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A final report estimating whole-energy system benefits of large-scale deployment of MADE concept.

July 2019

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1. Introduction

While it is expected that the bulk of future electricity will be provided through large-scale investment in low-carbon generation and flow from the transmission network to end users, the provision of flexibility and resilience will increasingly move to distributed energy sources provided by end consumers – who will be transformed from passive consumers to active prosumers. By exploiting the flexibility of emerging DERs, it will be possible to achieve very significant cost savings relative to a system that continues to rely on conventional generation to deliver flexibility and security of supply.

The MADE project is investigating the network, consumer and broader energy system implications of high-volume deployment of the combination of domestic vehicle to home (V2H) EV charging with hybrid heating systems with solar PV generation and battery storage. The main device for delivering the benefits of residential flexibility is the application of PassivSystems' smart aggregation and predictive control solution that ensures cost-efficient outcomes for the end customers while meeting their comfort level requirements.

2. Large-scale deployment

To facilitate the roll-out of a MADE concept large scale trial, new policies would need to be developed to consider the demonstrated lesser impact of combined asset control on the network allowing the connection of more LCTs at a lower cost, helping to bring forward the UKs low carbon ambitions. A large-scale trial would investigate the wider system benefits of coordinated control and inform suppliers, heart pump manufacturers, vehicle manufacturers relevant parties. The combination of network benefits pushed to the market by DNOs, alongside the wider benefits pushed by third parties, should act as a driver for adoption. Scrutiny from the MADE project partners would ensure that the project outputs are accessible, relevant, practical and easily deployable.

Imperial's Whole-electricity System Investment Model (WeSIM) has been used to estimate the whole-system benefits of the MADE concept to support the development of a business case for a large-scale trial. Distribution network reinforcement costs have been estimated using Imperial's Load Related Expenditure (LRE) model, based on detailed modelling of statistically representative networks calibrated against actual GB DNO networks.

An assessment for a large-scale deployment trial of the MADE concept has estimated the whole-system benefits for plausible GB power system scenarios in both the short (around 2030, with approximately 100 gCO2/kWh carbon intensity) and long-term (around 2050, with fully decarbonised energy supply). Distribution network implications are quantified in detail by assessing the avoided network reinforcement cost across all DNO areas in GB as well as for areas managed by WPD. Through the implementation of the MADE methods across GB, the benefits that would be delivered are summarised in the table below and detailed in Appendix 10.1 and 10.5.

🌍	**Carbon Savings (2050)**	
	WPD Roll-out (4 Licence Areas) **62.49m tonnes of CO2**	GB Roll-out (14 Licence Areas) **239.4m tonnes of CO2**
£	**Financial Savings (2050)**	

	WPD Roll-out (4 Licence Areas)	GB Roll-out (14 Licence Areas)
	£939m	**£ 3,596m**

Table 3.1: **Annual benefits generated by the MADE concept:**

3. System benefits of a large-scale deployment of MADE in the 2030 horizon

The benefits of the MADE concept in the short-term have been assessed by focusing on the 2030-time horizon, with the power system achieving approximately 100 gCO2/kWh carbon intensity, and for two scenarios regarding the EV and HHP uptake, Baseline and High Uptake, based on the CCC scenarios. Baseline scenario assumed 12.2 million EVs and no HHPs in 2030 (with about 2.2 million electric HPs), while the High Uptake scenario assumes 23.9 million EVs and 3.9 million HHPs.

The benefits of a large-scale deployment of the MADE concept are found by evaluating the value of unlocking the potential of coordinated domestic flexibility control. 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.

System benefits of a large-scale deployment of MADE in the GB power system reflecting the expected evolution until 2030 are shown in Figure 3.1. Cost savings are reported as annual values, consisting of annual operating costs and annualised investment costs for different asset types. The results from the modelling of NIA projects (Freedom, SoLa Bristol and Electric Nation) suggest that the flexibility delivered via MADE smart aggregation solutions can achieve system benefits of between £3.9bn and £4.1bn per year. These figures omit costs of implementation and levels of participation which are addressed.

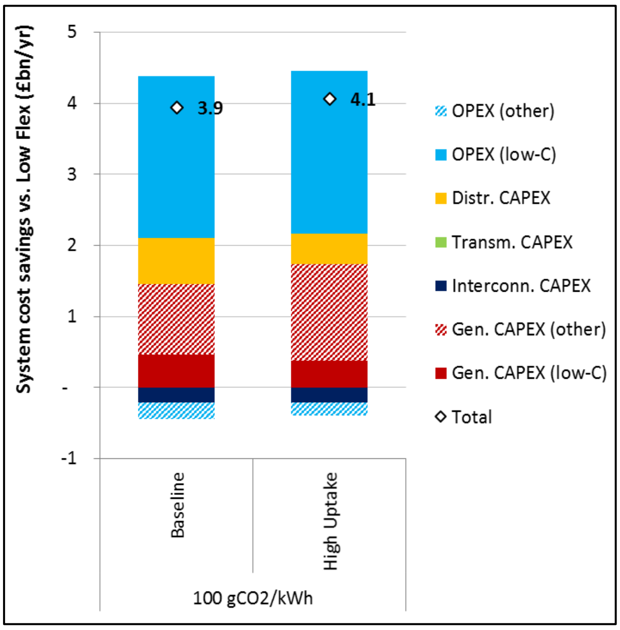

Figure 3.1: **System cost savings driven by MADE concept in 100 gCO2/kWh scenario.**

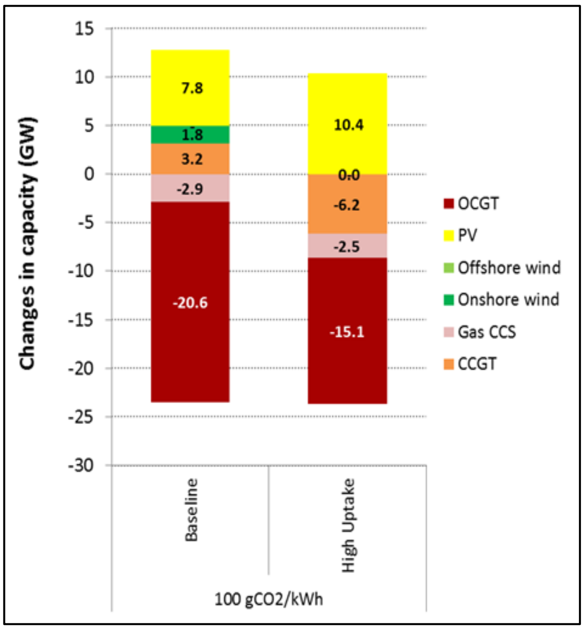

Figure 3.2: **Changes in generation mix driven by MADE concept in 100 gCO2/kWh scenario.**

The main categories of cost savings from the MADE Concept include:

- Reduced investment cost of low-carbon generation: distributed flexibility allows cheaper sources of low-carbon electricity to be integrated more efficiently, and displace other low-carbon sources;
- 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;
- Reduced investment cost of distribution networks: highly distributed flexible resources can help reduce the loading level of local distribution grids and decrease the requirements to reinforce distribution grids in order to cope with an increase in electricity demand;
- Reduced operating cost of low-carbon generation: flexibility can also displace the output of low-carbon generation with relatively high operating cost, e.g. biomass;
- Reduced cost of seasonal demand management: decarbonising heat will add a significant seasonal element to future demand.

Figure 3.2 illustrates how the additional flexibility unlocked through MADE affects the cost-optimal generation mix and delivers a more cost-effective portfolio of low-carbon and conventional generation technologies. MADE allows for more low-cost solar PV to be connected to the grid, as its integration becomes less challenging, whilst displacing the more expensive CCS generation. The total capacity of conventional generation (OCGT and CCGT) is significantly reduced as the result of enhanced flexibility, which also serves to reduce the level of peak demand in the system.

4. Distribution network benefits

Significant distribution network reinforcements could be needed to accommodate rapid uptake of EVs and HHPs. Its effect could increase the total cumulative expenditure on distribution networks by up to £50bn by 2035.

In order to assess the GB distribution network reinforcement requirements driven by heat and transport electrification and the related impact of distributed flexibility in the same 100 g/kWh scenario, the LRE model has been run to investigate the implications of high EV and HHP uptake on necessary network upgrades across different voltage levels, asset types and DNO areas.

Figure 3.3 shows the effect of MADE-enabled flexibility on annualised GB network reinforcement cost for the scenarios analysed in this report. Cost savings in Figure 3.3 are broken down according to asset types, voltage levels and reinforcement drivers as follows:

- LV-I: low-voltage network reinforcement driven by thermal loading
- LV-V: low-voltage network reinforcement driven by voltage constraints
- DT: Distribution Transformers
- HV-I: high-voltage network reinforcement driven by thermal loading
- HV-V: high-voltage network reinforcement driven by voltage constraints
- PS: Primary Substations
- EHV+: Extra High Voltage
- GT: Grid Transformers

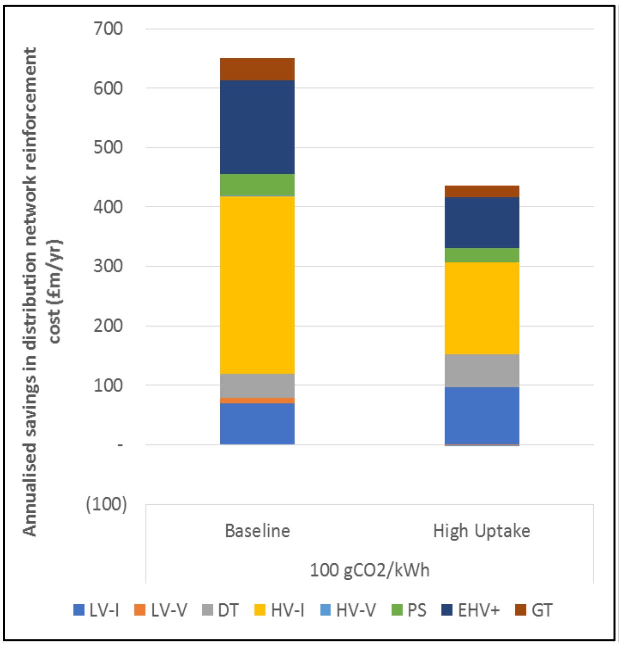

Figure 3.3: **Breakdown of annualised savings in network reinforcement cost driven by a large-scale deployment of the MADE concept for all GB DNOs across voltage levels and asset types.**

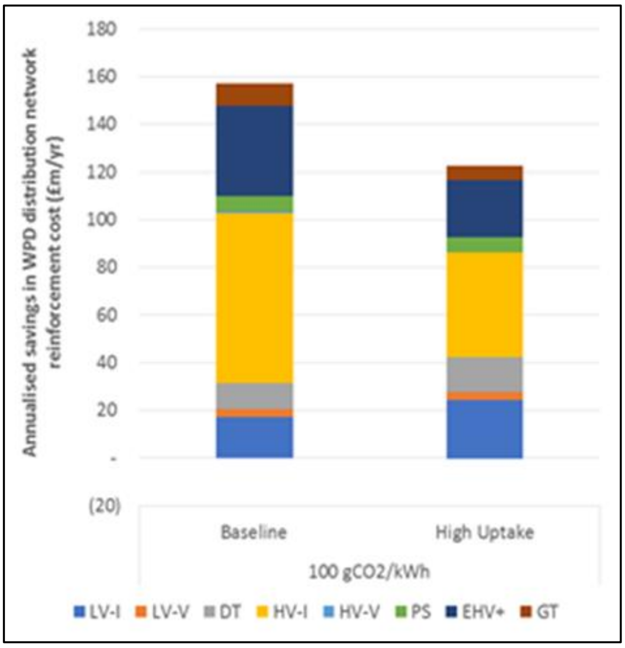

Figure 3.4: **Breakdown of annualised savings in network reinforcement cost driven by a large-scale deployment of the MADE concept for WPD DNO areas across voltage levels and asset types.**

The results show that the distribution network benefits of distributed flexibility around 2030 can reach up to around £650m per year in annualised reinforcement cost, and are spread across LV, HV and EHV levels. Reinforcement cost savings diminish to around £435m per year at higher penetrations of EVs and HHPs assumed in that time horizon, given that for High Uptake energy requirements become a more prominent driver for reinforcements than power requirements.

Figure 3.4 shows the breakdown of annualised savings in network reinforcement cost driven by MADE for WPD DNO areas across voltage levels and asset types. Net benefits for the WPD network in 2030 are estimated at between £122m and £157m per year.

5. Long term system benefits of a large-scale deployment of the MADE concept

In the context of full co-decarbonisation of electricity, heat and transport sectors in 2050 (zero carbon emissions), deploying at scale the MADE based flexibility will play a major role in supporting the integration of low-carbon generation technologies leading to significant reduction in the cost of decarbonisation. The cost of a future GB energy system with fully flexible EVs and HHPs is £18bn/year lower than the cost of the inflexible system as shown in Figure 3.5.

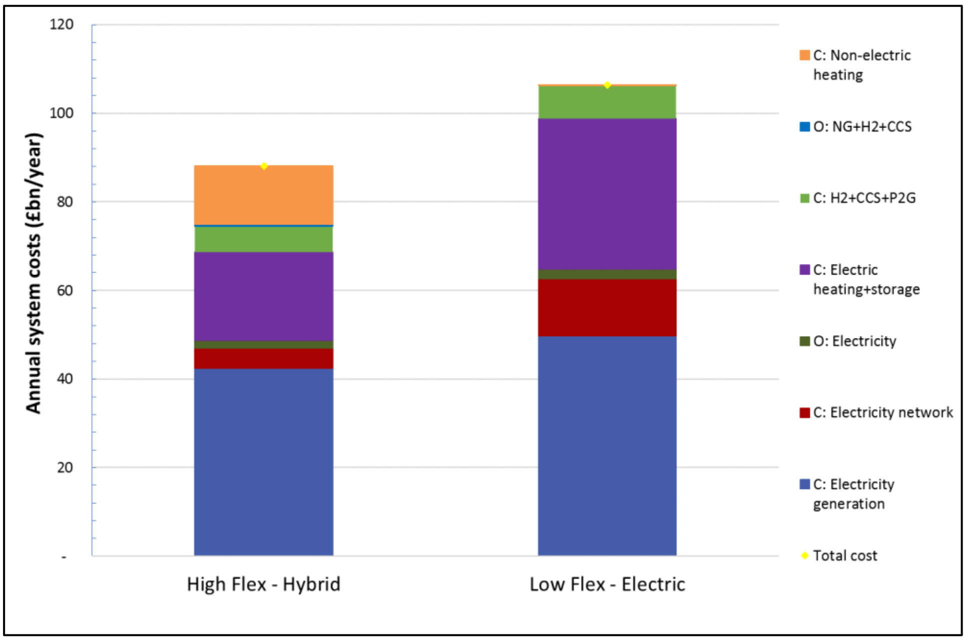

Figure 3.5: **Savings from integrated heat and electricity system operation paradigm.**

The results demonstrate that MADE based flexibility will reduce the capital cost of electricity generation, electricity network, electric heating, although the cost of non-electric heating (i.e. gas-based heating infrastructure) is larger.

Figure 3.6 shows the optimal generation portfolios for a system with low and high flexibility in order to demonstrate the impact of flexibility provided by smart EVs and HHP including thermal storage, etc. on the ability of the system to accommodate low-cost variable low-carbon generation. The low-flexible system will require a higher capacity of nuclear generation in order to provide firm low-carbon generation to meet the carbon target than the high-flexible system. Improving flexibility will allow significant increase particularly in the capacity of solar PV.

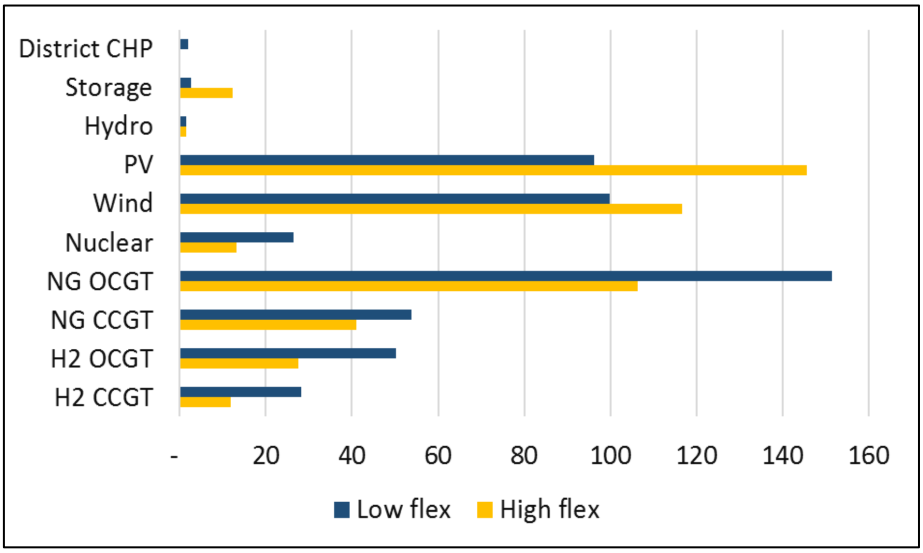

Figure 3.6: **Flexibility enhances the system ability to accommodate low-cost variable low-carbon generation**

6. MADE – consumer benefits - towards customer choice-driven system development

Given the very significant size of potential savings enabled by MADE based end-use flexibility, consumers should be allowed to modify their energy usage according to market forces. Our analysis suggests that in a future low-carbon electric system, the energy bill of a flexible consumer would be 50% of the energy bill of an inflexible consumer, although they both would consume the same total amount of energy.

Two examples of the benefits related to flexible end-use assets are illustrated below. Figure 3.7 shows how the application of controlled charging of EVs can reduce the emissions associated with the electricity supplied to the vehicles in the 2030 UK system for 15% penetration of EVs. Reduction in carbon emissions through smart charging of EVs is driven by improved load factors of low-carbon generation and reduced renewable generation curtailment. Fully smart control would enable EVs to provide primary frequency response by injecting power back into the grid in case of a plant outage. This solution would make the carbon emissions driven by very flexible EVs negative, given improved efficiency due to reduced requirement for conventional generators to provide frequency regulation services, which also reduces the curtailment of renewable generation.

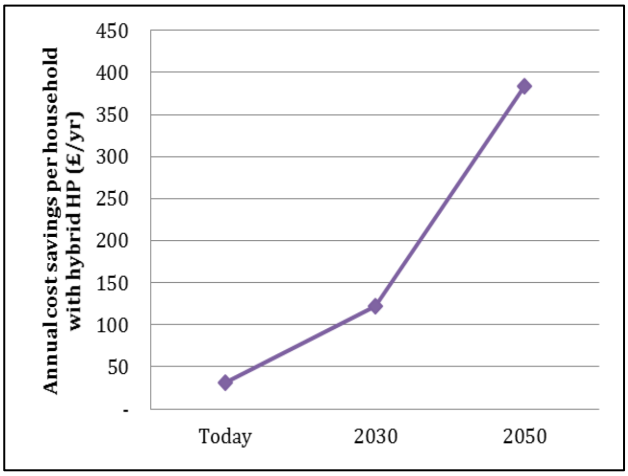

Figure 3.7: **Impact of EV control technologies on carbon emissions.**

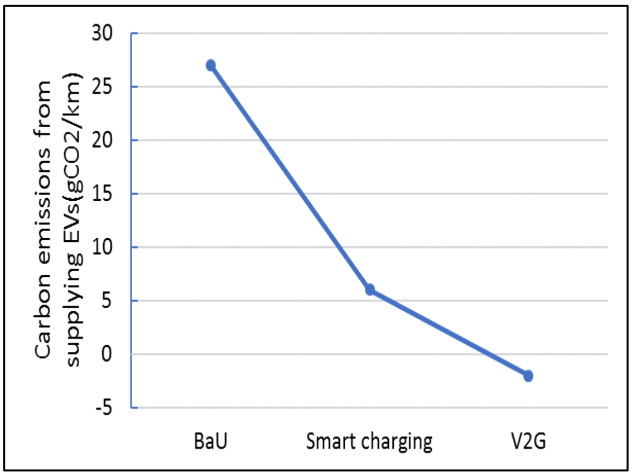

Figure 3.8: **Annual cost savings per household driven by smart operation of hybrid heat pump.**

Another example shown in Figure 3.8 demonstrates that the consumer benefits of smart control of domestic hybrid heat pumps (HHPs) that are optimally controlled to maximise the benefits of delivering system-balancing and network services, while not compromising consumer comfort. In this example it is assumed that 50% of domestic consumers have adopted smart control of their HHPs.

Although the value of flexibility in the current system is relatively modest, with an accelerated uptake of renewable generation and electrification of transport and heat sectors in the 2030-2050 time-horizons, smart control of end-use appliances could generate very significant reductions in consumer bills, while still delivering the same comfort levels to end users.

7. Appendix 1: Benefits Tables

Table 7.1: Financial Benefits

Cumulative Net Financial Benefit					
Scale	**Method Cost (£m)**	**Base Case (£m)**	**2030 (£m)**	**2040 (£m)**	**2050 (£m)**
Post-Trial Solution (Individual Deployment)	1.872	0	0.0140	0.0325	0.0582
Licensee Roll-Out Scale(If applicable, indicate the number of relevant sites on the Licensees" Network)	5,315	0	74	299	939
GB Roll-Out Scale(If applicable, indicate the number of relevant sites on the Licensees" Network)	20,365	0	285	1,147	3,596

Table 7.2: Carbon Benefits

Cumulative Carbon Benefit					
Scale	**Method Cost (£m)**	**Base Case (£m)**	**2030 (mtCO2)**	**2040 (mtCO2)**	**2050 (mtCO2)**
Post-Trial Solution (Individual Deployment)	1.872	0	0.001427	0.003944	0.005742
Licensee Roll-Out Scale(If applicable, indicate the number of relevant sites on the Licensees" Network)	5,315	0	5.11	24.63	62.49
GB Roll-Out Scale(If applicable, indicate the number of relevant sites on the Licensees" Network)	20,365	0	19.6	94.4	239.4

Table 7.3: Capacity Benefits

Cumulative Carbon Benefit					
Scale	**Method Cost (£m)**	**Base Case (£m)**	**2030 (mtCO2)**	**2040 (mtCO2)**	**2050 (mtCO2)**
Post-Trial Solution (Individual Deployment)	1.872	0	0.001427	0.003944	0.005742
Licensee Roll-Out Scale(If applicable, indicate the number of relevant sites on the Licensees" Network)	5,315	0	5.11	24.63	62.49
GB Roll-Out Scale(If applicable, indicate the number of relevant sites on the Licensees" Network)	20,365	0	19.6	94.4	239.4

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