellings in Great Britain, of which 14.748 million are detached, semi-detached houses and bungalows, while the rest are terraced houses and flats. Given that a full deployment of MADE concept will typically require a household with an opportunity to install an EV charger, rooftop PV, a hybrid heat pump system and a residential battery system, it was assumed that only detached houses, semi-detached houses and bungalows will have sufficient space to install a full range of LCTs that are included into the MADE concept. This is a simplifying assumption, but is still useful to quantify the system-level benefit of MADE.

Household energy assets:

Each MADE-eligible household was assumed to have installed the following LCTs: 1) a hybrid HP system, 2) rooftop PV generation, 3) two EVs (on average), and 4) a residential battery system (only if participating in MADE rollout). If a household had a MADE control system installed (i.e. if it was a part of the MADE rollout), its hybrid HP management, EV charging (including V2G) and battery control were assumed to be carried out with the objective to reduce the overall system cost. This was equivalent to assuming that flexible assets were used to provide services in a fully efficient and cost-reflective market for energy and grid services. EV charging control for vehicles in participating households also allowed for discharging the batteries i.e. providing V2G services if cost-efficient. If this was not the case, i.e. for non-participating households the utilisation of hybrid HP and EV was assumed to follow less efficient usage patterns, while residential batteries were not available.

Average ratings of energy assets were chosen to be representative of the parameters of the actual installations used in MADE field trials. Note that for some parameters diversified values were used given the diversified nature of electricity and heat demand patterns for a large number of households that is consistent with the whole-system model. The ratings used were:

- Hybrid heat pump: 8 kW_{th}
- PV generation: 4 kWp
- Electric vehicle: 40 kWh battery with 32 A (bidirectional) charger
- Residential battery: sonnen-type system with 5 kWh and 2.5 kW diversified peak output

Cost assumptions for residential flexibility:

The cost of purchasing hybrid HP systems and EVs were not included in the cost estimate of the MADE concept, as it was assumed that these purchasing decisions would be made regardless of whether a household opts to participate in MADE-type control or not.
On the other hand, the cost of installing residential battery storage and the cost of implementing the hardware and software required for smart control were assumed to be in direct correlation with the adoption of MADE concept, i.e. they were considered to represent the direct cost of enabling MADE.
The cost of residential battery storage systems was estimated based on Lazard's levelised cost of storage analysis. The following cost parameters were assumed:

- Capital cost per unit of power: £395/kW
- Capital cost per unit of energy: £197.5/kWh
- Total investment cost for 2.5 kW / 5 kWh battery: £987.5
- Lifetime: 20 years
- Cost of capital: 7%
- Annualised cost per household: £93.2/yr

The cost of implementing the MADE concept was assumed based on information obtained from PassivSystems, also accounting for the likely cost reductions if this solution is rolled out at scale. The assumed cost of smart control was as follows:

- Upfront cost of hardware, PassivSystems' hub and connectivity: £80 per household
- Service cost: £60 per household per year
- Equipment lifetime: 10 years
- Cost of capital: 7%
- Total annual cost of MADE control: £70.1

Therefore the total annual cost per MADE household, consisting of the cost of residential battery storage and the cost of implementing MADE control, is estimated at **£163.3 per year**.

Electricity system scenario:

The whole-system benefits of MADE concept in this report are assessed for a GB power system scenario that achieves a carbon intensity of 50 gCO_2/kWh in the 2035 time horizon. This scenario assumed a high uptake of EVs and HHPs in order to be able to assess a broad range of MADE uptake levels. A total of 37 million EVs was assumed on the system, of which 80% was assumed to be connected to MADE-eligible households. The number of hybrid HPs on the system was assumed to be one per MADE-eligible household, or 14.75 million in total.

Initial features of the system were assumed as follows:

- Variable renewables: onshore wind 29.5 GW, offshore wind 28.6 GW, solar PV 68.3 GW (of which 9.3 GW were large-scale PV and the remaining 59 GW were rooftop PV in MADE-eligible households)
- Nuclear: 7.9 GW
- CCS: 2 GW
- CCGT: 20 GW
- Other renewables: biomass 7.1 GW, hydro 1.7 GW, other 1.2 GW
- Interconnection: 20 GW
- Energy storage: pumped-hydro 2.7 GW, large-scale battery storage 5 GW (not including residential battery storage associated with MADE rollout)
- Demand-side response: 20% of DSR uptake was assumed in the baseline scenarios for the I&C sector, and for household appliances, while for the lower bound estimate the baseline scenario additionally included smart charging of the entire EV fleet (note that any MADE-enabled flexibility was additional to this)

In order to meet the 50 gCO_2/kWh target, as well as system security, the model was allowed to add more CCS, onshore and offshore wind, CCGT and OCGT capacity, as well as to expand interconnection capacity if cost-efficient.

Quantitative results

Due to the whole-system nature of the modelling approach, the resulting benefits will be 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 i.e. the cost of residential battery storage and smart control is also included in total system cost and net benefit figures.

Total system cost across the five scenarios (counterfactual plus four MADE uptake scenarios) is shown in Figure 11. The two charts correspond to upper and lower bound estimates, which differ on the assumption on EV charging in the baseline scenario (upper bound assumed non-smart EV charging, while lower bound assumed smart EV charging). Note 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.

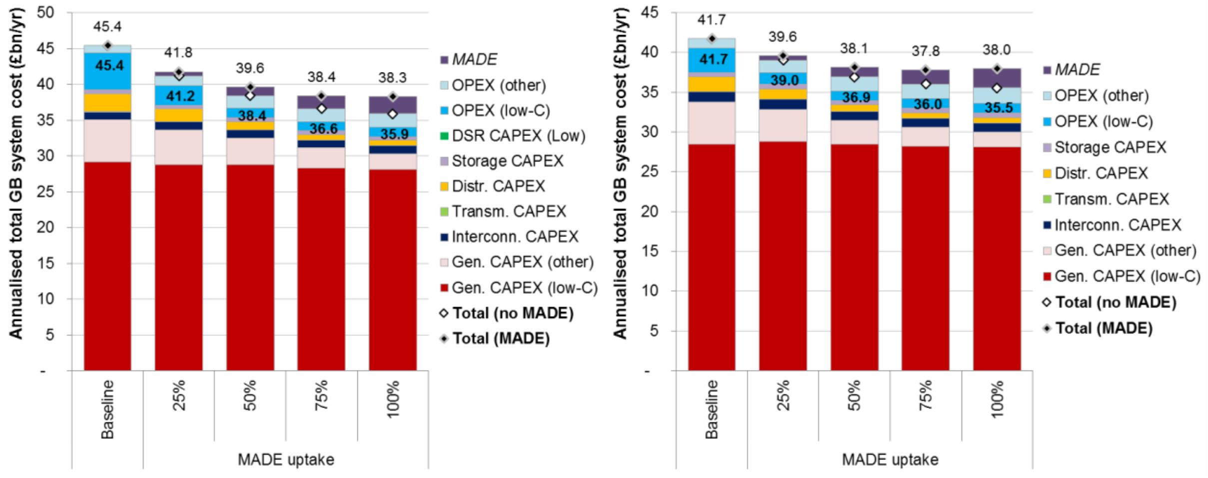
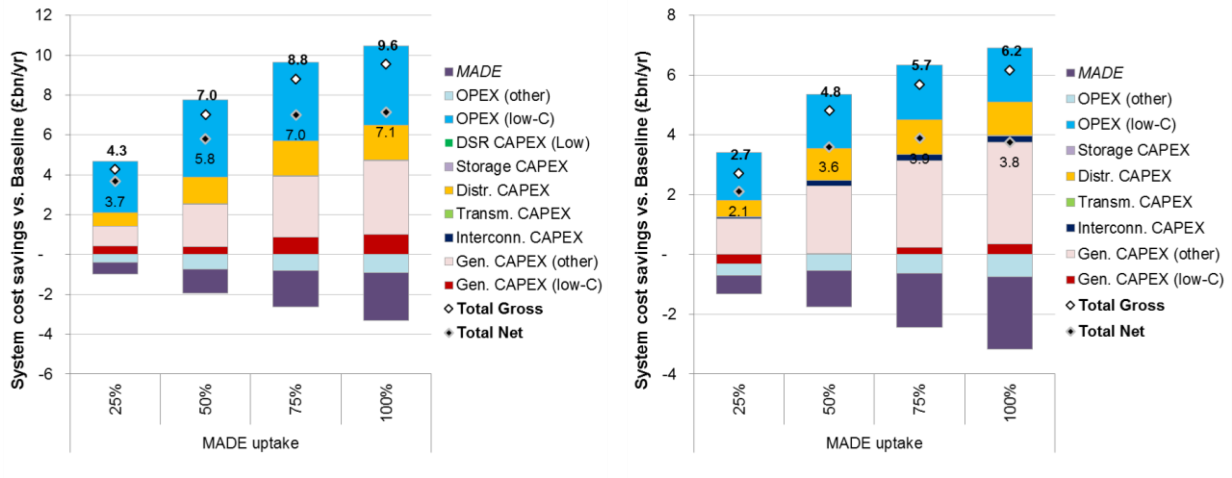


Figure 11: Total system cost across different MADE scenarios for upper bound (a) and lower bound (b) estimates

The majority of the system cost is associated with investment in low-carbon generation, with sizeable components associated with conventional generation CAPEX, generation OPEX, interconnection CAPEX and distribution network reinforcement cost. As expected, the overall system cost is lower in the lower bound estimate, i.e. with smart EVs included in the baseline. 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 very little 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's recent estimate for the total system cost in 2020 was around £27bn/yr. CAPEX of the existing assets base for 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 here 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 £0.7bn/yr in the scenario with 100% MADE uptake. However, note that the demand assumed for 2020 was significantly lower due to far lower electrification levels for heat and transport (it may therefore be more informative to compare the cost per kWh of electricity supplied). According to official statistics, the UK electricity demand in 2019 was 346 TWh (although the impact of COVID pandemic is likely to make 2020 demand significantly lower), and the assumed demand for the 2035 scenario with high electrification, as considered in this report, had the annual power demand of 505 TWh.

System benefits of a large-scale deployment of MADE concept across the four uptake scenarios can be found as differences between a given MADE uptake scenario and the relevant counterfactual (or baseline) scenarios for both upper and lower estimates, as shown in Figure 11 Cost savings are reported as annual values, consisting of annual operating costs and annualised investment costs for different asset types. As in Figure 12 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).



(a) (b)

Figure 12: System cost savings driven by MADE concept across scenarios for upper bound (a) and lower bound (b) estimates

The results suggest that the flexibility delivered via MADE solutions can achieve substantial system benefits in the order of billions of pounds per year, reaching almost £10bn per year in gross benefits for full MADE penetration in the upper bound estimate. Lower gross benefits are observed in the lower bound estimate, at around £6bn/yr for 100% 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. For the upper bound estimate the maximum net system value of £7.1bn/yr is observed, while in the lower bound estimate the highest observed system value of MADE is £3.9bn/yr.

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. 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;

Figure 13 shows the average system value of MADE per participating household, obtained as total system benefit divided by the number of participating MADE-enabled homes. The value is shown as both gross and net system value, where the latter also includes the cost of enabling MADE. Also, both upper and lower bound estimates are given in Figure 13 to account for the possible presence of smart EV in the baseline scenario.

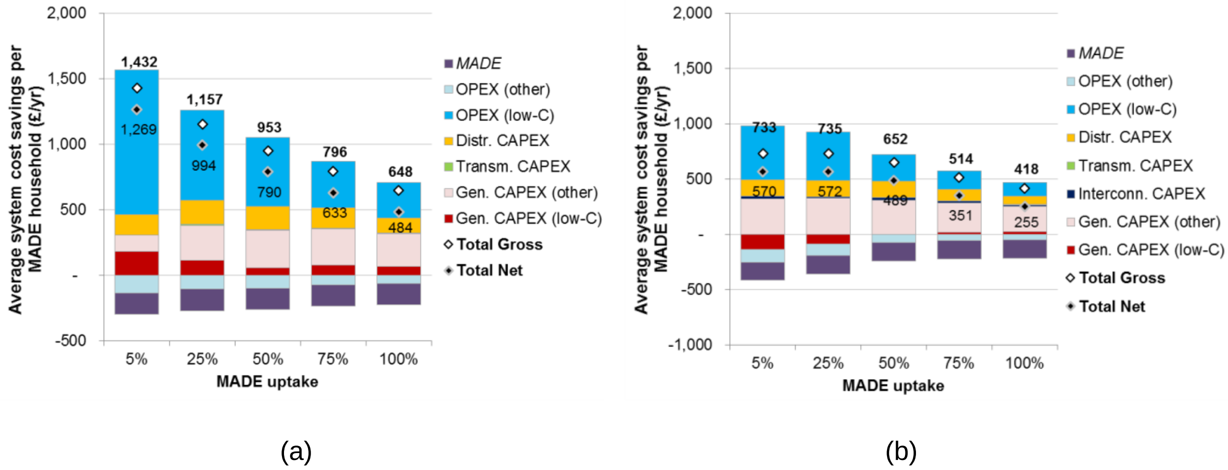


Figure 13: System cost savings per participating MADE household for upper bound (a) and lower bound (b) estimates

Gross cost savings are the highest at low penetrations of MADE concept, and vice versa. At a low MADE penetration of just 5% the gross value is estimated at £1,432 per participating household per year at the upper bound and £733 at the lower bound. However, these values diminish as the number of participating households increases: for a full (100%) penetration, the average benefit per household drops to between £418 (lower bound) and £648 (upper bound) per MADE household per year. If the cost of MADE is deduced from gross benefits to quantify net benefits, the value to the system reduces by £163 per household, which is the annualised cost of installing the necessary equipment as discussed. Nevertheless, even after subtracting the cost of MADE the average net value is still positive even at the highest MADE uptake levels.

Next steps

Final work is being concluded on the re-run Everoze work. Alongside the analysis from Imperial College, this will feed into the final report.

3 Progress Against Budget

The project has progressed well against the budget and is currently tracking a slightly lower spend than expected. Table 3-0 summarises the details of the progress that has been made with respect to the project budget.

Table 3-0: Project finances

Spend Area	Budget (£k)	Expected Spend to Date (£k)	Actual Spend to Date (£k)	Variance to expected (£k)	Variance to expected %
WPD Project Management	£81,221	£58,869	£56,826	£2,043	3%
PassivSystems costs	£1,357,000	£1,352,435	£1,327,458	£24,977[2]	2%
Contingency	£116,825	£0	£0	£0	0%
TOTAL	**£1,555,046**	**£1,411,304**	**£1,384,284**	£27,020	2%

Comments around variance

1. The total expected spend was re-baselined to £62,430 following lower than expected resource usage in the initial stages of the project.
2. Some deliverables have been delayed and have not been invoiced yet.

4 Progress Towards Success Criteria

Good progress has been made on the Success Criteria within this reporting period, with the data coming from the trial feeding into their progress. Table 4-0 presents the progress towards the project objectives as documented in the MADE Project Registration and PEA document.

Table 4-0: Progress towards project 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 4-1presents the progress towards the success criteria as documented in the MADE Project Registration and PEA document.

Table 4-1: Progress towards 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.	**In progress:** WPD, PassivSystems and the project partners have presented at a number of events and the project has been referenced in several publications. This is the key focus of the next reporting period.

5 Learning Outcomes

Within the project to date we have created the following learning:

- Because EV charging session notifications are only sent once, if the hub goes offline we need to know whether a charge session is still in place once it comes back online. Logic has been added to use power values sent by the EV charger to deduce whether or not a session in place after the hub has gone offline.
- We have seen examples of homes overheating when there is lots of excess solar or negative electricity prices. MADE2 in particular displayed clear examples of overheating due to excess solar on 4th, 6th and 7th April. After this point a temperature limit was placed on the home which has reduced the amount the home will overheat by.
- "During winter on the Agile tariff the battery was 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. As we are moved towards increased solar and warmer temperatures (little heating demand) the battery has moved back to one cycle per day. Charge using excess solar and discharge over the course of the evening
- We have successfully demonstrated that the optimisation produces a sensible output for Secure (advanced notice) and Dynamic (no advanced notice) style flexible power interventions.
- Successful examples of alternately charging and discharging the battery like an accordion to varying tariff to help meet EV load using cheapest possible electricity
- Simulations run over real days have shown the impacts of different control regimes over the same days and show the relative cost impact of going from no smart control, to uncoordinated smart control, and then to fully optimised control.
- The analysis of consumer benefits was carried out based on quantifying marginal benefits available to participating households, assuming a perfectly efficient market. The results show a relatively high level of benefit available to early adopters of the MADE concept, at the level of more than £1,400 per year, while at 50% penetration this reduces to around £600 per year and further to below £200 at 100% penetration of MADE solution."

  Imperial's high-granularity distribution network analysis suggests that there is also a significant potential for distributed flexibility to deliver distribution network cost savings across different voltage levels and asset types, potentially exceeding £1bn per year in avoided reinforcement cost in the 2030 horizon."

6 Intellectual Property Rights

Table 6-0 presents a complete list of all IPR generated within the reporting period from all project partners. The IP register is reviewed on a quarterly basis.

Table 6-0: IPR generated within this project reporting period

IPR	Category	Owner
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

7 Risk Management Current Risks

Our risk management objectives are to:

- Ensure that risk management is clearly and consistently integrated into the project management activities and evidenced through the project documentation;
- Comply with WPDs risk management processes and any governance requirements as specified by Ofgem; and
- Anticipate and respond to changing project requirements.

These objectives will be achieved by:

- Defining the roles, responsibilities and reporting lines within the Project Delivery Team for risk management;
- Including risk management issues when writing reports and considering decisions;
- Maintaining a risk register;
- Communicating risks and ensuring suitable training and supervision is provided;
- Preparing mitigation action plans;
- Preparing contingency action plans; and
- Monitoring and updating of risks and the risk controls.

7.1 Current Risks

The MADE risk register is a live document and is updated regularly. There are currently 18 live project related risks. Mitigation action plans are identified when raising a risk and the appropriate steps then taken to ensure risks do not become issues wherever possible. In Table 7-0, we give details of our top five current risks by category. For each of these risks, a mitigation action plan has been identified and the progress of these are tracked and reported.

Table 7-0: Top five current risks (by rating)

Details of the Risk	Risk Rating	Mitigation Action Plan	Progress
Final reports are delayed due to PassivSystems resource constraints	Major	Clear communication of expectations and resource allocated	A draft report has been created
Final reports are delayed due to delays from partner reports	Major	Clear communication of expectations	Some partner reports were delayed. These delays were managed
The trial interventions by PassivSystems may increase the customer's bills. There is the slim possibility that the controls may have bugs and effect the homeowner's usage.	Moderate	A well-defined engagement plan.	This has not been seen to date
Loss of data through customer disconnection of broadband	Moderate	A well-defined engagement plan.	Daily data checks and intervention reviews.
Final reports are delayed due constraints on WPD	Moderate	Resource allocated	Reviews are underway

review resource			

Table 7-1 provides a snapshot of the risk register, detailed graphically, to provide an on-going understanding of the projects' risks.

Table 7-1: Graphical view of Risk Register

Likelihood = Probability x Proximity	Certain/Imminent (21-25)	**0**	**0**	**0**	**0**	**0**
	More likely to occur than not/Likely to be near future (16-20)	**0**	**0**	**0**	**0**	**0**
	50/50 chance of occurring/Mid to short term (11-15)	**0**	**0**	**2**	**0**	**0**
	Less likely to occur/Mid to long term (6-10)	**0**	**7**	**4**	**0**	**0**
	Very unlikely to occur/Far in the future (1-5)	**1**	**3**	**3**	**1**	**0**
		1. Insignificant changes, re-planning may be required	2. Small Delay, small increased cost but absorbable	3. Delay, increased cost in excess of tolerance	4. Substantial Delay, key deliverables not met, significant increase in time/cost	5. Inability to deliver, business case/objective not viable
		Impact				

	Minor	Moderate	Major	Severe	
Legend	**14**	**5**	**2**	**0**	**No of instances**
Total	**21**				No of live risks

Figure 7-0 provides an overview of the risks by category, minor, moderate, major and severe. This information is used to understand the complete risk level of the project.

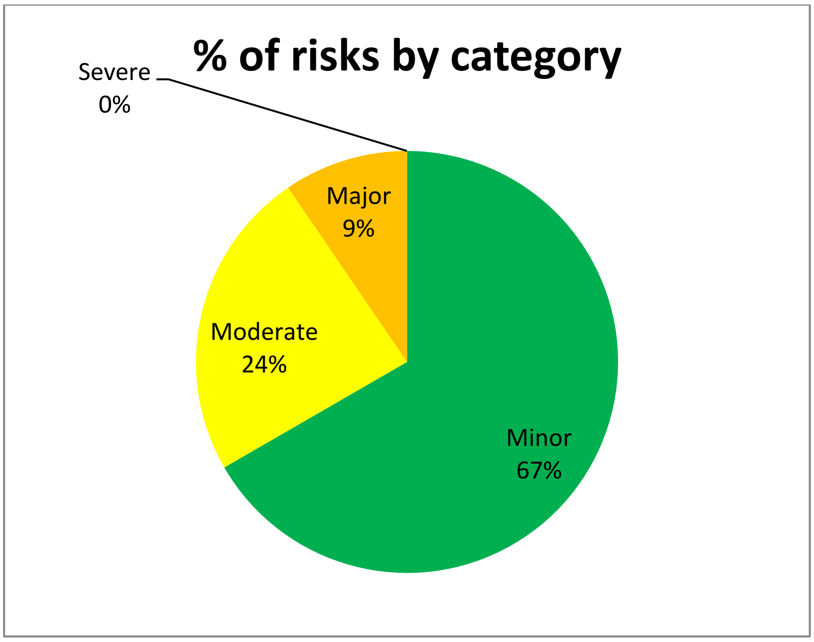


Figure 7-0: Percentage of Risk by category

7.2 Update for risks previously identified

Descriptions of the most significant risks, identified in the previous six monthly progress report are provided in Table 7-2 with updates on their current risk status.

Table 7-2: Risks identified in the previous progress report

Details of the Risk	Previous Risk Rating	Current Risk Rating	Mitigation Action Plan	Progress
Participants request to leave the trial early	Minor	Clear focus on customer needs. Clear customer engagement plan	Clear focus on customer needs. Clear customer engagement plan	Drop in likelihood and impact and the trial draws to an end
COVID 19 related risk	Minor	Detailed is captured in a specific COVID-19 RAID log	Detailed is captured in a specific COVID-19 RAID log	Drop in likelihood and impact and the trial draws to an end
The trial interventions by PassivSystems may increase the customer's bills. There is the possibility that the controls may have bugs and effect the homeowner's usage.	Moderate	A well-defined engagement plan.	A well-defined engagement plan.	Updating the trial participants with their energy use.
Customers interfere with controls	Moderate	A well-defined engagement plan. This will include clear instructions on what should and should not be	A well-defined engagement plan. This will include clear instructions on what should and should not be	Risk likelihood reduced

		adjusted.	adjusted.	
Loss of data through customer disconnection of broadband	Moderate	A well-defined engagement plan. This will include clear instructions on what should and should not be adjusted.	A well-defined engagement plan. This will include clear instructions on what should and should not be adjusted.	Daily data checks and intervention reviews.

8 Consistency with Project Registration Document

The scale and cost of the project has remained consistent with the registration document, a copy of which can be found here. The timeframe has been extended to allow for more testing in a heating season, following the impact of COVID 19 lockdown on asset usage patterns. This change was managed in accordance to WPD Innovation change management procedures.

9 Accuracy Assurance Statement

This report has been prepared by the PassivSystems MADE Project Manager (Tom Veli), reviewed by the WPD Project Manager (Matt Watson), and approved by the Innovation Team Manager (Yiango Mavrocostanti).

All efforts have been made to ensure that the information contained within this report is accurate. WPD confirms that this report has been produced, reviewed and approved following our quality assurance process for external documents and reports.

10 Glossary

Abbreviation	Term
BAU	Business as usual
BEIS	Department for Business, Energy and Industrial Strategy
CCC	Committee on Climate Change
DNO	Distribution Network Operator
DSO	Distribution System Operator
DUoS	Distribution Use of System
EV	Electric Vehicle
GB	Great Britain
HHP	Hybrid Heat Pump
HP	Heat Pump
HV	High Voltage
IPR	Intellectual Property Register
LCT	Low Carbon Technologies
LRE	Load Related Expenditure
LV	Low Voltage
MADE	Multi Asset Demand Execution
NIA	Network Innovation Allowance
NPV	Net Present Value
PV	Photovoltaic
V2G	Vehicle to Grid
WeSIM	Whole-electricity Scenario Investment Model
WPD	Western Power Distribution

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