Energy Innovation Needs Assessment

Sub-theme report: Smart systems

Commissioned by the Department for Business, Energy & Industrial Strategy

October 2019

Lead:

:vivideconomics
putting economics to good use

Partners:

CARBON TRUST

E4tech
Strategy | Energy | Sustainability

Imperial College London

FRAZER-NASH CONSULTANCY

Modelling support by:

CATAPULT Energy Systems

Contents

The views expressed in this report are the authors' and do not necessarily reflect those of the Department for Business, Energy and Industrial Strategy.

Acronyms and abbreviations

Table 1. **Key acronyms and abbreviations**

Acronym/abbreviation	Definition
ADVC	Advanced Distributed Voltage Controls
AEC	Alkaline Electrolysis Cell
AI	Artificial Intelligence
B2G	Building-to-Grid
BEIS	Department for Business, Energy and Industrial Strategy
BMS	Building Management System
BOP	Balance of Plant
CAES	Compressed Air Energy Storage
CCC	Committee on Climate Change
DER	Distributed Energy Resources
DG	Distributed Generation
DLR	Dynamic line ratings
DNO	Distribution Network Operator
DSO	Distribution System Operator
DSR	Demand-Side Response
EINA	Energy Innovation Needs Assessment
EN&S	Electricity Networks and Storage
EPCm	Engineering, Procurement, and Construction Management
ESC	Energy Systems Catapult
ESME	Energy System Modelling Environment
ESO	Energy System Operator
EV	Electric Vehicle
FCL	Fault Current Limiters
GVA	Gross Value Add
HTS	High Temperature Superconductor

HV	High Voltage
I&C	Industrial and Commercial
ICT	Information and Communication Technology
IT	Information Technology
LAES	Liquid Air Energy Storage
LCNF	Low Carbon Network Fund
LV	Low Voltage
ML	Machine Learning
MV	Medium Voltage
NIA	Network Innovation Allowance
NIC	Network Innovation Competition
OFGEM	Office of Gas and Electricity Markets
OFS	Oilfield Services
P2G	Power-to-Gas
PEM	Proton Exchange Membrane
PHS	Pumped Hydroelectric Storage
PV	Photovoltaic
RIIO	Revenue Incentives Innovations and Outputs
SME	Small or Medium-Sized Enterprise
SMES	Superconducting Magnetic Energy Storage
SO	System Operator
SOEC	Solid Oxide Electrolysis Cell
TRL	Technology Readiness Level
TSO	Transmission System Operator
V2G	Vehicle-to-Grid
VPP	Virtual Power Plant
WeSIM	Whole-electricity System Investment Model

Glossary

Table 2. **Key terms used throughout this report**

Term	Definition
Learning by doing	Improvements such as reduced cost and/or improved performance. These are driven by knowledge gained from actual manufacturing, scale of production, and use. Other factors, such as the impact of standards which tend to increase in direct proportion to capacity increases.
Learning by research, development, and demonstration	Improvements such as proof of concept or viability, reduced costs, or improved performance driven by research, development, and demonstration (RD&D); increases with spend in RD&D and tends to precede growth in capacity.
Sub-theme	Groups of technology families which perform similar services which allow users to, at least partially, substitute between the technologies. For example, a variety of technology families (heat pumps, district heating, hydrogen heating) have overlapping abilities to provide low-carbon thermal regulation services and can provide flexibility to the power system.
System value and Innovation value	Estimates of change in total system cost (measured in £ GBP, and reported in this document as cumulative to 2050, discounted at 3.5%) as a result of cost reduction and performance improvements in selected technologies. This is the key output of the EINAs and the parameter by which improvements in different technologies are compared. System benefits result from increasing deployment of a technology which helps the energy system deliver energy services more efficiently while meeting greenhouse gas targets. Energy system modelling is a vital tool in order to balance the variety of interactions determining the total system costs. Innovation value is the component of system value that results from research and development (rather than from ‘learning by doing’).
Technology family	The level at which technologies have sufficiently similar innovation characteristics. For example, heat pumps are a technology family, as air-source, ground-source and water-source heat pumps all involve similar technological components (compressors and refrigerants). Electric vehicles are also a technology family, given that the battery is a common component across plug-in hybrids and battery electric vehicles.
Gross Value Add	Gross Value Add (GVA) measures the generated value of an activity in an industry. It is equal to the difference between the value of the outputs and the cost of intermediate inputs.

Introduction

Box 1. **Background to the Energy Innovation Needs Assessment**

The Energy Innovation Needs Assessment (EINA) aims to identify the key innovation needs across the UK's energy system, to inform the prioritisation of public sector investment in low-carbon innovation. Using an analytical methodology developed by the Department for Business, Energy & Industrial Strategy (BEIS), the EINA takes a system-level approach, and values innovations in a technology in terms of the system-level benefits a technology innovation provides.[1] This whole system modelling in line with BEIS's EINA methodology was delivered by the Energy Systems Catapult (ESC) using the Energy System Modelling Environment (ESME^{TM}) as the primary modelling tool.

To support the overall prioritisation of innovation activity, the EINA process analyses key technologies in more detail. These technologies are grouped together into sub-themes, according to the primary role they fulfil in the energy system. For key technologies within a sub-theme, innovations and business opportunities are identified. The main findings, at the technology level, are summarised in sub-theme reports. An overview report will combine the findings from each sub-theme to provide a broad system-level perspective and prioritisation.

This EINA analysis is based on a combination of desk research by a consortium of economic and engineering consultants, and stakeholder engagement. The prioritisation of innovation and business opportunities presented is informed by a workshop organised for each sub-theme, assembling key stakeholders from the academic community, industry, and government.

This report was commissioned prior to advice being received from the CCC on meeting a net zero target and reflects priorities to meet the previous 80% target in 2050. The newly legislated net zero target is not expected to change the set of innovation priorities, rather it will make them all more valuable overall. Further work is required to assess detailed implications.

The smart systems sub-theme report focusses on technologies which provide flexibility to the electricity and wider energy system. A broad range of technologies are considered which allow both electricity demand and supply to become more flexible. This

[1] The system-level value of a technology innovation is defined in the EINA methodology as the reduction in energy system transition cost that arises from the inclusion of an innovation compared to the energy system transition cost without that innovation.

includes technologies which enable high resolution time- and location-based pricing, technologies which allow supply and demand to react to these price signals, and technologies which allow conversion between different energy carriers (e.g. electricity to hydrogen).

Smart systems and flexible infrastructure enable the integration of low-carbon technologies into the energy system at lower costs compared to the conventional system. As the electricity and wider energy system becomes more reliant on variable renewables, infrastructure will be required to ensure supply can always meet demand. Key smart innovations reduce the need for investments in additional infrastructure by increasing flexibility of both supply and demand. Benefits of this include reduced need for expensive flexibility options such as peaking power plants, increasing utilisation of variable low-carbon generation, and deferred investments in transmission and distribution networks. Deployment of such innovations depends on overcoming sectoral barriers, such as coordination requirements across the national and local electricity markets and demand uncertainty given the immaturity of many technologies.

The report has four sections:

- **Smart systems and flexible infrastructure and the electricity system:** Describes the role of smart systems, focussing on the electricity system. Vector coupling is also discussed, but smart solutions in other sectors. such as industry, are considered in specific sub-themes.
- **Innovation opportunities:** Provides lists of the key innovations available within smart systems and flexible infrastructure, and their approximate system benefits.
- **Business opportunities:** Summarises the export opportunities of smart systems and flexible infrastructure, the GVA and jobs supported by these opportunities, and how innovation helps the UK capture the opportunity.
- **Market barriers to innovation:** Highlights areas of innovation where market barriers are high and energy system cost reductions and business opportunities significant.

Key findings

Innovation areas in smart systems and flexible infrastructure

The main innovations for smart systems are identified below. The list is not a substitute for a detailed cost reduction study. Rather, it is a guide for policymakers on key areas to be considered in any future innovation programme design.

The innovation priorities below select individual innovations or groups of the top scoring ones. Table 3 maps the top scoring innovations to individual technology components, and Table 5 to Table 9 sets out the full list of innovations and their scores.

- **Demonstration of flexible platforms for smarter markets, at multiple levels of aggregation, to manage constraints** as the electricity system decarbonises and becomes more decentralised. Market platforms are key to efficiently coordinating flexible and decentralised supply and demand. They are necessary to maximise the system benefits of technologies, such as storage or electrolysers, which can provide flexibility. Flexible market platforms are likely to be required locally to manage location-specific electricity network issues. Moving beyond existing trials, innovation can focus on demonstration of platforms at multiple levels of aggregation and linking between aggregation levels (including improved interaction between SO, DSO, TSO) and to other energy vectors.

- **Understanding and enabling demand-side response (DSR)** will enable a great deal of flexibility in the electricity system. Constructing information and communication technology (ICT) platforms capable of coordinating DSR across disaggregated actors and developing strategies to coordinate this will require significant innovation, given the scale of potential future DSR. In addition, further trials to better understand consumer behaviour and willingness to shift electric vehicle (EV) charging and smart appliance use in response to dynamic tariffs and signals are key to understanding how to best maximise this significant resource.

- **Improvements in electricity storage performance and cost**. The greatest innovation potential is expected in lithium-ion (Li-ion) technologies, given they are expected to dominate the storage market in the near and medium term, further innovations would bring the greatest system benefit. There are various innovation opportunities focussed on stationary batteries, particularly around battery management and manufacture, which are unlikely to be driven by the

EV industry, where there may be a role for government. Support for immature bulk storage options may also yield significant system benefits in the long term.

- **Flexible electrolysers and the establishment of green gas blending walls for vector coupling.** Flexible electrolysers permit faster response to variable generation and mitigate degradation impacts from flexible operation common to existing electrolysers, while the establishment of a green gas blending wall is necessary to facilitate green gas injection into the existing natural gas grid.

- **Smart low voltage load management** will become increasingly important as distributed supply and storage become more prevalent. Moving from a passive distribution grid towards more active management will require a step change in data collection, and innovation in required control systems.

Business opportunities for the UK

Business opportunities within smart systems and flexible infrastructure are diffuse. Deployment of technologies is highly uncertain, which will affect the areas associated with the UK's greatest export opportunities. However, some indicative opportunities within the technology area have been quantified to provide some context on opportunities that may arise.

- **Exports of smart system equipment and services could plausibly support £2.7 billion in GVA and 14,000 jobs per annum in 2050.** Of the equipment opportunities quantified, V2G and smart vehicle chargers present the largest export opportunity to the UK. Exports of V2G and smart chargers could contribute up to £800 million in GVA and 7,800 jobs per annum by 2050. This assumes the UK captures 8% of the global smart vehicle charger market, which grows exponentially to 2050 under EV deployment forecasts. Other quantified opportunities include battery storage and smart networks equipment. These opportunities could add £400 million and £200 million to GVA and support 3,000 jobs each per annum by 2050 respectively.

- **In addition, services have been identified as offering substantial export opportunities. Export of aggregation services[2] alone could add £950 million of GVA and support 2,400 jobs per annum by 2050.** The UK could leverage expertise in aggregation, advisory, and consulting services to

[2] For the purposes of this report, the term aggregation services is used as a catch-all term describing aggregation of various types of grid services. For example, aggregation services can include aggregation of demand-side response and battery storage.

capture a large export opportunity across the different smart system markets. While difficult to quantify, these markets are likely to offer a UK opportunity greater than the equipment markets quantified above.

- **Domestic business opportunities are expected to be modestly less than export opportunities.** As with the export market, domestic business opportunities associated with smart energy technologies remain highly uncertain. However, the domestic market is developing rapidly, partly driven by active UK policy. This additional structure enabled more detailed quantitative estimates (beyond those available for exports), which are provided in the Appendix.

- **The domestic market could plausibly support nearly £1.3 billion GVA and 10,000 jobs per annum by 2050.** The domestic market for V2G and smart vehicle chargers and electricity storage could support around £710 million of GVA and 6,500 jobs per annum by 2050. This includes domestic opportunities associated with services such as installation and O&M, which are not considered as an export opportunity. In addition, the domestic market for aggregation services could support around £400 million of GVA and 1,100 jobs per annum by 2050.

Market barriers to innovation in the UK

HMG is already active in supporting the development of innovative smart technologies. Examples of recent HMG programmes include the Smart Energy Savings (SENS) competition and the FleX competition.[3] HMG has committed £70 million to smart energy innovation in the smart systems and flexibility plan, and expects to spend around £265 million in smart systems research, development and demonstration across Innovate UK, Research Councils and BEIS.

Further opportunities for HMG support exist when market barriers are significant and cannot be overcome by the private sector or international partners. In the market barriers section below, the barriers are set out by component where possible (Table 10 to Table 14). The main market barriers identified are:

- **A market barrier to innovation in flexible platforms** is that prices currently do not accurately reflect whole system benefits. The primary reward from flexible platform innovation would likely come from capturing some of the whole system value they provide, which is difficult without reflective pricing. Flexible platforms are part of the solution to providing whole system pricing,

[3] For more detail, see: https://www.gov.uk/guidance/funding-for-innovative-smart-energy-systems#research-on-realising-the-potential-of-demand-side-response

creating a chicken and egg problem. In addition to this, data on electricity consumption is currently not sufficiently collected and shared, slowing innovation.

- **Market barriers to innovation in DSR** centre on uncertainty amongst market participants around how future electricity market design, policy and regulation will interact to reward DSR. Given returns to DSR technologies are directly dependent on market design and the rewards for flexibility provision, this is perceived as a barrier to investment in innovative DSR technologies and business models.

- **Market barriers to innovation in electricity storage** focus on uncertainty about the future UK energy market, specifically with regards to the role of electrification of heat and transport and the value of storage more broadly. Investment in shared infrastructure for battery storage is uncertain, which reduces confidence in research and deployment. Partly as a result of uncertainty, access to finance can be challenging.

- **A market barrier to innovation in vector coupling** is the (regulatory) separation of gas and electricity networks and markets, which makes integrated planning between gas and electricity difficult and limits the development and funding of truly cross-vector projects.

- **Market barriers to innovation in networks and data** are most severe around the availability of data. Capturing the benefits of smart networks requires substantial coordination between actors. Government could play a role to encourage more effective coordination and data sharing.

Key findings by component

Government support is justified when system benefits and business opportunities are high, but market barriers prevent innovation.

Table 3. **Cost and performance in smart systems and flexible infrastructure (see key to colouring below)**

Overall statistics for smart systems and flexible infrastructure: 2050 system value = £19 billion (range: £17-40 billion)[4], 2050 export opportunity (GVA) = >£2 billion				
Component	**Example innovation**	**Business opportunity**	**Market barriers**	**Strategic assessment**
Smarter markets (market platforms and aggregation)	Demonstration, testing, and co-ordination of flexible trading platforms	(Aggregation services only)	Severe	Innovation in smarter markets is key to optimally coordinate flexible sources of demand and supply. Supporting the development of flexible trading platforms can help UK firms offer and develop innovative business offerings which monetize flexibility provision. The current energy market's design and price setting are critical and some key innovations in the UK will likely be significantly constrained without government intervention.
Demand-side response equipment	ICT platforms capable of coordinating large-scale DSR from smart appliances, smart EV charging and other technologies.	(Smart or V2G chargers only)	Severe	Future market conditions remain uncertain, given interdependence of various technologies, wider energy system design and policy development. This limits innovation in the UK, given uncertainty about future consumer needs. There are various DSR business opportunities for the UK, such as smart and V2G chargers, which can be pioneered domestically and then exported.
Electricity storage	Efficient manufacturing techniques for Li-ion	(Stationary batteries only)	Moderate	There are a range of storage technologies with innovation opportunities. These could offer business opportunities to the UK, although they are likely to be relatively small. Uncertainty about the future value of storage in the UK energy system and incomplete electricity markets are moderate barriers to innovation in storage. However, with a highly international market and linkages to electric vehicles, significant innovation is likely to occur, nonetheless.

[4] This is estimated on a different basis to the other EINAs. It is an estimate of the value of these technologies, rather than the value of innovating in these technologies. Further information on this, and the different models used, is in appendix 2.

Overall statistics for smart systems and flexible infrastructure: 2050 system value = £19 billion (range: £17-40 billion)[4], 2050 export opportunity (GVA) = >£2 billion				
Component	**Example innovation**	**Business opportunity**	**Market barriers**	**Strategic assessment**
Vector coupling*	Improved electrolyser flexibility	Medium-Low	Severe	Power-to-gas, particularly, is a clear innovation opportunity for the UK, with system benefits and increasing export opportunities. Vector coupling relies on low-carbon technology incentives. Therefore, innovation in the UK will likely be limited without government intervention.
Networks and data	Low voltage network load management	Medium-Low	Severe	Innovations in network equipment and data management would enable smarter (low voltage) network management, which is key for the integration of distributed generation and storage, and higher loads from electrified heat and transport. Associated export opportunities are appreciable and could nearly double the sector's current exports. Policy-dependent demand and coordination failures for smart networks mean that innovation in networks and data in the UK will be significantly constrained without government intervention.

Source: *Vivid Economics, Carbon Trust*

Note: *The main innovations per component are the innovations that score highest in the innovation inventory. This table only includes component-specific market barriers. Cross-cutting barriers are included in the market barriers section below. *Vector coupling refers to the coupling of different energy vectors in the energy system. For example, using electrolysers to produce hydrogen from electricity. We only include export markets in this assessment because it is more directly linked to additional benefits to the UK economy. However, an assessment of the domestic market is included in the report below.*

Table 4. **Key to colouring in the key findings by component**

Business opportunities	**Market barriers**
High: more than £1 billion annual GVA from exports by 2050	**Critical:** Without government intervention, innovation, investment, and deployment will not occur in the UK.
Medium-High: £600-£1,000 million annual GVA from exports by 2050	**Severe:** Without government intervention, innovation, investment ,and deployment are significantly constrained and will only occur in certain market segments / have to be adjusted for the UK market.
Medium-Low: £200-£600 million annual GVA from exports by 2050	**Moderate**: Without government intervention, innovation, investment, and deployment will occur due to well-functioning industry and international partners, but at a lower scale and speed.
Low: £0-200 million annual GVA from exports by 2050	**Low:** Without government intervention, innovation, investment, and deployment will continue at the same levels, driven by a well-functioning industry and international partners.

Source: Vivid Economics, Carbon Trust

Box 2. **Industry workshop**

A full-day workshop was held on 28th February 2019 with delegates from UK industry, the academic community, and research agencies. Key aspects of the EINA analysis were subjected to scrutiny, including the innovation opportunity assessment, and the business and policy opportunities assessment. New views and evidence were suggested; these have been incorporated into an update of the assessments.

The views of the attendees were included in the innovations assessment and are detailed in the report.

Smart systems and the whole energy system

Current situation

As aspects of the energy system change, the need for flexibility increases. Various drivers combine to create greater demand for flexibility. Key drivers include:

- **A greater share of the energy supplied will be from intermittent renewables.** This requires more system balancing and reserves to maintain system reliability.
- **Closure of some thermal plants** (coal, oil, gas, and nuclear) due to carbon taxes and end-of-life retirements, which were previously able to provide baseload power and a degree of flexibility.
- **Increasing peak demand** if heat and transport electrify at scale.[5] This drives greater total demand and may change the profile and predictability of that demand.
- **Rising embedded generation and decentralisation** of renewables increases the need to supply electricity to meet demand at the right location.

A range of technologies and services offer significant opportunities to mitigate these emerging energy system challenges. For the purposes of this report, these are classified as 'smart systems and flexibility' technologies and services. The innovation opportunities considered involve a combination of business models and technologies**:**

- **Smarter market platforms.** Smarter market platforms could enable the energy price reflect the whole system value. Innovation here requires both technical (platform) innovation, combined with innovative business models which leverage the platforms. Smart markets are not yet deployed at scale in the UK, although regulatory changes are underway to develop half-hourly settlement, standards for smart appliances, and smart charging standards for electric vehicles (EVs).
- **Demand-side response (DSR).** DSR equipment considered in this report includes smart meters, controllers, smart devices, and EV integration in homes and businesses. Currently, demand-side response occupies a limited

[5] Note, even in a scenario with only modest heat pump penetration, total electricity demand and capacity would increase significantly. See CCC (2018). Analysis of Alternative UK Heat Decarbonisation Pathways. https://www.theccc.org.uk/wp-content/uploads/2018/06/Imperial-College-2018-Analysis-of-Alternative-UK-Heat-Decarbonisation-Pathways.pdf

role in the Great Britain electricity system. The Committee on Climate Change (CCC) suggests that a modest 1 GW of DSR is currently available (2% of peak demand on a typical day).[6] The smart meter rollout is more advanced, with approximately 13.8 million smart meters installed as of December 2018.[7]

- **Electricity storage:[8]** The decreasing cost of electricity storage technologies is unlocking new potential and use cases for smart systems. Key technologies include distributed storage (Li-ion, sodium sulphur, redox, liquid air, flywheels, and super-capacitors) and bulk storage options (pumped hydro, compressed air energy storage (CAES)). There is around 3.3GW of storage capacity (including pumped storage projects) now operational in the UK and a further 5.4GW has planning consent - including 4.8GW of battery storage.[9] By 2050, National Grid expects between 14GW and 28GW of electricity storage capacity.[10] Note, hydrogen storage, an avenue to effectively store electricity through vector coupling, is discussed in the Hydrogen sub-theme.
- **Vector coupling:** This includes the use of power to gas (P2G) and power-to-liquid (converting power to gas then gas to liquid) transformation facilities. There are trials for P2G for around 1,500 homes in the UK[11] and the UK operates two of the largest hydrogen from electrolysis refuelling stations in Europe.[12] Gas (hydrogen) to power is considered in the Hydrogen EINA sub-theme.
- **Networks and data**: Innovations in networks include both innovations in equipment, but crucially will also require significant improvement in the use of data to enable efficient grid management. The transmission network is already reasonably 'smart' to enable real-time system balancing. However, on the distribution network, which is more passive, there is considerable scope for improvement.

[6] Table 2.3 CCC (2018) Reducing UK emissions: 2018 Progress Report to Parliament https://www.theccc.org.uk/wp-content/uploads/2018/06/CCC-2018-Progress-Report-to-Parliament.pdf
[7] This includes gas and electricity smart meters. BEIS (2019) https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/789632/2018_Q4_Smart_Meters_Report_FINAL.pdf
[8] Note, hydrogen and heat storage are discussed in the Hydrogen and Heating and Cooling EINA sub-themes repectively.
[9] RenewableUK (2018) Energy storage capacity set to soar, 300 UK-based companies involved in new sector https://www.renewableuk.com/news/425522/Energy-storage-capacity-set-to-soar-300-UK-based-companies-involved-in-new-sector.htm
[10] National Grid (2019) Future Energy Scenarios http://fes.nationalgrid.com/media/1409/fes-2019.pdf
[11] ITM Power (2018) Ofgem funding for UK's first hydrogen trials on the public gas network http://www.itm-power.com/news-item/ofgem-funding-for-uks-first-hydrogen-trials-on-the-public-gas-network
[12] E4tech (2016) Hydrogen and fuel cells: opportunities for growth. A roadmap for the UK http://www.e4tech.com/wp-content/uploads/2016/11/UKHFC-Roadmap-Final-Main-Report-171116.pdf

Future deployment scenarios

In the future, smart technologies and markets will provide four key sources of value to the energy system:

- They reduce the capacity of low-carbon generation needed to achieve carbon reduction targets by improving the utilisation of intermittent low-carbon generation.
- They enable system balancing at a lower cost by displacing more expensive flexibility options such as peaking power plants.
- They improve the utilisation of existing conventional generation and defer investments in transmission and distribution network reinforcement.
- They enable greater consumer participation in the energy market, improving the customer experience and empowering consumers to capture value associated with their assets (such as EVs).

Box 3. **Removing barriers to smart systems**

In July 2017, HMG published the Smart Systems and Flexibility Plan, which aims to enable the trading of flexible resources in markets. National Grid (System Needs and Product Strategy) and the Office of Gas and Electricity Markets (Ofgem) (the Targeted Charging Review: Significant Code Review) have also outlined strategies to enable flexibility. If these programmes are implemented, the CCC suggests, these actions will level the playing field and remove the barriers to entry for smart technologies.

Scenario exercises and energy modelling have estimated the potential uptake of smart systems and flexibility to 2050. An introduction and discussion of two of the widely used optimising energy system models, ESME and Whole-electricity System Model (WeSIM), is set out in Appendix 2. In addition to model-driven scenarios from ESME and WeSIM, the National Grid's Future Energy Scenarios (FES) provide scenarios for potential smart system uptake by 2050.[13] Estimates for each of the smart technologies, where available, are set out below:

Smart markets

- National Grid assumes that between 61%-78% of consumers engage with smart EV charging technologies, by 2050, and;
- 27%-68% of residential consumers engage with smart pricing by 2050.

[13] http://fes.nationalgrid.com/fes-document/

DSR

- The CCC sets out the required levels of some smart system technologies to be consistent with the low-cost path to meeting carbon targets. It estimates that by 2030, 4-18 GW of DSR capacity is required.
- Modelling using Imperial College London's WeSIM (see Appendix 2) estimates that by 2050, the cost-effective amount of DSR could rise further, up to 35 GW.
- The National Grid's Future Energy Scenarios[14] sets out a range of futures for smart systems technologies. In the residential sector, smart options like Time-of-Use-Tariffs and smart appliances could reduce residential peak demand by 1-2 GW in 2050. For industrial and commercial (I&C) consumers, there could be around 3.8-7.7GW of (I&C) demand-side response by 2050.

Storage

- The CCC suggests that by 2030 around 8-38 GW of storage is required.
- WeSIM modelling estimates that the 2050 level of storage is at the upper end of the 2030 CCC range.
- National Grid's FES scenarios indicate there could be between 12-29 GW of storage deployed by 2050.

The overall benefit from smart systems, i.e. enhanced flexibility, could deliver system benefits of £17-40 billion from 2016 to 2050. This can be realised through a combination of smart and flexible technologies. Box 4 highlights modelling efforts to assess the system benefit. Assigning precise system benefits to each of these options is difficult given that sources of flexibility can both complement and compete. For example, DSR makes behind-the-meter storage more attractive, but also reduces the need for utility scale storage. Despite this complex relationship, indications of system benefits of specific technologies are provided in the next section where possible. Box 5 highlights the role of innovation in unlocking the potential system benefit.

[14] National Grid (2018) Future Energy Scenarios http://fes.nationalgrid.com/fes-document/

Box 4. **Modelling system benefits: SMART systems in the UK energy system**

In contrast to other EINAs, where modelling was conducted in the Energy System Modelling Environment (ESME), the smart systems and flexibility EINA adopted a different approach.

Measuring the value of smart and flexible technologies is a known weakness of energy system models like ESME and TIMES, which do not have a fine-grained time breakdown and hence do not explicitly model the value of short-term flexibility. It is expected that ESME may undervalue these technologies.

In this project we have relied on estimates from WeSIM, another energy system model with an improved representation of the temporal aspect of electricity systems. It is likely to include a better representation of the value of smart systems overall (see Appendix 2 for more information).

A challenge of this approach is that the previous modelling runs are not directly comparable with ESME modelling. There are structural modelling differences, and the scenarios have very different input assumptions.

Nonetheless, a clear finding of the WeSIM modelling is that smart systems and flexibility technologies have substantial value for the UK energy system. Considering a range of different scenarios, the net value of these technologies is estimated to be between £17-40 billion (cumulative savings to 2050 discounted at 3.5%).[15,16]

Further work is required to estimate the value of particular innovation areas, or how these estimates may change in the case of different energy system scenarios.

[15] Imperial College and Carbon Trust (2016) An analysis of electricity system flexibility for Great Britain https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/568982/An_analysis_of_electricity_flexibility_for_Great_Britain.pdf

[16] Scenarios consider variations for electricity demand, energy storage costs, demand-side response (DSR) costs, and future levels of interconnection.

Box 5. **Learning by doing and learning by research**

The total system benefit from innovations follows from two types of technology learning:

- **Learning by doing:** Improvements such as reduced cost and/or improved performance. These are driven by knowledge gained from actual manufacturing, scale of production, and use. Other factors, such as the impact of standards, which tend to increase in direct proportion to capacity increases.
- **Learning by research:** Improvements such as proof of concept or viability, reduced costs, or improved performance driven by research, development, and demonstration (RD&D). It increases with spend in RD&D and tends to precede growth in capacity.

The EINAs are primarily interested in learning by RD&D, as this is the value that the government can unlock as a result of innovation policy. Emerging technologies will require a greater degree of learning by RD&D than mature technologies. Academic work suggests that for emerging technologies around two-thirds of the learning is due to RD&D, and for mature technologies it contributes around one-third.[17]

To reach a quantitative estimate of the system value attributable to RD&D, these ratios are applied to the system value. This implies that, as an emerging technology, around £19 billion of the £28.5 billion system value (taken as the medium of above WeSIM estimate) follows from RD&D efforts. Note, this is an illustrative estimate, with the following caveats:

- The learning-type splits are intended to apply to cost reductions. However, in this study, they are applied to the system value. As system value is not linearly related to cost reduction, this method is imperfect.
- In practice, learning by research and learning by doing are not completely separable. It is important to deploy in order to crowd-in investment to more RD&D, and RD&D is important to unlock deployment.

These estimates are used in the EINA Overview Report to develop a total system value that results from innovation programmes across the energy system.

[17] Tooraj Jamasb (2007) Technical Change Theory and Learning Curves
https://econpapers.repec.org/article/aenjournl/2007v28-03-a04.htm

Innovation opportunities within smart systems and flexible infrastructure

Introduction

Box 6. **Objective of the innovation opportunity analysis**

The primary objective is to identify the most promising innovation opportunities within smart systems and highlight how these innovations may be realised and contribute to achieving the system benefit potential described above.

The innovations included in this section of the report are those that require government support to become commercialised, rather than innovations that are more likely to be delivered by industry. A longlist of innovation needs was compiled, dividing them into those two categories. The list was circulated to the attendees before the workshop. During the workshop it was confirmed that the innovation needs were correctly divided.

This section provides:

- A brief description of how the considered smart components relate to wider system costs and potential system costs savings (system benefits) described above.
- A list of identified innovation opportunities, and an assessment of their importance to reducing costs and deployment barriers.

In order to realise the system benefits of smart technologies, see Box 4, innovation is required across a range of technologies. These are all capable of providing flexibility for the electricity system and help to link various energy vectors to provide wider energy system flexibility. The innovation opportunities involve a combination of business models and technologies**.** We consider innovation opportunities within five areas:

- **Smarter markets (market platforms and aggregation)** considers innovations that promote the development of flexible platforms to match electricity, and potentially wider energy supply and demand, at high temporal, and potentially spatial, resolutions.
- **Demand-side response** considers innovations that enable domestic and commercial consumers to shift and modulate electricity demand. This includes both hard and software solutions, including in smart meters, to enable DSR

from buildings and electric vehicles. Notably, storage can play a key role in increasing demand flexibility from buildings. Innovations which enable this are considered here, whereas innovations in the storage (battery) technology itself are considered under storage.
- **Electricity storage** considers three types of storage: bulk, distributed, and fast response services. The focus is on intra-day storage, with interseasonal (hydrogen) storage primarily considered in vector coupling and the Hydrogen sub-theme.
- **Vector coupling** considers innovations to improve electrolyser flexibility and establish blending walls for green gas injection to the existing natural gas grid.
- **Networks and data** focusses on innovations within the use of data and operation of grids, with some key hardware innovations highlighted.

The inventory of innovation opportunities below sets out the role of each technology in a smart system in more detail and prioritises key innovations to unlock the potential system benefits of a smart system. Prioritisation of cost reduction and barriers to deployment was elaborated by the Carbon Trust and reflects expert input gathered in a workshop. The magnitude of the contributions to cost reduction and reducing deployment barriers are described in qualitative terms relative to other innovation opportunities:

- Significantly above average = 5
- Above average = 4
- Average = 3
- Below average = 2
- Significantly below average = 1

An indicative timeframe for each innovation is provided. The timeframe given relates to the year the technology is deployed commercially at scale (gaining 10-20% market share).

Inventory of innovation opportunities

Smarter markets (market platforms and aggregation)

Smarter markets offer an opportunity to more efficiently manage increasingly variable supply and demand in the energy system. Smarter markets can benefit the entire electricity system by reflecting the whole system value in price formation, allowing more efficient market operation. Smarter markets are effectively match-making platforms that process supply and demand signals from generators, consumers, and storage to optimise the dispatch (or activation) of electricity.

Smart markets maximise the system value of storage, DSR, and other sources of flexibility. Innovative market platforms can provide a means for price signals, reflecting spatial and temporal prices, to be sent to flexibility providers. This could be done directly, with electricity consumers and suppliers receiving high frequency signals, or with a distribution system operator (DSO) or transmission system operator (TSO) as an intermediary. For example, the Piclo Flex platform, supported by BEIS, provides a platform which allows DSOs and flexibility providers to contract with each other.[18] Alternatively, the local energy market (LEM) trial in Cornwall more directly links consumers and producers.[19] By ensuring demand and supply are coordinated, a smart market maximises the value from demand-side response, storage, and generators, and reduces the need to invest in transmission and distribution infrastructure. It is the capability to actively adjust both supply and demand close to real time that marks the departure from traditional electricity markets, where supply is actively adjusted to meet passive demand.

Box 7. **Defining smarter markets and identifying innovation needs**

- The evolution of the structure of the electricity market will depend on both innovation and complex regulatory decisions.
    - A flexibility market could develop alongside the existing electricity market structures (wholesale and various balancing and ancillary markets).
    - Alternatively, the wholesale market itself could become highly temporally and spatially disaggregated and hence ensure a balanced grid by rewarding flexibility directly.
- The prioritised innovations in this report are agnostic to the precise future market structure and hence are labelled as innovations to support smarter markets.

The development of trading platforms, integrated across various levels of aggregation, to manage capacity and network constraints and reward flexibility is a key innovation priority. Several platforms are already being trialled locally. These can alleviate pressure on DSOs but are broadly designed to operate within the existing electricity market architecture. However, flexible market platforms could be implemented at multiple levels. For example, local markets, such as the

[18] Ofgem and BEIS (2018). Upgrading Our Energy System. Smarts Systems and Flexibility Plan: Progress Update. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/756051/ssfp-progress-update.pdf
[19] Centrica (2019). Cornwall Local Energy Market. Available from: https://www.centrica.com/innovation/cornwall-local-energy-market

Cornwall LEM, could trade excess local energy between each other, creating a highly disaggregated electricity market made up of interconnected platforms. System operators (SOs) and DSOs could trade via such a platform with small-scale generators and consumers would be indirectly exposed to wholesale price signals. Alternatively, it may be possible for small-scale consumers and producers to directly trade on a 'wholesale' platform.

In addition to existing trials, there is a need to demonstrate, test, and coordinate the formation of flexible platforms at multiple levels. Demonstration of how local markets could be linked with innovative regional or national wholesale platforms would help establish the optimal technical and regulatory arrangements for the future energy system. It would also help unlock additional potential value in local market platforms, which are currently hampered by the existing overarching market infrastructure.[20]

In order to manage capacity and network constraints, a flexible market platform requires enabling innovations in data sharing and management. The ability of the flexible market to manage constraints depends on its ability to use data from a diverse set of electricity system assets. Standardised data platforms for improved sharing and coordination of demand- and supply-side resources are a necessary enabling innovation. With consideration of privacy requirements, the development of data standards and the establishment of an encryption framework are also essential for the creation of secure, high quality data that can be processed by flexible market platforms or aggregators.

Additional innovations in electricity demand and supply forecasting can enhance the operation of flexible market platforms by providing better information. These innovations include**:**

- Creating a forward demand curve that incorporates improved forecasting of demand behaviour and resource availability.
- Improving supply forecasting with more accurate prediction of variable renewable generation and transmission grid constraints.

The table below highlights the specific innovation needs for smarter markets and their respective impacts on reducing the costs and deployment barriers. The workshop participants discussed the contents of the table and offered feedback. The updated table was circulated amongst workshop delegates, who were given the opportunity to provide further comments.

[20] Open Utility (2019). Local Grid Charging. Available from: https://piclo.energy/publications/open-utility-local-grid-charging-white-paper.pdf

Box 8. **Industry workshop feedback**

- The key innovation opportunity in smarter markets is the development of flexible market platforms for constraint and ancillary service management.
- The lack of standardised, high quality, and shareable data is a major barrier to the development of flexible market platforms.
- The creation of a forward demand curve that incorporates electricity supply and demand forecasts would be a major improvement in market operations.

Table 5. **Innovation mapping for smarter markets**

Component	Innovation opportunity	Cost reduction	Deployment barrier reduction	Relevant technology	Impact on other energy technology families	Timeframe
Market platforms and aggregation	**Demonstration, testing, and co-ordination of flexible trading platforms for constraint management at multiple levels.** This includes national and decentralised markets and SO and DSO interaction, in order to manage system and grid needs and ancillary services	5	5	Storage, DSR	DGs, EVs, heat pumps	2020s
	Develop data platforms for improved sharing and coordinating of resources including establishing a framework for data ownership and security (encryption) and the creation of high quality and standardised data	4	5	Storage, DSR	DGs, EVs, heat pumps	2020s
	Enabling easy use of data through automation, compatibility, and interoperability, including standardising data collection, sharing, and encryption (this innovation opportunity is a higher priority if the data platform opportunity does not happen)	3	3	Storage, DSR	DGs, EVs, heat pumps	2020s
	Improve the forward curve for demand, through improved forecasting behaviour and use of VPPs (demand), resource availability (supply), interaction with existing energy markets, demand aggregation, and scalability of architecture and systems	3	5	Storage, DSR	DGs, EVs, heat pumps	2020s
	Improved forecasting of supply, including more accurate forecasting of resource availability (e.g. grid renewable availability) and transmission grid constraints	2	5	Storage, DSR	DGs, EVs, heat pumps	2020s

Source: Carbon Trust, Vivid Economics, expert workshop

Demand-side response

Demand-side response (DSR) creates flexibility in the amount and timing of electricity demand. This is achieved by shifting or reducing or increasing energy consumption using financial incentives, either through behavioural incentives or automated processes. To enable flexibility from consumers, enabling equipment must be deployed, consumer behaviour understood, and coordination systems in place.

This report focusses on innovations which will develop DSR in residential and commercial buildings, which are expected to be concentrated in smart appliances and implementation of vehicle-to-grid (V2G) charging, which has been identified as a large potential source of DSR capacity.[21] Given V2G is likely to mostly occur at the home or office car parks, it is considered as residential or commercial demand for the purpose of this report.

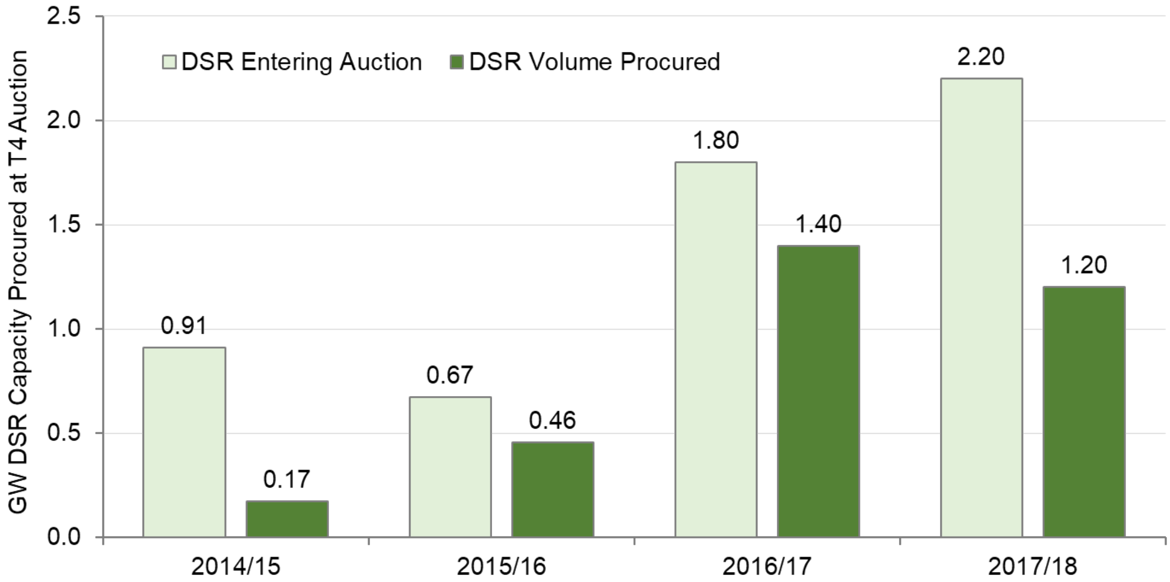
DSR currently occupies a limited role in the UK electricity system. To illustrate, the 2017/18 T-4 capacity auction saw 1.2 GW of DSR capacity secured. This is only 2.4% of total secured capacity.[22,23] However, the procurement of DSR in these auctions has increased by over 600% since 2014/15, as shown in Figure 1. Further innovation in demand-side response could enable significantly more DSR to become available in the UK electricity system.

[21] BEIS (2017) Realising the Potential of Demand-side Response to 2025: https://www.gov.uk/guidance/funding-for-innovative-smart-energy-systems#research-on-realising-the-potential-of-demand-side-response

[22] A T-4 auction is held annually to procure capacity for the electricity market four years in advance. Existing generators and interconnectors won 90% of contracts in the recent T-4 auction; for more information, see Grey Cells Energy (2018) An Introduction to Britain's Capacity Market https://greycellsenergy.com/articles-analysis/an-introduction-to-britains-capacity-market/

[23] Ofgem (2018) Annual Report on the Operation of the Capacity Market https://www.ofgem.gov.uk/system/files/docs/2018/08/20180802_annual_report_on_the_operation_of_cm_2017-18_final.pdf

Figure 1. **DSR capacity entering and being procured at capacity market auctions has markedly increased since 2014/15**



Source: *Vivid Economics based on OFGEM*

Deployment of DSR is expected to increase to 2050 in order to meet carbon targets at low costs. The CCC estimates 4-18 GW of DSR will be required by 2030 to help integrate increased levels of variable renewable generation. By 2050, Imperial College's Whole System Investment Model (WeSIM) estimates that the cost-effective amount of DSR could reach 35 GW, see Appendix 2.

Innovations in DSR have the potential to enable deployment of further smart technologies. By establishing a demand-side response infrastructure, the UK can unlock additional innovations that will further reduce system costs and deployment barriers. For example, developing ICT platforms capable of coordinating DSR will enable large-scale peer-to-peer trading (an innovation opportunity within smarter markets).

The priority innovation opportunities for DSR are coordinating DSR with distribution network operators (DNOs) and conducting further trials to better understanding consumer behaviour. These innovations have the greatest potential to reduce technical barriers to widespread deployment of DSR in smart V2G chargers and buildings, by building on existing innovation support administered in UK domestic applications of DSR.[24] Notably, they are not innovations around equipment, but focus on coordinating and ensuring the deployment of DSR at scale enables flexibility. Key innovations include:

[24] BEIS (2018). Available at: https://www.gov.uk/guidance/funding-for-innovative-smart-energy-systems#funding-for-innovative-domestic-demand-side-response-demonstrations

- **Strategies for whole system optimisation and coordination**, across distribution system operators (DSOs) and transmission system operators (TSOs). This will require close coordination with the development of smart markets, such as flexibility markets or peer-to-peer trading, described above.
- **ICT platforms** capable of coordinating DSR from large-scale smart charging and smart appliance management, and interacting with broader market (trading) platforms described above.
- **Trials to understand consumer behaviour and willingness** to use EVs and smart appliance for DSR in response to tariffs and signals.

Notably, this report does not prioritise significant further innovations around smart meter hardware. Smart meters are critical to household DSR, and further innovations are available around, for example, load control, including EV chargers, through smart meters. However, there is already significant ongoing effort being undertaken by HMG.[25]

The table below highlights the specific innovation needs for demand-side response and their respective impacts on reducing energy system costs and deployment barriers. The workshop participants discussed the contents of the table and offered feedback.[26] The updated table was afterwards circulated amongst workshop delegates, who were given the opportunity to provide further comments.

Box 9. **Industry workshop feedback**

- Specific conditions in the UK mean there is a limit to what can be learnt from innovations in other countries.
- Monitoring and coordinating the large number of actors and assets poses a significant challenge to overcome.
- EVs are paramount in driving DSR at a large scale and therefore should be considered alongside DSR.
- Understanding consumer behaviour is key within DSR; engagement with consumers and forecasting behaviour will be important enablers of DSR.

[25] BEIS (2018). Smart metering implementation programme. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/767128/smart-meter-progress-report-2018.pdf
[26] A full list of workshop participants is listed in Appendix 1.

Table 6. **Innovation mapping for demand-side response**

Component	Innovation opportunity	Cost reduction	Deployment barrier reduction	Relevant technology	Impact on other energy technology families	Timeframe
DSR – Homes/ buildings	Developing robust interfaces with **building management systems** (BMS) to better understand profiles and load type to unlock capacity for system services	3	3	DSR	Networks, Wind, solar PV, heat pumps	2020s
	Develop **optimisation and control strategies** for DSR from different loads to be used, whole system services across DSO and SOs to improve value and coordination (SO, DSO, TSO)	4	5	DSR	Networks, Wind, solar PV, heat pumps	2020s
	Advanced control strategies going beyond Industrial and Commercial (I&C) loads for network management at different levels	3	3	DSR	Networks, Wind, solar PV, heat pumps	2030s
	Develop and test improved **virtual power plant (VPP) coordination strategies** with multiple technologies, such as smart appliances, and at different scale to maximise benefit and minimise conflicts (markets, network/system needs)	4	4	DSR	Networks, Wind, solar PV, heat pumps	2020s
	Develop consistent and defined **metering and communications standards.** This allows third parties to develop interfaces with different loads/equipment to then provide services to network or system	3	5	Enabler	Enabler	2020s
	Home energy management systems for grid services and extension to B2G services – leveraging smart meter infrastructure and uptake of smart appliances	3	4	DSR	Networks, Wind, solar PV, heat pumps	2020s
	Trials to better understand **customer behaviour and willingness** over time to use smart appliances in response to tariffs	4	4	DSR	Networks, Wind, solar PV, heat pumps	2020s

Component	Innovation opportunity	Cost reduction	Deployment barrier reduction	Relevant technology	Impact on other energy technology families	Timeframe
DSR – EV integration	Develop and test **ICT platforms** to manage coordination of large-scale smart charging aligned with DSO operational needs and requirements	4	5	EVs	Networks, Wind, solar PV, heat pumps	2020s
	Develop improved **standardisation of V2G charging controllers** –targeting cost reduction	4	3	EVs	Networks, Wind, solar PV, heat pumps	2020s
	Develop **V2G capacity forecast models** for ESO/DSO to estimate capacity availability across time accurately to improve confidence on providing services when required	3	4	EVs	Networks, Wind, solar PV, heat pumps	2020s
	Develop robust **VPP models that can aggregate and coordinate V2G** units to deliver services across the system and reduce conflicts with other services and actors	3	5	EVs	Networks, Wind, solar PV, heat pumps	2030s
	Trials to better understand **customer behaviour and willingness** over time to use EVs for V2G provision in response to tariffs	4	4	EVs	Networks, Wind, solar PV, heat pumps	2020s

Source: Carbon Trust, Vivid Economics, expert workshop

Electricity Storage

There are a several storage technologies which can provide a range of flexibility services. Electricity storage can provide both ancillary services to the grid, and deliver energy through the wholesale market to smooth wholesale mismatches in supply and demand. Their deployment can reduce the need in network investment and backup generation capacity and bring significant system benefits. We consider three broad categories of storage service to the grid:

- **Bulk storage** options that can supply significant capacity over several hours (at minimum). The response time of these options is typically seconds or minutes. Hence, the primary service bulk storage provides is energy on the transmission network, rather than fast response power. Note, longer term inter-seasonal storage is primarily considered in the Hydrogen sub-theme, and briefly in the context of vector coupling in this report.
- **Distributed storage** options are smaller in scale. They can be installed in homes or at commercial sites, and frequently sit 'behind the meter'. Distributed storage options can respond within seconds and hence may be used in balancing services.
- **Fast response services** can respond within milliseconds and can be used in rapid frequency response services on distribution networks.

There are storage technologies which could provide multiple use cases. For example, Li-ion batteries are typically considered as distributed storage, but larger Li-ion batteries capable of over 100 MW of capacity for hours have been installed.[27] By their nature, electrochemical batteries (such as Li-ion) consist of interconnected cells which typically scale relatively easily. For simplicity, storage technologies are categorised by the service they are (primarily) expected to provide, but priority ratings reflect their broader potential.

The primary innovations with the greatest potential to reduce both storage costs and deployment barriers are expected to be in Li-ion technologies. This is primarily because Li-ion chemistries are expected to dominate the storage market for at least the next 10-20 years.[28] The scale of the EV industry and the large economies of scale associated with battery production are expected to rapidly drive

[27] As Li-ion cell costs continue to decline, partly driven by the EV market, Li-ion use for bulk storage may well become more common.

[28] MIT (2018) Energy Storage for the grid: Policy options for sustaining innovation http://energy.mit.edu/wp-content/uploads/2018/04/MITEI-WP-2018-04.pdf

costs down compared to more niche storage options.[29] In 2017, Li-ion accounted for 90% of all utility-scale batteries commissioned, up from 41% in 2011, partly driven by the growing economies of scale in Li-ion production.[30]

Given Li-ion batteries can be flexibly deployed for bulk and distributed applications, they are likely to dominate the storage market, at least in the short-to-medium term. Consequently, innovation to reduce deployment barriers and further reduce cost in this storage technology, which is expected to capture the bulk of the market, is likely to bring the greatest system benefit, particularly in the short term. Notably, the UK already provides significant support for Li-ion innovation through the Faraday challenge.[31] However, although there is a current support programme for recycling EV batteries towards stationary applications, the primary focus of the Faraday challenge is on batteries for automotive applications, leaving room for further innovation opportunities in Li-ion for stationary applications.

Innovations in Li-ion may be in the cell chemistry itself, but various other innovations are available. Innovations most often mentioned by experts can be categorised into innovations in the electrode, electrolyte, and battery management.[32] While Li-ion innovation is likely to be driven by the EV industry, and the availability of key inputs (such as Cobalt), there remains significant room for innovation in the use of Li-ion for stationary applications.

- **Electrode:** Incremental chemistry change, cost-effective materials, higher cathode voltage, and adding silicon to graphite anodes.
- **Electrolyte:** Development of solid electrolyte and larger cell format.
- **Battery management system:** Improved operation pattern (optimised for stationary use), improved 'smart' invertors, improved cooling efficiency, and packaging for stationary use.
- **Manufacturing and installation:** Standardisation could reduce cost significantly, innovation in the provision of 2nd life batteries for stationary storage (i.e. repurposing EV batteries) may be a significant opportunity.

Innovation in less mature options may also be valuable. Compared to Li-ion, innovation in alternative storage technologies receives relatively little industry funding. Given the known large system benefit of storage, specialised applications of different storage technologies, and the risk of Li-ion 'lock in', there remains

[29] Cost projections of $100/kWh by 2030 are not uncommon now, compared to around $500/kWh in 2015. See MIT (2018) Energy Storage for the grid: Policy options for sustaining innovation http://energy.mit.edu/wp-content/uploads/2018/04/MITEI-WP-2018-04.pdf
[30] IEA (2019). Energy Storage. Available from: https://www.iea.org/tcep/energyintegration/energystorage/
[31] Faraday battery challenge. Available from: https://www.gov.uk/government/collections/faraday-battery-challenge-industrial-strategy-challenge-fund
[32] Based on a forthcoming Imperial College report.

significant value in innovating in other storage technologies. To reflect this, the table below prioritises innovation across a wide range of storage technologies.

Box 10. **Industry workshop feedback**

- There is likely to be significant global innovation in batteries. The UK could likely rely on this to a significant degree, particularly in innovations with crossover between the EV and stationary battery industries.
- Li-ion is likely to play a dominant role in the energy system given wider industry dynamics. This warrants a focus on innovation in this area compared to more niche (and unlikely to be deployed at scale) alternatives.

Table 7. **Innovation mapping for storage**

	Innovation opportunity	Cost reduction	Deployment barrier reduction	Relevant technology	Impact on other energy technology families	Timeframe
Bulk storage	**Pumped hydroelectric storage (PHS):** There is a need for increasing flexibility by developing a full range variable-speed motor generator and a wider pump-turbine working range. To decrease the geographical limitations, it is important to prioritise the options to reduce the installation costs in alternative locations. This includes in the sea or near to the coast (to use seawater) and underground by improving alternative reservoir concepts. Given the maturity of this technology, however, innovation potential is thought to be relatively low.	2	2	Bulk storage	Intermittent renewables on high voltage networks, interconnectors	2020s
	Compressed air energy storage (CAES): Innovations in turbo machinery design and manufacturing can help to reach efficient large-scale compressor and expander technologies as well as highly efficient low-cost thermal storage technologies. In addition, there is an opportunity in developing and demonstrating alternative plant configurations, storage systems, and business models for CAES facilities (an alternative to the option of CAES with caves). Given the relative maturity of this technology, however, innovation potential is thought to be relatively low.	2	3	Bulk storage	Intermittent renewables on high and medium voltage networks, interconnectors	2020s
	Liquid air energy storage (LAES): There is an opportunity to provide support and industrial uptake for further technical development in LAES and to enhance the market readiness level. Industrial-academic consortia should be supported to design, implement, and operate full-scale LAES demonstrations in multiple technical/economic environments.	3	3	Bulk storage	Intermittent renewables on high voltage networks, interconnectors	2020s
	Alternate bulk storage systems: Several alternatives have been tested based on the storage of gravitational energy produced by the displacement of different sort of masses. There is a need to increase the technology readiness level (TRL) of these technologies to reach market readiness and potentially provide a cost-effective alternative to other bulk storage options, including Li-ion to compete with bulk storage technologies such as PHS and CAES.	4	3	Bulk storage	Intermittent renewables on high voltage networks, interconnectors	2030s

	Innovation opportunity	Cost reduction	Deployment barrier reduction	Relevant technology	Impact on other energy technology families	Timeframe
Distributed storage	**Li-ion technology:** Innovations that lead to improvements in the Li-ion production chain can decrease the development cost using low-cost materials and efficient manufacturing techniques with material recovery from old batteries. There are also opportunities relating to increasing the TRL of novel components for the electrode architecture to increase the specific energy, cycle-life, and calendar life cost.	5	5	Distributed storage	EVs, wind, PV, Heat pumps	2020s
	Mg and Mg-S technology: Current Mg systems still suffer from comparably low discharge voltages and low energy efficiency. There is a need for innovations that can increase both the discharge voltages and energy efficiency.	3	3	Distributed storage	EVs, wind, PV, Heat pumps	2030s
	Metal-air technology (Zn-air and Li-air): Only Zn-air batteries are currently available for demonstration purposes. Innovations are needed that can improve the technology’s round-trip efficiency and power-to-energy ratio. Li-air is at the prototype level and improvements are needed in cycle life and energy density.	3	3	Distributed storage	EVs, wind, PV Heat pumps	2030s
	High temperature battery technology (sodium base, such as Na-S): Innovations are needed that can improve electrode chemistry to reach more flexible ambient temperature designs and address safety constraints cost-effectively. Innovations are also needed to develop new cells capable of ensuring significantly improved and suitable performance for energy-driven storage applications.	4	3	Distributed storage	EVs, wind, PV Heat pumps	2030s
	Flow batteries: Innovations are needed that can help achieve cost reduction of key components including alternative reactants and electrolytes. There are also opportunities to improve the power and energy density as well as the type of membrane and materials for improved membrane lifetime. However, the main challenge of all flow technologies is to reach a volume level that will allow for economies of scale and achieving a competitive cost.	4	4	Distributed storage	EVs, wind, PV Heat pumps	2030s

	Innovation opportunity	Cost reduction	Deployment barrier reduction	Relevant technology	Impact on other energy technology families	Timeframe
Distributed storage	**Balance of plant (BOP) and control:** Innovations are needed around the control and optimisation of storage for grid services and reduced degradation. Battery operating system weight and thermal management are important areas for system improvements to reduce maintenance costs and increase lifetimes.	4	4	Distributed storage	EVs, wind, PV	2020s
	Flywheels: Innovation opportunities in flywheels include the development of systems with robust bearings and utilisation of novel high-stress materials (e.g. graphene) as well as flexible control strategies and applications to provide fast response and inertia to interconnected power systems. The focus should be on reaching improved TRL, integrating these technologies, and testing their reliability for grid applications.	3	2	Fast response storage	Wind Electrified heat and transport	2020s
Fast response storage	**Supercapacitor:** There are innovation opportunities around reaching improved TRLs for novel hybrid designs and technologies, for example using natural carbon sources and focussing on cost-effective electrolytes with less toxicity. There are also opportunities around large-scale demonstration projects in grid applications beyond the current common use of supercapacitors in Uninterruptible Power Systems (UPSs).	2	2	Fast response storage	Wind Electrified heat and transport	2020s
	Superconducting magnetic energy storage (SMES): There are innovation opportunities around new superconducting materials with novel designs and systems to decrease the costs of cooling systems. In particular, improving the cost-performance ratio of High-Temperature Superconductor (HTS) materials would improve the economic viability.	2	2	Fast response storage	Wind Electrified heat and transport	2030s

Source: Carbon Trust, Vivid Economics, expert workshop

Vector coupling

Vector coupling is an emerging source of flexibility that can optimise the utilisation of intermittent renewables and grid capacity. Vector coupling can maximise the utilisation of surplus variable renewable generation during times of weak demand and, by 2050, could be a key source of demand-side response during peak power demand. Although it is difficult to quantify system benefits from vector coupling, the ability of vector coupling projects to reduce electricity demand at peak times suggests its system value is similar to that of demand-side response. Furthermore, by storing hydrogen, vector coupling can provide inter-seasonal balancing, with significant benefits for the energy system.

This report primarily considers coupling of electricity to other energy vectors. Other energy vectors can also be converted to electricity; most notably hydrogen can be used to generate electricity. Various key innovations in, for example, fuel cells, are discussed in more detail in the Hydrogen, Heating and Cooling, Road Transport, and Industry EINA sub-themes.

The primary innovations required for large-scale deployment of vector coupling help to overcome technical barriers. These innovations are particularly aimed at increasing the scale and flexibility of power-to-gas (P2G) projects that produce hydrogen. Given the expected deployment profile of P2G projects, innovations are needed in the short term (5 years) to ensure they can be incorporated during a scale roll-out. Key innovations include:

- **Improving electrolyser flexibility** to mitigate degradation impacts and allow for faster electrolyser response to variable renewable generation. This innovation is applicable across electrolyser types.
- **Establishing green gas blending walls** to allow partial decarbonisation of the natural gas grid by injecting renewable hydrogen from P2G projects. This opportunity includes determining optimal blends of hydrogen, syn-methane, or biogas with natural gas.

Learning by doing can contribute to reducing costs and demonstrating more complex forms of vector coupling. Scale production will be key to reducing the capital cost of electrolysers. Furthermore, demonstration projects can be particularly effective to capture UK-specific learnings and establish a supply chain.[33] Opportunities include:

[33] Both power-to-gas and power-to-liquid will have various UK-specific aspects associated with them, such as the purity of the CO_2 stream and cost of the produced hydrogen (which is heavily dependent on electricity cost). A UK demonstrator would be beneficial to demonstrate commercial viability within the UK context.

- **Demonstration of a full-scale power-to-gas project.** This would test the operation of flexible electrolysis production, and hydrogen storage and injection into the gas network, and demonstrate the feasibility at scale.
- **Demonstration of a pilot-scale power-to-liquid project.** This would use captured carbon from carbon capture, utilisation, and storage (CCUS) facilities and hydrogen from electrolysis to produce synthetic fuels for aviation, shipping, or heavy-duty transport to prove the concept.

The table below highlights the specific innovation needs for vector coupling and their respective impacts on reducing the costs and deployment barriers. The workshop participants discussed the contents of the table and offered feedback. The updated table was afterwards circulated amongst workshop delegates, who were given the opportunity to provide further comments.

Box 11. **Industry workshop feedback**

- The key innovation for vector coupling is reducing electrolyser degradation from flexible operation (across all three types of electrolysers).
- There is a significant need to develop automated manufacturing at scale, particularly if the UK wants to gain market share in large markets.
- Vector coupling, specifically power-to-liquid, is one of the few options to decarbonise aviation and this requires innovations across several technologies, including lower electrolysis and carbon capture costs.

Table 8. **Innovation mapping for vector coupling**

	Innovation opportunity	Cost reduction	Deployment barrier reduction	Relevant technology	Impact on other energy technology families	Timeframe
Power-to-gas	Efficient system design of electrolysers for flexible operation for **alkaline electrolysis cells (AEC)** to reduce the impact of flexible operation on efficiency, purity reduction, and degradation	2	3	Hydrogen	Solar, Wind	2020s
	Modelling and optimisation of proton exchange membrane (PEM), improving PEM lifetimes and reducing degradation during flexible operation	2	4	Hydrogen	Solar, Wind	2020s
	Improving overtime system lifetimes of solid oxide electrolysis cell (SOEC) during flexible operation – aiming to increase system lifetime to over 7,000 hours (and 10,000 hours for stack)	2	3	Hydrogen	Solar, Wind	2030s
	Coordination and control of electrolysers in line with system requirements	3	4	Hydrogen	Solar, Wind	2020s
	Supporting the development of **10-100 MW electrolysers** capable of high-pressure output into the gas transmission networks	4	4	Hydrogen	Solar, Wind	2020s
	Development of efficient production scale-up process through automation to reduce cost	4	4	Hydrogen	Solar, Wind	2020s
	Examine different power and gas distribution and generation **coordination models to optimise vector coupling in operation**	2	5	Hydrogen	Solar, Wind	2030s
	Ammonia – Optimise production methods using intermittent renewables (aim to lower energy use and cost)	3	3	Ammonia	Solar, Wind	2040s
	Cavern storage – understand and validate performance in different UK geologies, such as West vs. East where depth varies, and develop appropriate standards for long-term use	3	3	Hydrogen	Solar, Wind	2020s

	Innovation opportunity	Cost reduction	Deployment barrier reduction	Relevant technology	Impact on other energy technology families	Timeframe
Power-to-gas	Efficient system design of electrolysers for flexible operation for **alkaline electrolysis cells (AEC)** to reduce the impact of flexible operation on efficiency, purity reduction, and degradation	2	2	Hydrogen	Solar, Wind	2020s
	Develop and validate a full system demonstration of the entire process of hydrogen production from intermittent renewables to storage and withdrawal for different uses	4	5	Hydrogen	Solar, Wind	2020s
	Non-cavern storage – examine the viability of hydrogen storage in sites other than salt storage, such as reusing existing offshore gas infrastructure around UK	3	3	Hydrogen	Solar, Wind	2020s
Power-to-heat	**Develop a full-scale demonstration of integrated heat networks powered by intermittent renewables, including matching supply and demand using appropriate thermal storage devices**	4	5	Heat pumps, Resistance heaters	Wind, Solar, Solar thermal	2020s
	Examine routes to optimising 'green-gas' blending percentages and appropriate mix (e.g. syn. methane, bio gas, hydrogen, bio gasification to reach a 100% blend)	4	4	Hydrogen, Heat pumps, Resistance heaters	Wind, Solar, Solar thermal	2020s
Power-to-liquid	**Methanol production** – Develop lower cost methods of synthesis, including lower cost of CO_2 capture, cost of electrolysis (covered in H_2 EINA) and development of larger plant size for cost reduction	2	2	Methanol, Hydrogen	Solar, Wind, Industry, Shipping	2020s
	Synthetic diesel/gasoline - Develop lower cost methods of synthesis, including lower cost of CO_2 capture, cost of electrolysis (covered in H_2 EINA), and larger plant size for cost reduction	3	4	Syn-fuels, Hydrogen	Solar, Wind, Aviation, Shipping, Heavy transport	2030s
	Aviation fuel production – Develop lower cost synthesis methods including CO_2 capture, cost of electrolysis, and develop larger plant sizes for cost reduction	5	5	Syn-fuels, Hydrogen	Wind, Solar, Aviation	2040s

Source: Carbon Trust, Vivid Economics, expert workshop

Networks and data

Given large expected increases in peak electricity demand, innovations in network management will be important to enable 'smart' grid operation reduce reinforcement investment needs. Between 2010-2014, £3-4 billion was invested in the grid annually.[34] This is expected to increase significantly as the electrification of transport and heat increases electricity demand and hence load on the network. The degree of investment required in networks will, however, vary significantly depending on the rollout of DSR, storage, and other enablers of flexibility. In particular, the need for distribution grid reinforcement varies greatly.

Innovation in smart network hardware and management reduces system costs both directly and by enabling other technologies. While the innovations discussed do lower the costs of some relatively expensive equipment, even basic high voltage (HV) transformers can cost £50k, the key benefits of the listed innovations are the broader system benefits. Smarter networks help reduce overall system costs through three primary channels:[35]

- **Enabling flexibility solutions** with large associated system benefits, such as distributed storage and balancing at a local level.
- **Helping to optimise grid infrastructure investment** to strengthen the overall grid most cost-effectively.
- **Directly reducing system operating** cost and renewable curtailment.

Within networks, there are several innovation priorities to enable efficient deployment of distributed generation (DG) and distributed energy resources (DER) more broadly. These innovations are all expected to contribute to cost reductions, by reducing the cost of the distribution (low voltage (LV) and medium voltage (MV)) network. Crucially, they are key enablers to the deployment of distributed storage and generation. Innovations include those in specific electrical equipment, such as fault current limiters (FCLs), but also involve innovation in the broader control systems for the distribution network. Crucially, there is a need to support innovations which ensure the interoperability of newly introduced smart electrical equipment. Table 9 provides a full list.

To enable smarter grid operation and planning, several innovations are required around the use, collection, and analysis of grid data. The growth of sensors and controls across the network to manage power flows and switching requires collecting, storing, and processing several orders of magnitudes more data

[34] DECC (2015) Delivering UK Energy Investment: Networks https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/394509/DECC_Energy_Investment_Report_WEB.pdf
[35] Beyond the listed benefits, smarter networks can also help improve power quality.

than current practice. Innovations in computing, machine learning (ML), and artificial intelligence (AI) are likely to be primarily driven by other sectors. However, there are specific innovation opportunities to ensure advances in other sectors are effectively transferred into the electricity one and can be utilised in grid management. These can be categorised in 3 broad groups:

- **Innovations to enable data collection and storage:** Innovations to enable data on electricity consumption, local grid loads, and generation to be collected and combined are a key enabler. Without this, smart grid operation is unlikely to develop. Although not included as an energy innovation, the 5G network is a further enabler (see Box 12). These innovations in themselves are unlikely to lead to large cost reductions, but are crucial to enabling the cost reductions available from use cases of data insights.
- **Innovations in analysis of data:** This involves understanding the biases of data sets and improving learning algorithms by training on UK system data and developing tailored ML algorithms. Innovations here would be valuable, but are a lower priority than those in data collection as established methods can be used.
- **Innovations in use cases:** This focusses on linking the ML and AI insights into grid operation and planning. AI can be used to automate short-term grid management, locally, regionally, and nationally. This would consider near real-time data and significantly lower costs. Similarly, ML can be used to optimise grid investment.

The table below highlights the specific innovation needs for networks and data and their respective impacts on reducing costs and deployment barriers. The table contents were discussed with workshop participants. Based on feedback, the updated table was circulated amongst workshop delegates, who were given the opportunity to provide further comments.

Box 12. **5G and data collection**

- Fifth generation telecommunication (5G) will be rolled out in the UK from 2019 onwards. It is expected to increase networking speed by five-fold (compared to 4G) initially, and up to 20-fold as the network matures.
- This step change in communication speed is expected to enable a move towards the 'Internet of Things' (IoT) across the economy.
- For the energy sector, it would enable sensors across the grid, and appliances, vehicle chargers etc. to easily communicate with central databases and platforms without needing a traditional internet connection, reducing cost.

Box 13. **Industry workshop feedback**

- The innovations to get to a genuine 'smart' network are heavily interlinked. A coherent package of innovation will be required to unlock value.
- There is a significant amount of further network optimisation that can be achieved without necessarily requiring big data/AI/ML.

Table 9. **Innovation mapping for networks and data**

	Innovation opportunity	Cost reduction	Deployment barrier reduction	Relevant technology	Impact on other energy technology families	Timeframe
Networks	**Fault current limiters (FCL):** To allow network protection systems to isolate faults in a safe manner by limiting the maximum fault current. Deployment will help the safe, cost-effective deployment of synchronous sources in the distributed grid, and improve fault visibility. Initial trials are ongoing, but there is room for further innovation in designs and commercialisation of the technology.[36]	3	4	Network	Enables synchronous generators (e.g. CHP)	2020s
	Advanced distributed voltage control (ADVC): With the increased penetration of distributed generators, there is a greater need for more precise and near real-time monitoring and control. The integration of ADVCs in MV and LV grids provides the ability for more active control of voltage levels by leveraging power electronics and deployment of solid-state devices within the LV grid.	3	4	Network	Enables integration of EV (V2G), DG, and storage in the LV network	2020s
	Advanced control systems and network automation (sub 132 kV): Complexity of power flows in the distribution network is growing. This is due to the increased deployment of distributed energy resources (DERs). As a result, there is an increasing requirement to monitor and control power characteristics at lower voltage levels to ensure safety and quality of supply.	4	4	Network	Enables integration of EV (V2G), DG, and storage in the LV network	2020s
	LV modelling and mapping: There is an increased need for modelling and mapping of the LV grid due to the transformation of household consumers into prosumers. A better understanding of the dynamics of the grid will help improve active management and the operation of the LV grid, which has historically been developed on a 'fit and forget' basis. . Trials are ongoing, but a significantly higher coverage, including an understanding of interactions between local grids, will be required.	3	4	Network	DERs in LV network	2020s
	Alternative transformer technologies: The digitalisation of the LV network will require having smart secondary distribution substations. The digitalised transformer will be a key component of these substations. These types of transformers will allow the network operator to visualise in real time the operation of the transformer MV/LV, as is possible today with HV/MV transformers at the primary distribution substation.	3	3	Network	DERs in LV network	2020s

[36] Ofgem (2017). RIIO Network Innovation Competition. https://www.ofgem.gov.uk/ofgem-publications/107894

	Innovation opportunity	Cost reduction	Deployment barrier reduction	Relevant technology	Impact on other energy technology families	Timeframe
Applications of HPC, AI and ML in data-rich energy systems	**Enabling data collection: Cyber security and privacy** Standards and safeguards must be developed for platforms capable of appropriately balancing the benefits of easily shared and accessible data with security and privacy.	2	5	Smart grids	DG, EV, Storage	2020s
	Enabling data collection: Address data quality and bias. Establish 'golden data sets' as standards for data quality and for use in algorithms' training.	3	5	Smart grids	DG, EV, Storage	2020s
	Enabling data collection: Sensors across LV network and LV assets. This includes establishing the appropriate balance of sensors required across the LV system, given the significant cost (up-front and maintenance) of sensors.	3	5	Smart grids	DG, EV, Storage	2020s
	Enabling data collection: Platforms to manage and store large quantities of metering/sensor data to a common standard, at a minimum quality level, and easily accessible	2	4	Smart grids	DG, EV, Storage	2030s
	Enabling AI/ML application: Develop tailored ML methods: Methods for rapid classification and validation for learning algorithms in smart grid environments	2	3	Smart grids	DG, EV, Storage	2020s
	Enabling ML/AI application: Scalable architectures for conducting advanced analytics and control of numerous devices in power systems	2	3	Smart grids	DG, EV, Storage	2020s
	Use cases: Load management, power flow management, system coordination, high resolution control of DGs/storage/EVs	5	3	Smart grids	DG, EV, Storage, DSR, Networks	2020s
	Use cases: Forecasting and optimisation algorithms for system/network management – load forecast, EV journey/charging, battery charge/discharge	3	3	Smart grids	DG, EV, Storage, DSR, Networks	2020s
	Use cases: Infrastructure planning	4	3	Smart grids	DG, EV, Storage, DSR, Networks	2020s

Source: Carbon Trust, Vivid Economics, expert workshop

Business opportunities within smart systems and flexible infrastructure

Overview

Box 14. **Objective of the business opportunities analysis**

The primary objective is to provide a sense of the relative business opportunities against other energy technologies. To do so, the analysis uses a consistent methodology across technologies to quantify the 'opportunity'; in other words, what *could* be achieved by the UK. The analysis assumes high levels of innovation but remains agnostic about whether this is private or public. This distinction is made in the final section of the report. The two key outputs provided are:

- A quantitative estimate of the gross value added, and jobs supported associated with SMART systems, based on a consistent methodology across technologies analysed in the EINA. Note, the GVA and jobs supported are *not* necessarily additional, and may displace economic activity in other sectors depending on wider macroeconomic conditions.

- A qualitative assessment of the importance of innovation in ensuring UK competitiveness and realising the identified business opportunities. Note, the quantitative estimates for GVA and jobs supported cannot be fully attributed to innovation.

The following discussion details business opportunities arising both from exports and the domestic market. An overview of the business opportunities, and a comparison of the relative size of export and domestic opportunities, across all EINA sub-themes is provided in the overview report.

- More detail on the business opportunities methodology is provided in the Appendix.

The market for smart energy system technologies is potentially large, as countries increasingly electrify and deploy variable renewables. Global investment in electricity transmission and distribution networks reached $303 billion in 2017, with $33 billion spent on smart grid technologies aimed at incorporating variable renewables and improving operating efficiency.[37] As more renewables and storage are incorporated into

[37] IEA (2018) World Energy Investment 2018 https://www.iea.org/wei2018/

global energy systems, the share of spending on smart system technologies is expected to increase.

The 2050 market for smart system technologies is highly dependent on how electricity systems, and the associated market arrangements, develop. Business cases for most smart grid technologies crucially depend on how flexibility is remunerated. With the notable exception of behind-the-meter storage, smart technologies will only be attractive in countries where the electricity market rewards, at least partially, flexibility services.

Given the diffuse nature of export opportunities for smart energy systems, our analysis attempts to provide an indication of potential opportunities rather than quantifying all opportunities. The analysis presented illustrates potential business opportunities across several key markets, but is not a comprehensive assessment of all smart export opportunities. This analysis focuses on smart decarbonisation systems. There are wider smart business opportunities and crossover opportunities (e.g. between decarbonisation and lifestyle services), however, these are outside the EINA's focus on energy. Where possible the EINA's bottom up methodology (Appendix 3) is applied. However, markets and business models around smart goods and services are very immature. Consequently, this analysis is focussed primarily on market sizing, and the results are intended as an indication of the size of commonly discussed opportunities, rather than a comprehensive quantifying of the overall opportunity. Domestic business opportunities for each smart system technology are set out at the end of this section and supplementary estimates of business opportunities from domestic markets are available in Appendix 5.

Of the export opportunities in associated equipment, the export of smart chargers for EVs could be the greatest opportunity for the UK, followed by smart network equipment and batteries:

- Exports of smart vehicle chargers could add £800 million in GVA and 7,800 jobs per annum by 2050, driven by growth in demand from the EV market.[38]
- The potential annual export of equipment and associated services for smart networks could be around £200 million per annum by 2050, supporting 3,000 jobs.[39]

[38] See Appendix 3 for the methodology to estimate this opportunity.
[39] Ernst & Young (2012) Smart Grid: a race worth winning? https://www.ey.com/Publication/vwLUAssets/Smart-Grid-A-race-worth-winning/$FILE/EY-Smart-Grid-a-race-worth-winning.pdf

- Battery storage exports could support £400 million GVA and 3,000 jobs per annum by 2050, with exports focussed on the European market.[40]

There are substantial export opportunities in services, with potentially £950 million GVA per annum by 2050 in aggregation services alone.[41] The UK is a leader in aggregation services, with the opportunity to perform these for the EU27 market**.** Expert consultation identified advisory and consultancy services as a large opportunity across the different smart system markets. Furthermore, established UK competencies in engineering, procurement, and construction management (EPCm) services and digital services can be leveraged to deliver vector coupling projects and grid management software and services. Although immature and uncertain, the total service opportunity could well be larger than the export opportunity for goods.

The business opportunities analysis is set out as follows:

- *Export opportunities* across smarter markets, DSR, storage, vector coupling, and networks and data are discussed in turn in turn. Where possible, opportunities for both goods and services are quantified.
- *Domestic opportunities* are set out after the export opportunities. The relative size of domestic and export opportunities is shown in Appendix 5.

[40] See Appendix 3 for the methodology to estimate this opportunity
[41] Aggregation is a simplified description of the services provided by companies in this space as it only refers to the main business model. Associated software platforms can also offer broader services.

Box 15. **The UK's current SMART systems industry**

- The UK is a strong competitor in aggregation services (demand-side response and constraint management) and UK companies, such as KiWi Power, have exported platforms and expertise to European utilities.[42]
- There are flexible market start-ups with innovative offerings such as peer-to-peer electricity trading and blockchain-secured flexible market platforms.[43]
- In order to enable the UK's DSR industry, smart meters have been rolled out since 2012. HMG is committed to ensuring smart meters are offered to all homes and small businesses by 2020, with 70-75% deployment expected by 2020.[44]
- DSR is currently focussed on larger industrial customers, with some trials in the domestic sector but limited engagement.[45]
- The UK has some battery manufacturing capability, primarily for the Nissan Leaf.
- The UK is one of the leaders in power-to-gas vector coupling projects, having deployed two of the largest hydrogen from electrolysis refuelling stations in Europe.[46]
- Power-to-gas projects are supported by emerging UK capabilities in fuel cells and hydrogen grids, which provide a domestic end use for P2G-produced hydrogen.

[42] KiWi Power (n.d.) Partners https://www.kiwipowered.com/clients-partners/partners/
[43] Piclo (P2P) and Electron (blockchain).
[44] National Audit Office (2018) https://www.sms-plc.com/insights/blogs-news/national-audit-office-publishes-report-on-uk-smart-meter-rollout/
[45] BEIS (2017) . Realising the potential of demand-side response to 2025. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/657141/DSR_research_report.pdf
[46] E4tech (2016) Hydrogen and fuel cells: opportunities for growth. A roadmap for the UK http://www.e4tech.com/wp-content/uploads/2016/11/UKHFC-Roadmap-Final-Main-Report-171116.pdf

UK business opportunities from export markets

Box 1. **Interpretation of business opportunity estimates**
The GVA and jobs estimates presented below are *not* forecasts, but instead represent estimates of the potential benefits of the UK capturing available business opportunities. The presented estimates represent an unbiased attempt to quantify opportunities and are based on credible deployment forecasts, data on current trade flows, and expert opinion, but are necessarily partly assumption-driven. The quantified estimates are intended as plausible, but optimistic. They assume global climate action towards a 2 degree world and reflect a UK market share in a scenario with significant UK innovation activity.[47] More information on the methodology, including a worked example, is provided in Appendix 3, and a high level uncertainty assessment across the EINA subthemes is provided in Appendix 4.

Smarter markets

Across the globe, the market for smart market platforms and aggregation services is immature. Grid dispatch remains predominately unidirectional, adjusting supply to meet demand. Most demand does not face real-time price signals, requiring supply to actively adjust. Given that supply is becoming more variable as intermittent renewables are incorporated into the grid, the value of flexibility is increasing. However, relatively few global jurisdictions have markets comparably as flexible as the UK today, and future market developments and sizes are uncertain and difficult to accurately predict.

The size of export opportunities for smart market platforms and services is highly contingent on how electricity markets develop in other jurisdictions. The development and expansion of flexible markets depends on an enabling regulatory environment that allows for innovative electricity market services and business models. If a jurisdiction opts to meet the dual challenge of integrating variable renewables and increased electrification of transport and heat by substantially building out physical grid infrastructure, opportunities for flexible markets and aggregation services will be limited.

The UK is competitively positioned to export highly traded technical and advisory services and supporting software. The UK's liberalised and increasingly competitive supplier market means UK companies can develop business models for flexible markets domestically and leverage existing knowledge of consumer behaviour, billing services, and engagement models.

[47] Note, other IEA climate scenarios were also used as a sensitivity. Where the level of global climate action has a meaningful impact on market size, this is highlighted in the market overview section. Full results are available in the supplied Excel calculator.

- **The UK is in a strong position to export technical and advisory services to assist in the development of flexible markets abroad.** This can draw on expertise gained from UK flexible market initiatives already underway. Examples are the UK Power Network's online market place for local flexibility,[48] Western Power Distribution, Centrica's Cornwall Local Energy Market,[49] and HMG's Prospering from the Energy Revolution industrial strategy challenge fund.[50] There are also likely to be competitive spillovers from the UK's well established financial, consulting, telecommunications, and computer services sectors, which each exported over £6.8 billion of services in 2017.[51]
- **The UK can leverage existing competitive sectors, and developing specialised expertise, to export underlying flexible market platform software and services.** The UK's existing strengths in AI, ML, IT, and financial services could help the UK create innovative products, given the significant talent pool. Furthermore, the Industrial Strategy is aiming to keep the UK at the forefront of AI, naming AI combined with data as one of the first of four Grand Challenges.[52] There are UK start-ups currently engaged in building peer-to-peer electricity markets and blockchain-secured flexible electricity markets that could export software or services in the future.[53] UK distribution companies, including UK Power Networks and Northern Power Grid, are pioneering dynamic (power) line ratings (DLRs),[54] which could be packaged into a software offering and exported.

The export of aggregation services is an opportunity for the UK, with a large market and potential UK competitiveness.[55] Indicative estimates suggest the UK could capture around £950 million in GVA annually in the EU27 market by 2050. The UK's early electricity market liberalisation has helped position UK companies as leaders in aggregation services. To illustrate the size of this opportunity, we assume the UK captures a 10% market share of the future EU27 market for aggregation services. Assuming 33% of EU27 capacity becomes flexible and aggregated, the total EU27

[48] Open Utility (2018) UK Power Networks and Open Utility to trial new energy trading platform https://piclo.energy/publications/open-utility-UKPN-flex-marketplace-collaboration-press-release.pdf
[49] Western Power Distribution (n.d.) Plugs and Socket/Cornwall Local Energy Market https://www.westernpower.co.uk/customers-and-community/community-energy-schemes/articles-and-case-studies
[50] The Prospering from the Energy Revolution industrial strategy challenge fund includes an international engagement workstream to access overseas markets. See: Innovate UK (2018) Prospering from the energy revolution: full programme details https://www.gov.uk/government/news/prospering-from-the-energy-revolution-full-programme-details
[51] ONS (2019) International trade in services, UK: 2017 https://www.ons.gov.uk/businessindustryandtrade/internationaltrade/bulletins/internationaltradeinservices/2017
[52] BEIS (2018) The Grand Challenges https://www.gov.uk/government/publications/industrial-strategy-the-grand-challenges/industrial-strategy-the-grand-challenges#artificial-intelligence-and-data
[53] Piclo (formally Open Utility) and Electron respectively.
[54] IRENA (2019) Innovation Landscape for a Renewable-Powered Future: Solutions to Integrate Variable Renewables https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Feb/IRENA_Innovation_Landscape_2019_report.pdf
[55] For example, KiWi power has exported aggregation services to the EU27.

market for aggregation services could add £9.5 billion per annum to GVA by 2050. From this market, the UK could conceivably capture £950 million in GVA and support around 2,400 jobs per annum by 2050.[56]

The UK is likely to face considerable competition from the US, Germany, Japan, and Australia in the future. The UK is expected to face competition from countries with high levels of variable renewables, high uptake of DSR and storage, and competitive electricity markets. This set of countries is likely to include the US, Germany, Japan, and Australia. The UK has an opportunity to blunt future competition if it moves early on introducing a domestic flexible market and effectively leverages strengths in IT, financial settlement, aggregation, and advisory services.

Box 2. **Industry workshop feedback regarding business opportunities**

- The UK is strong in flexible market design and establishing a corresponding regulatory framework that balances trade-offs and co-optimises generation. This unique set of expertise could support the export of advisory and consultancy services.
- UK firms are likely to excel in the role of a flexible market system integrator that combines hardware, software, and expertise to bring a functioning flexible market together.
- The expansion of flexible markets in developing countries could become a key market for UK advisory and consultancy services.[57]
- The existing competitive electricity market is an advantage for UK firms and helps the UK lead on existing consumer and service models that can be adapted to more flexible markets.
- There is also an opportunity for the UK to provide educational services on how to manage a flexible market or use advanced digital technologies to forecast electricity supply and demand.

[56] 2050 generating capacity (low estimate in 2050) from Carbon Trust and Imperial (2016) An analysis of electricity system flexibility for Great Britain. This indicative estimate expects 1,338 GW of EU27 generating capacity in 2050. See low scenario of Carbon Trust and Imperial (2016) An analysis of electricity system flexibility for Great Britain.
[57] The Energy Catalyst programme is already supporting flexible market trials in Sub-Saharan Africa and South Asia. See: Innovate UK (2018) Competition guidance for Energy Catalyst round 6: transforming energy access https://www.gov.uk/government/publications/competition-guidance-for-energy-catalyst-round-6-transforming-energy-access

Demand-side response

DSR is expected to be the fastest growing segment of the European smart grid market to 2025.[58] In the UK, the National Grid's Power Responsive programme aims to increase participation in DSR and storage.[59] Trials to date have focussed on industrial and commercial customers, with engagement from residential customers expected to increase further down the line.

The current market within DSR is focussed on the roll-out of enabling technologies such as smart meters. The global stock of installed smart meters reached 570 million units in 2016,[60] growing at 22% annually from 2012. The UK currently captures 4% of the EU market for electricity meters, though this includes the wider market beyond smart meters. However, the UK's domestic roll-out of smart meters may provide a knowledge base for DSR technologies.

In future, export opportunities within DSR are expected to include advisory services, as well as hardware such as smart or V2G chargers. Expert consultation indicates the UK is active in understanding how to effectively operate DSR, which presents services market opportunities. This includes services around the installation and linking of equipment into markets. Early experience with deployment of smart systems and DSR trials[61] offer opportunities to develop knowledge for export. In addition, the markets for hardware, such as smart vehicle chargers, are expected to grow with deployment of technologies like electric vehicles, representing domestic manufacturing opportunities.

The UK has academic strength and numerous demonstration projects within DSR; coordinating this with industry could allow the UK to develop expertise around data analytics. Research on DSR potential has been undertaken by academics in Imperial College London, the University of Sussex, and many other domestic institutions.[62] Alliances between manufacturers and other companies with specialised knowledge could allow exporters to reach wide export markets in both goods and services. Domestic deployment is likely to be key in developing an exportable business model.

[58] Frost & Sullivan (2016) European Smart Grid Market Overview https://ww2.frost.com/files/2314/7151/3698/European_Smart_grid_market.pdf
[59] Power Responsive http://powerresponsive.com/
[60] IEA (2017) Energy Snapshot https://www.iea.org/newsroom/energysnapshots/global-contracted-installations-of-electricity-smart-meters.html
[61] DECC (2012) Demand Side Response in the domestic sector https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/48552/5756-demand-side-response-in-the-domestic-sector-a-lit.pdf
[62] BEIS (2017) Realising the Potential of Demand Side Response to 2025 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/657144/DSR_Summary_Report.pdf

Given its relative maturity, we consider the market for smart or V2G chargers as an indicative manufacturing export opportunity.[63] As grids (particularly grid management systems) are upgraded to accommodate V2G charging, and the market for electric vehicles grows exponentially, the tradeable market for smart chargers is expected to grow to £24.4 billion annually by 2050. The UK has an opportunity to leverage its existing expertise in smart systems and its early production facilities of EVs.[64] However, competition is expected to be strong from other countries with EV production, such as Germany and China. We therefore estimate the UK could capture 8% of the global market by 2050. This is twice the UK's current market share of ICEV production and assumes the UK can leverage EV production into packaging smart vehicle chargers.

The market for smart or V2G chargers could add £800 million in GVA and support 7,800 jobs per annum by 2050. This relies on the assumption that the UK grows its share of the global smart charger market to 8% through innovation. Almost 80% of this opportunity comes from markets outside Europe, as it is assumed the UK can export globally at a minimal disadvantage. This market is aligned with the International Energy Agency (IEA)'s 2-degree scenario, which forecasts deployment of 796 million EVs by 2050. Under the more ambitious Beyond-2-degree scenario, deployment of 1.3 billion EVs could grow the UK export opportunity to over £1.7 billion GVA and support 17,000 jobs per annum by 2050.

In addition, future markets for DSR services are unclear but are likely to present large opportunities. While installation is likely to be conducted locally, there is expertise associated with linking equipment such as vehicle chargers into the grid that could be exported. The opportunities associated with the aggregation of demand-side response are discussed in the preceding section on smarter markets.

Box 3. **Industry workshop feedback regarding business opportunities**

- Developing the existing knowledge base could give the UK exportable expertise in services, which are likely to present the greatest opportunity.
- Domestic deployment is crucial in developing know-how for export.
- The UK has academic strength in DSR, which could be key in developing goods and services for export.

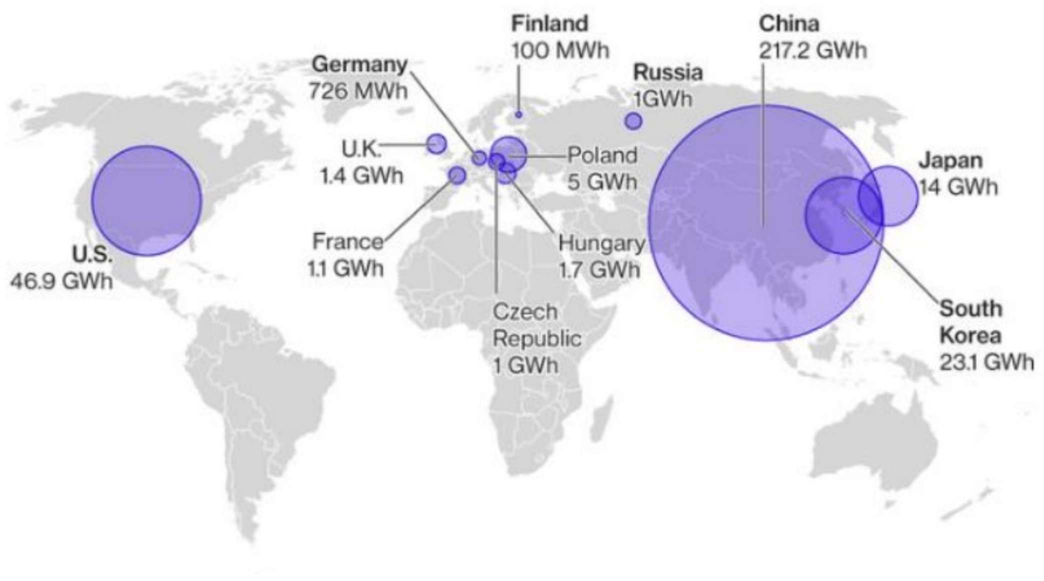
[63] An explanation of the methodology followed to calculate GVA and jobs can be found in Appendix 3.
[64] Green Alliance (2018) How the UK can lead the electric vehicle revolution https://www.green-alliance.org.uk/resources/How_the_UK_can_lead_the_electric_vehicle_revolution.pdf

Electricity storage

The market for storage, particularly batteries, is expected to grow rapidly to 2050. Global stationary battery storage capacity is expected to increase from approximately 50GWh today to nearly 4,000GWh by 2050.[65] To achieve this, around £600 billion of global investment, cumulatively to 2050, will be required. Around 20% of this, £120 billion, is expected in Europe. Given the immaturity of other tradeable battery types, the following focusses on Li-ion, but the overall opportunity is likely to be of a similar size if different storage technologies come to dominate the stationary storage market.

Batteries are highly traded, with the bulk of production in large-scale factories. The scale of battery production factories is rapidly increasing. Tesla's Gigafactory is the best-known example, with a production capacity of around 20GWh per year.[66] The trends towards large-scale battery manufacturing is likely to persist, with the benefits of economies of scale (if not for full battery packs, at least for the cells) typically outweighing (regional) transport costs. Figure 9 shows current and planned production capacity for batteries for the combined EV and stationary market. Although production clearly concentrates in the east, the UK has a notable share of European productive capacity.

Figure 2. **Existing and planned battery manufacturing capacity (EV and stationary)**



[65] Bloomberg (2018) Energy Storage is a $620 Billion Investment Opportunity to 2040 https://about.bnef.com/blog/energy-storage-620-billion-investment-opportunity-2040/
[66] Tesla (2018) Tesla Gigfactory https://www.tesla.com/en_GB/gigafactory

Source: Bloomberg New Energy Finance[67]

The ability of the UK to capture international market share in scale manufacturing is uncertain. The UK currently has one significant battery manufacturing plant, producing batteries for the Nissan Leaf. However, most of the parts for production are imported through Nissan's supply chain.[68] The UK does nevertheless have several advantages which could allow it to capture market share in a rapidly growing market.

- Appreciable research expertise around batteries and alternative forms of stationary storage.
- A significant automotive industry, creating potential spillovers from battery production and development for EVs into stationary applications.
- Ongoing programmes such as the Faraday Battery Challenge and the Prospering from the Energy Revolution challenge, which explicitly focus on export market development.

Indicatively, UK stationary battery exports could add around £400 million GVA and support 3,000 jobs per annum by 2050. This estimate is based on relatively bullish Bloomberg estimates for the stationary battery market. Furthermore, it assumes that the UK captures around 8% of the European market, driven by continued innovation and spillovers from the UK's automotive industry. The UK is assumed to capture 2% of the rest of the global market, as battery storage is expected to favour regional deployment.

Despite using optimistic market forecasts, and appreciable UK market shares, the number of jobs supported by stationary battery manufacture is relatively modest. This is driven by four factors:

- The market for stationary batteries, while significant, is an order of magnitude smaller than the wider battery market.
- Battery costs are expected to decrease significantly, reducing revenue from manufacturing.
- We do not consider the impact on the wider supply chain for battery manufacturing.[69] Although this is line with current trends in UK battery manufacturing (with most parts imported), this may change in future, which would imply further jobs indirectly supported through battery manufacturing.

[67] Reproduced from MIT (2018) Energy Storage for the grid: Policy options for sustaining innovation http://energy.mit.edu/wp-content/uploads/2018/04/MITEI-WP-2018-04.pdf
[68] Battery production for Nissan vehicles is done by AESC, a joint venture between Nissan, NEC, and Tokin corporation.
[69] This is consistent with the wider EINA methodology.

- Battery manufacturing is relatively highly automated, with high labour productivity. Hence, relatively few jobs are associated with significant GVA.

Vector coupling

The global market for vector coupling is still in its infancy, but significant growth is possible by 2050. There are around 50 pilot and demonstration power-to-gas facilities globally, with most located in Europe, followed by Japan and the US.[70] All projects to date use small-scale electrolysers (<10MW). However, a 10MW electrolyser has been announced and a large 50-100MW electrolyser studied for deployment in the UK.[71] Existing pilot and demonstration plants are split between pure hydrogen and synthetic methane production for use in transport, stationary fuel cells, and direct injection into the gas grid.[72] The IEA is anticipating tempered growth in hydrogen production.[73] However some organisations, such as the Hydrogen Council, expect power-to-gas pilot projects to scale significantly more quickly, along with large-scale natural gas with CCS reforming projects.[74]

High value vector coupling components and services, such as electrolysers and engineering services, are likely to be highly traded. Existing UK-based companies have exported electrolysers and have won contracts to construct electrolysers in Europe.[75] High value components for these projects are typically produced by specialists and exported. Furthermore, the design and construction of P2G projects are expected to represent 10-15% of the project value, with associated EPCm services, and to be highly traded.[76] Bulk components, such as concrete and steel pipes, are sourced closer to the project site.

The UK is well positioned to export high value components and services for vector coupling projects. The UK has strengths in electrochemistry and catalysis, and electrolyser manufacturing and has demonstrated deployment of electrolyser-based refuelling stations. UK-based companies have deployed two of the largest hydrogen

[70] Oxford Institute for Energy Studies (2018) Power-to-gas: Linking Electricity and gas in a Decarbonising World? https://www.oxfordenergy.org/wpcms/wp-content/uploads/2018/10/Power-to-Gas-Linking-Electricity-and-Gas-in-a-Decarbonising-World-Insight-39.pdf
[71] Ibid.
[72] Ibid.
[73] The IEA expects only 418PJ, or about 0.1% of final energy demand, to be met with hydrogen in 2050 under a 2-degree scenario. See: IEA (2017) Energy Technology Perspectives 2017. On the other hand, the Shell Sky scenario estimates 8,700PJ of hydrogen demand in 2050. See Shell (2018) Sky Scenario https://www.shell.com/energy-and-innovation/the-energy-future/scenarios/shell-scenario-sky.html
[74] Hydrogen Council (2017) Hydrogen scaling up: a sustainable pathway for the global energy transition http://hydrogencouncil.com/wp-content/uploads/2017/11/Hydrogen-Scaling-up_Hydrogen-Council_2017.compressed.pdf
[75] ITM power (2018) World's largest hydrogen electrolysis in Shell's Rhineland refinery http://www.itm-power.com/news-item/worlds-largest-hydrogen-electrolysis-in-shells-rhineland-refinery
[76] Akin to the ratio of the value of these services to capex in general high capex projects in industry (specifically oil and gas).

refuelling stations by volume in Europe.[77] The UK is also competitive in engineering, procurement and construction management (EPCm), and project management, which it currently successfully exports in related industries. In particular, the UK's engineering and oil and gas industries are well suited to lend their expertise to vector coupling projects, particularly P2G producing hydrogen for refineries. The UK is typically competitive in this area. For example, in 2016, the UK captured 11.8% of the global oilfield services (OFS) market, worth £36 billion in turnover.[78]

Deploying domestic vector coupling projects at scale would be a strong enabler for UK exports. Successful deployment of multiple power-to-gas projects across gas types (hydrogen or synthetic methane) and end uses (transport, heat, or industry) would enhance the UK's export position. It would demonstrate the UK supply chain can deliver a diverse array of power-to-gas projects. These projects would be strong export enablers for both components, such as flexible electrolysers, and EPCm services.

The key international competitors in vector coupling are Germany, the US, China, and Japan. Germany is the main European competitor, capturing a 25% share of the EU's electrolyser market, compared to the UK's 6% share in 2017. China, Japan, the US, and Italy also manufacture and export electrolysers.[79] Regions with very low renewable generation costs, such as Australia, could also compete with the UK in the export of hydrogen.

Exports of hydrogen, although highly uncertain, could be a significant opportunity. The UK has some of the most favourable onshore and offshore wind sites in Europe. This may enable the UK to produce relatively cheap hydrogen from electrolysis for the EU27 market.[80] Indicative market sizing suggests that if 5% of the UK's 2050 hydrogen production is exported to the EU, this would equate to approximately £380 million in GVA annually.[81] Note, this is a speculative estimate and, depending on how the global market for hydrogen develops, may not materialise at all.

[77] E4tech (2016) Hydrogen and fuel cells: opportunities for growth. A roadmap for the UK http://www.e4tech.com/wp-content/uploads/2016/11/UKHFC-Roadmap-Final-Main-Report-171116.pdf
[78] Three-year average applied to calculate market share (2014-2016).
[79] Market shares and competing electrolyser manufacturers based on analysis of COMTRADE data using HS code 854330.
[80] Up to 466GW of fixed and floating offshore wind capacity. See: The Offshore Valuation Group (2010) A valuation of the UK's offshore renewable resource http://publicinterest.org.uk/download/archive/offshore_valuation_full.pdf
[81] This indicative estimate applies an assumed 160TWh of UK hydrogen production in 2050 in line with ESME modelling. It applies the same 2050 cost of hydrogen production as the Hydrogen subtheme EINA and assumes a GVA/turnover ratio of 53%, in line with that of industrial gases.

Box 4. **Industry workshop feedback regarding business opportunities**

- The UK is competitive in the manufacture of electrolysers and the engineering services for P2G projects.
- The UK's large domestic gas grid and high-quality wind resource are strong enablers for the UK domestic P2G market, which can support UK international competitiveness.
- EU27 industry is likely to demand renewable hydrogen for the decarbonisation of steel and aluminium production. The UK could potentially export hydrogen generated from domestic P2G projects to meet this demand.
- By 2050, renewable hydrogen demand from EU27 industry could be a substantial export opportunity if the UK deploys a substantial quantity of P2G facilities.

Networks and data

The market opportunities for smart networks and data can be broadly split into hardware, and software and services.

- **The market for network equipment is large and highly traded globally.** Current global trade in transformers, invertors, convertors, and related parts is £64 billion. The UK is a sizeable exporter, with around £1 billion of exports in 2017.[82] Currently, only a fraction of this trade represents innovative and smart equipment. However, in future the ability to supply smart equipment will likely provide a competitive edge and an opportunity for the UK to capture a larger market share.
- **In addition to equipment, there is an opportunity to export network management software and expertise.** The UK's research expertise, combined with experience in managing an increasingly decentralised grid, creates several export opportunities. Workshop participants and wider research suggest software solutions for network management and associated services around designing and implementing smarter networks are particularly significant opportunities.[83]

Successfully exporting smart network equipment and services may be hindered by varying network standards. Particularly for small and medium enterprises (SMEs)

[82] Based on COMTRADE data using HS8504.
[83] Ernst & Young (2012) Smart Grid: a race worth winning? https://www.ey.com/Publication/vwLUAssets/Smart-Grid-A-race-worth-winning/$FILE/EY-Smart-Grid-a-race-worth-winning.pdf

which have developed a successful UK business model, it may not be straightforward to export abroad given the highly regulated nature of networks and network data.

The potential annual exports associated with equipment and services for smart networks are expected to be around £200 million per annum by 2050.[84] This is based on Ernst and Young research, which suggests most of the export opportunity is likely to come from equipment rather than services. Based on productivity in the sector, smart grid related exports would support approximately 3,000 jobs per annum by 2050.

UK business opportunities from domestic markets

In addition to the domestic deployment of the goods and services identified above, installation and operations and maintenance services offer opportunities for domestic businesses. Given the uncertainty of the future deployment of smart systems, this analysis values indicative business opportunities associated with smart energy systems which aid decarbonisation.[85] There are wider smart business opportunities, such as lifestyle services, however, these are outside the EINA's focus on energy. Indicative domestic business opportunities within smart systems are assessed for the following 4 technologies:

- **V2G and smart chargers:** considers manufacturing, installation and operations and maintenance (O&M) services.
- **Electricity storage:** includes business opportunities associated with the manufacture and installation of battery storage.
- **Smart network equipment:** considers the equipment and services associated with smart grids. This is essentially transmission and distribution infrastructure owned and operated by network companies, which includes sensors and communications, management and control systems and substation automation, in line with the Department of Energy & Climate Change (DECC) and OFGEM Smart Grid Vision and Roadmap.[86]
- **Aggregation services:** assesses aggregation of demand-side response and constraint management services.[87]

High levels of smart system deployment in the UK energy system to 2050 are possible, but uncertain. The future deployment of smart systems is uncertain given the commercial immaturity of smart system technologies, the evolving nature of smart

[84] Ibid.
[85] A spectrum of other technologies and services which could be considered 'smart' are being developed which add value beyond the provision of energy.
[86] DECC & OFGEM (2014) Smart Grid Vision and Roadmap: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/285417/Smart_Grid_Vision_and_RoutemapFINAL.pdf
[87] Aggregation is a simplified description of the services provided by companies in this space as it only refers to the main business model. Associated software platforms can also offer broader services.

business models, and the continuing development of associated regulatory frameworks. Scenario exercises and energy modelling have estimated the potential uptake of smart systems to 2050. For V2G and smart charger and electricity storage deployment estimates, detailed bottom up studies are used to complement ESME estimates as the value, and therefore deployment, of EV charging and battery storage is partially dependent on spatial factors that ESME does not account for. These deployment estimates are set out below:

- **V2G and smart chargers:** uses public charger deployment estimates by Systra, Cenex and Next Green Car for the CCC in line with the fifth carbon budget, which estimates the need for 29,000 public chargers by 2030.[88] Private charger deployment estimates rely on ESME EV deployment estimates and the 1.1 ratio of private chargers to EVs identified by the IEA.[89] The IEA ratio implies an increase from today and should be considered a relatively high estimate for the UK.
- **Electricity storage:** uses storage deployment estimates from Carbon Trust and Imperial College (2016).[90] This storage estimate includes 2.8 GW of pumped hydro, which is excluded to obtain a battery storage deployment estimate of 12GW in 2050. However, the demand for electricity storage is sensitive to estimates of the 2050 electricity generation mix and the availability of alternative source of electricity system flexibility. For example, National Grid's Future Energy Scenarios estimates between 17 and 29 GW of electricity storage, which includes pumped hydro and other types of electricity storage, could be needed by 2050.[91]

The share of the smart systems market captured by domestic businesses is uncertain given the immaturity of the market. The current share of similar UK goods and services offers guidance on plausible future shares. Across the components considered within smart systems, market shares are outlined in Appendix 5 and detailed below:

- **V2G and smart charger hardware:** the UK's share of the V2G and smart charger hardware market will likely depend on UK charger OEM's partnering with EV manufacturers to become the preferred suppliers. Although the UK currently has a strong position in V2G as a result of a HMG funded innovation project, given the immaturity of the V2G and smart charger market today, the ability of UK

[88] Systra, Cenex and Next Green Car (2018) Plugging the gap: An assessment of future demand for Britain's electric vehicle public charging network https://www.theccc.org.uk/publication/plugging-gap-assessment-future-demand-britains-electric-vehicle-public-charging-network/
[89] IEA (2018) Global EV Outlook https://www.iea.org/gevo2018/
[90] Carbon Trust and Imperial College (2016) An analysis of electricity flexibility for Great Britain https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/568982/An_analysis_of_electricity_flexibility_for_Great_Britain.pdf
[91] National Grid (2018) Future Energy Scenarios http://fes.nationalgrid.com/media/1363/fes-interactive-version-final.pdf

firms to become preferred suppliers is uncertain. Accordingly, the UK share of the domestic market for V2G and smart charger hardware is assumed to be the same as the UK's share of the EV market as determined in the transport subtheme; 13 % today, rising to 20% in 2050.

- **Electricity storage hardware:** Given prevailing cost trends and future cost projections, stationary batteries are expected to dominate the electricity storage market in the UK to 2050.[92] The UK's share of the domestic market for battery hardware is likely to correspond to the UK's share of the domestic EV market. This relationship is driven by EVs becoming the main source of battery demand to 2050, which will influence the choice of chemistry in stationary batteries and the location of production given the likely fall in cost from the economies of scale in EV battery manufacturing. Supporting hardware, including balance of plant and other peripheral components are also covered in the assessment of domestic business opportunities.[93] Accordingly, the UK's share of electricity hardware in the domestic market is assumed to be the same as the UK's share of the EV market as determined in the transport subtheme; 13.4% today, rising to 20% in 2050.
- **Installation and O&M services:** given the low tradability of installation and O&M services, the UK is assumed to capture a 95% share of the domestic market.
- **Smart transmission and distribution network equipment and services:** According to estimates from Ernst and Young, the UK is expected to capture 60% of the domestic market for smart network equipment and services, in line with the UK's current market share in network equipment and services.[94]
- **Aggregation services:** The UK is a leader in aggregation services with existing UK companies offering demand-side response and constraint management services.[95] This market continues to evolve and there is little data to robustly estimate future UK market share. To provide an indicative estimate, UK leadership in aggregation services is expected to continue and it is assumed that UK firms capture 75% of the domestic market in 2050. This market share is speculative, though it is driven by the UK's strong position in the provision of these services today, highly competitive IT sector and the nature of aggregation services, which are highly traded and scalable.

Domestic business opportunities within V2G and smart chargers and electricity storage could support over £710 million GVA and 6,500 jobs per annum by 2050.

[92] A discussion of battery costs relative to other types of storage technologies can be found in the inventory of innovation opportunities section. Also see, Schmidt et al. (2019) Projecting the Future Levelized Cost of Electricity Storage Technologies https://www.cell.com/joule/fulltext/S2542-4351(18)30583-X?_returnURL=https%3A%2F%2Flinkinghub.elsevier.com%2Fretrieve%2Fpii%2FS254243511830583X%3Fshowall%3Dtrue

[93] These components are assumed to be 30% of the cost of the battery pack. See IRENA (2017) Electricity Storage and Renewables: Costs and Markets to 2030 https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Oct/IRENA_Electricity_Storage_Costs_2017.pdf

[94] Ernst & Young (2012) Smart Grid: a race worth winning? https://www.smartgrid.gov/files/Smart_Grid_Race_Worth_Winning_Report_on_Economic_Benefits_201209.pdf

[95] For example, KiWi power has exported aggregation services to the EU27.

This is less than the export opportunity for these technologies, which is expected to support £1,200 million GVA and around 11,000 jobs annually by 2050 (see Appendix 5). The larger export opportunity is driven by the UK's share (8% by 2050) of the substantial global market for V2G and smart charger and electricity storage hardware, which is larger than the domestic market. Domestically, services associated with smart systems offer a sizeable opportunity. Within V2G and smart chargers and electricity storage, the installation and O&M of V2G and smart chargers offers the largest domestic opportunity, supporting £560 million in GVA and around 5,100 jobs per annum by 2050.

Box 5. **Business opportunities within smart network equipment and services**

Business opportunities within smart network equipment and services could support around £210 million GVA and 2,400 jobs per annum by 2050. This arises from an investment of around £1 billion per year across the period, with around 60% of this investment captured by UK businesses. The market is expected to peak at around £340 million and 4,300 jobs per annum in the mid-2020s as the smart grid roll-out accelerates.[96]

A significant UK opportunity could be aggregation services, which indicative estimates suggest could support £400 million in GVA and 1,100 jobs per annum by 2050. To illustrate the size of this opportunity, we assume the UK captures a 75% market share of the 2050 domestic market for aggregation services. Assuming one third of UK peak capacity becomes flexible and aggregated, in line with the central scenario from the disruptive subtheme, the total UK market for aggregation services could add £500 million to GVA per annum by 2050. UK firms could conceivably capture £400 million in GVA and support 1,100 jobs per annum.[97] This is an indicative estimate given the limited data on aggregation services today. The high GVA per worker is driven by the high capital intensity of aggregation services the green productivity factor common to low-carbon jobs.[98]

The size of the business opportunities associated with smart systems for decarbonisation are dependent on the structure of the energy system, the level of domestic climate action, and the ability of UK businesses to capture the resulting levels of deployment.

[96] Ernst & Young (2012) Smart Grid: a race worth winning? https://www.ey.com/Publication/vwLUAssets/Smart-Grid-A-race-worth-winning/$FILE/EY-Smart-Grid-a-race-worth-winning.pdf

[97] UK 2050 peak capacity based on ESME Clockwork scenario of approximately 80GW. See ETI (2018) Options, Choices, Actions: Updated https://es.catapult.org.uk/wp-content/uploads/2018/10/Options-Choices-Actions-Updated-Low-Res..pdf

[98] Jobs are determined using GVA per worker estimates from the ONS. For jobs in aggregation services, SIC Code D (electricity, gas, steam and air-condition supply) is combined with the green productivity factor and estimated economy-wide productivity growth to 2050.

- The regulatory framework governing the operation of businesses that provide smart system goods and services is evolving. As business models respond to market conditions and a developing regulatory environment, eventual business models may differ from anticipated business models.
- Unanticipated changes in the electricity system, such as innovative low-cost and low-carbon firm-generation or low-cost (fuel cell electric vehicles) FCEVs, could reduce the need for smart technologies and reduce deployment levels to 2050.
- On the other hand, accelerating the electrification of the energy system is likely to increase the demand for smart technologies that provide supply and demand flexibility, lifting deployment.
- In addition, since the UK has adopted a net-zero emissions target in-line with the CCC recommendation, the overall smart systems market will likely exceed the estimates presented here, increasing the total business opportunities available.
- Lastly, given the immaturity of these markets the indicative market shares used to determine business opportunities are highly uncertain. In particular, while V2G and battery storage estimates are based on the UK’s perceived competitiveness in the EV market, innovation in smart systems may establish a more competitive domestic sector, growing these market shares and increasing the domestic opportunity that smart systems could present.

Market barriers to innovation within smart systems and flexible infrastructure

Introduction

Box 6. **Objective of the market barrier analysis**

Market barriers prevent firms from innovating in areas that could have significant UK system benefits or unlock large business opportunities. Market barriers can either increase the private cost of innovation to levels that prevent innovation or limit the ability of private sector players to capture the benefits of their innovation, reducing the incentive to innovate.

Government support is needed when market barriers are significant and they cannot be overcome by the private sector or international partners. The main market barriers identified by industry are listed in Tables 10 to 14, along with an assessment of whether HMG needs to intervene.

Market barriers for smart systems and flexible infrastructure

The tables below list the main market barriers in smart systems and flexibility, along with an assessment of whether the government needs to intervene. For each identified market barrier, an assessment of the need for government intervention is provided. Some of the barriers are relevant for multiple technologies and are therefore repeated in the tables below. The assessment categories are low, moderate, severe, and critical.

- **Low** implies that without government intervention, innovation, investment, and deployment will continue at the same levels, driven by a well-functioning industry and international partners.
- **Moderate** implies that without government intervention, innovation, investment, and deployment will occur due to well-functioning industry and international partners, but at a lower scale and speed.
- **Severe** implies that without government intervention, innovation, investment, and deployment are significantly constrained and will only occur in certain market segments or must be adjusted for the UK market.
- **Critical** implies that without government intervention, innovation, investment, and deployment will not occur in the UK.

Smarter markets

Table 10. **Market barriers to innovation in market platforms and aggregation**

Market barriers to smart markets	Need for public support
Prices fail to fully account for whole system benefits, leading to them not reflecting the actual cost to the system and consumers not being able to fully optimise their energy consumption. Flexible markets rely on price signals to inform consumer decision-making.	Severe
Data on electricity consumption is currently not sufficiently collected or shared. Innovation in designing smart markets require an understanding of consumer responses to market signals, which can be understood from data on past and current behaviour. A lack of understanding of the potential benefits and costs involved, and the absence of a definition of relevant datasets, common standards, data trust frameworks, and practical sharing arrangements means data holders are reluctant to make their data available.	Severe
Due to a highly regulated market, electricity demand is partly dependent on policy signals. The complex interplay between technology and regulatory development creates an uncertain future market environment. Without knowing the features of the future market, and therefore future consumers, it is difficult to direct innovation towards meeting the needs of these consumers.	Moderate
Consumers fail to fully account for the whole system benefits in their purchasing decision. In part, this is due to products not being clearly differentiated and therefore the added benefits of green energy are not easily understood.	Low

Source: *Vivid Economics analysis and stakeholder input*

Demand-side response

Table 11. **Market barriers to innovation in DSR**

Market barriers	Need for public support
Due to a highly regulated market, electricity demand is partly dependent on policy signals. The complex interplay between technology and regulatory development creates an uncertain future market environment. Without knowing the features of the future market, and therefore future consumers, it is difficult to direct innovation towards meeting the needs of these consumers.	Severe
The long term energy infrastructure plans of HMG are not yet defined. Due to coordination failure within industry, government is needed to support integrated infrastructure planning. Without certainty of the type and timing of infrastructure investments, Distribution Network Operators are unsure about when adopt smart technologies, reducing uptake.	Moderate
Infrastructure tends to have a long lifetime, meaning there is a requirement to make investments for the future market today. This conflicts with maintaining a high degree of flexibility for future market design and demand patterns. As a result, flexible innovations may not be able to be implemented, due to infrastructure 'locking in' existing market design.	Low

Source: *Vivid Economics analysis and stakeholder input*

Electricity storage

Table 12. **Market barriers to innovation in storage**

Market barriers	Need for public support
There is significant uncertainty around the future value of storage in the UK energy market. Despite increasing modelling evidence, both the total value, and which electricity market actors may be able to capture this value, remains uncertain. Without understanding the role storage will play in the system, it is difficult to direct innovation towards fulfilling this role. Particularly for capital-intensive bulk storage, the future level of infrastructure investments for battery storage are uncertain, which reduces confidence in research and deployment.	Severe
Payback periods for storage technologies are often longer than the private sector is willing to accommodate. Private funding generally requires short life spans with payback in the first three years. Bulk storage technologies, in particular, are often high capex, and firms cannot recoup investment in the short term.	Severe
The estimation of the volume-value of storage depends on future energy scenarios. There is disagreement across the sector on what these scenarios will look like, which makes cross-sector agreement on the actual system needs difficult. Without agreeing on what is needed, it is difficult to innovate towards meeting the need.	Moderate
Innovation funding is typically target at either networks or generation (including storage) rather than at integrated projects. Low Carbon Networks Fund/ Network Innovation Allowance/ Network Innovation Competition funding is targeted at network assets**.** Storage is considered a generation asset and, therefore, it does not qualify for funding.	Moderate

Source: *Vivid Economics analysis and stakeholder input*

Vector coupling

Table 13. **Market barriers to innovation in vector coupling**

Market barriers to vector coupling	Need for public support
The (regulatory) separation between gas and electricity networks and markets makes integrated planning between gas and electricity difficult, which limits the development and funding of vector coupling opportunities. For example, due to this separation, there are legal impediments to gas and electricity networks jointly funding vector coupling projects.	Severe
HMG planning and regulation is not driven by whole system analysis. As a result, planning for electricity, heat, and gas is not aligned and missing out on potential synergies. Without aligned planning, vector coupling innovation opportunities are limited as they rely on the above policies to be successfully implemented.	Moderate
Carbon budgets and decarbonisation roadmaps are not explicitly providing strategic guidance for alternate vectors (such as green gas) in difficult-to-treat sectors (such as heating, heavy transport, and industry).	Moderate
Access to finance is difficult and requires substantial coordination due to the many actors involved. Coordination and appropriate financing frameworks could support investment in innovation.	Moderate
Consumers fail to fully account for the whole system benefits in their purchasing decision. In part, this is due to products not being clearly differentiated and therefore the added benefits of green energy are not easily understood.	Low

Source: Vivid Economics analysis and stakeholder input

Networks and data

Table 14. **Market barriers to innovation in networks and data**

Market barriers	Need for public support
Data on electricity consumption is currently not sufficiently collected or shared. Innovation in designing networks and data require an understanding of consumer behaviour. A lack of understanding of the potential benefits and costs involved in collecting and sharing data, and the absence of a definition of relevant datasets, common standards, and practical sharing arrangements means data holders are reluctant to make their data available. Coordination failure in the industry means there could be a role for government to facilitate this process.	Severe
The features of the long term electricity market remain uncertain. Without knowing, for example peak demand in the future market, it is difficult to direct innovation towards meeting the needs of the system and consumers.	Moderate
Price-setting periods are significantly shorter than lifetime of assets, prohibiting mass application of innovative technologies.	Low

Source: *Vivid Economics analysis and stakeholder input*

Box 7. **Industry workshop feedback**

Industry experts raised an ongoing review of policy and regulation that may reduce the severity of the barriers outlined above. Areas discussed in the workshop but not covered in the tables above are:

- **Market barriers to innovation in smarter markets** are focussed on market design and opportunities for more dynamic pricing, with temporal and spatial flexibility. In July 2017, HMG published the Smart Systems and Flexibility Plan, which aims to enable the trading of flexible resources in markets. National Grid and Ofgem have also outlined strategies to enable flexibility.[99] If these programmes are implemented, the CCC suggests, these actions will level the playing field and remove the barriers to entry.[100]

- **Market barriers to innovation in DSR** are focussed on limited opportunities for dynamic tariffs to incentivise peak demand reductions, which reduces a key incentive for DSR. Industry perceives future demand to be uncertain, in part due to a policy-dependent market combined with an unclear policy position in the UK. Given the electricity network consists of several regional monopolies, the network is closely regulated. The key framework is known as RIIO (Revenues= Incentives + Innovation + Outputs). The Current RIIO framework runs to 2021, with RIIO-2 coming into force after this. Both main barriers for DSR will potentially be addressed in the course of the RIIO-2 framework consultation process.

- **Market barriers to innovation in networks** should also be viewed within the context of the RIIO framework. RIIO-2 has undergone significant consultation during its design stage and has to appropriately balance the short- and long-term needs of electricity consumers, grid operators, generators, and other stakeholders.[101] Given the need to balance competing stakeholder needs, the framework will not always be optimal from a pure innovation perspective.

- **Market barriers to innovation in vector coupling** are created by uncertainty of the UK's low-carbon heat policy and uneven heat incentives impeding investment in hydrogen power-to-gas projects. For example, heat pumps currently receive more support than green gases and the Climate Change Levy on natural gas is not charged to domestic customers, providing insufficient incentives for vector coupling projects.

- **Market barriers to innovation in stationary storage** will, to a significant degree, be driven by the EV industry. There are several innovations specific to stationary storage and its interaction with the UK grid, which are slowed down by market barriers.

International opportunities for collaboration

There are potential international opportunities to collaboratively innovate. For example:

- In terms of data collection and sharing, the UK can learn from Germany, where three transmission system operators work with research institutes to improve weather and power forecasts for wind turbines and solar PV plants.[102]
- For DSR, the UK can learn from Belgium, where demand-side response solutions are embedded in daily electricity market operations. The transmission system operator accepts the distributed energy resource capacity to compensate the mismatches between production and peak power demand, in which industrial customers are given vital importance. Finland has introduced dynamic pricing structures and smart homes enable demand-side management at the household level.[103]
- For storage, a large part of the Li-ion development will likely happen abroad driven by EV industry, and the UK can adopt innovations.

[99] National Grid (2017) System Needs and Product Strategy https://www.nationalgrideso.com/document/84261/download ; Ofgem (n.d.) Targeted Charging Review: Significant Code Review https://www.ofgem.gov.uk/electricity/transmission-networks/charging/targeted-charging-review-significant-code-review
[100] CCC (2018) Reducing UK emissions 2018 Progress Report to Parliament https://www.theccc.org.uk/wp-content/uploads/2018/06/CCC-2018-Progress-Report-to-Parliament.pdf https://www.ofgem.gov.uk/electricity/transmission-networks/charging/targeted-charging-review-significant-code-review
[101] Ofgem (2019) Network price controls from 2021 (RIIO-2) https://www.ofgem.gov.uk/network-regulation-riio-model/network-price-controls-2021-riio-2
[102] IRP Wind (2016) Yearly report on IRPWIND and EERA JP Wind Activities, Integrated Research Programme on Wind Energy
[103] IRENA (2019) Innovation Landscape For a Renewable-Powered Future: Solutions to Integrate Variable Renewables https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Feb/IRENA_Innovation_Landscape_2019_report.pdf

Appendix 1: Organisations at expert workshop

- Association of Decentralised Energy
- Bloomberg
- Department for Business, Energy and Industrial Strategy
- Electron
- Elexon
- Energy Systems Catapult
- Energy UK
- Flexitricity
- Imperial College London
- ITM Power
- Innovate UK
- Manchester Energy (University of Manchester)
- National Grid Power Responsive Team
- Northern Gas Networks
- Ofgem
- OVO
- Renewable Energy Association
- RenewableUK
- Smart Energy GB
- Sustainable Gas institute
- UK Research and Innovation

In addition, the Energy Networks Association has reviewed the report and provided comments from a DNO perspective.

Appendix 2: Modelling the value of smart systems technologies

Whether it is undertaken in ESME, WeSIM, or another energy system model, the EINA Methodology prescribes the approach taken to assess the system-level value of technological innovation. This involves creating a baseline energy system transition without innovation (from which a baseline energy system transition cost is derived). Then, on a technology-by-technology basis, the energy system transition cost impact of 'innovating' that technology is assessed. Innovation in a technology is modelled as an agreed improvement in cost and performance out to 2050.

Introduction to ESME

Following the BEIS EINA Methodology, whole energy system modelling was conducted using the ESME^{TM} Version 4.4. It estimates where innovation investments could provide the most value to support UK energy system development.

ESME is a peer-reviewed whole energy system model covering the electricity, heat, and transport sectors, and energy infrastructure. It derives cost-optimal energy system pathways to 2050 meeting user-defined constraints (e.g. 80% greenhouse gas (GHG) emissions reduction). The model can choose from a database of over 400 technologies which are each characterised in cost, performance, and other terms (e.g. maximum build rates) out to 2050. The ESME assumption set has been developed over more than 10 years and is published (with data sources) at https://www.eti.co.uk/programmes/strategy/esme. ESME is intended for use as a strategic planning tool and has enough spatial and temporal resolution for system engineering design.

Like any whole system model, ESME is not a complete characterisation of the real world. It can provide guidance on the overall value of different technologies, and the relative value of innovation in them.

System value of innovation in smart technology in ESME

ESME is whole energy system model that generates lowest-cost energy system transition pathways meeting user-defined constraints. These technology options are characterised in cost, performance, and other terms out to 2050, with associated ranges of uncertainty.

'Smart' itself is not modelled within ESME, rather there are a range of technology options within ESME that can be classified as falling under the umbrella of Smart.

The technologies classified and modelled in the EINA analysis in this way are shown in Table 15. The resultant energy system value of innovation for these technologies derived using BEIS's EINA analytical methodology are also shown in Table 15. There are many interacting factors and uncertainties that can influence and change the energy system value of innovating a technology. These include the mix and performance characteristics of energy-generation technologies, the service demands across the energy system that need to be fulfilled, and the individual cost and performance assumptions associated with each individual technology.

Table 15. **Smart technologies in ESME**

Technology	System value of Innovation in £million cumulative by 2050, discounted at 3.5% p.a.
EV Charging Point (on street outside home)	337
EV Charging Point (private off street for LGVs)	95
EV Charging Point (private off street)	440
EV Charging Point (workplace)	84
Natural gas vehicle refuelling	69
Battery – Li-ion	102
Battery – NaS	0
Compressed air storage of electricity	0
Flow battery – Redox	0
Flow battery – ZnBr	0
Pumped heat electricity storage	0
Pumped storage of electricity	0

Note: *The system value is calculated per BEIS's EINA Methodology.*

Source: *Vivid Economics and Energy Systems Catapult*

ESME estimates the cumulative system cost value of these technologies to be £1 billion in 2050 (£million cumulative by 2050, discounted at 3.5% p.a.). This estimate will be updated following the completion of new ESME modelling runs for the attribution value analysis.

Introduction to WeSIM

WeSIM estimates the pattern of investment in, and operation of, electricity system resources which minimises the overall electricity system cost while meeting a carbon target. Key features of WeSIM include:

- **Detailed characterisation of all relevant electricity system resources.** WeSIM models generation, network, storage, demand-side response, and interconnection resources.
- **Detailed characterisation of electricity system reliability.** WeSIM models reliability needs in detail, including adequacy, inertia, reserve, and response.
- **Accurate modelling of important electricity system characteristics.** WeSIM accurately represents power flow limits, dynamic characteristics of generation plants, and operational constraints of storage and demand-side response.
- **Representation of multiple energy carriers.** The WeSIM model captures the interaction across different energy carriers. Examples are actions in the heating system, such as retaining hot water stores, which can complement measures in the electricity system. In this case, the model can use the opportunities to minimise the overall energy system costs.

WeSIM estimates the pattern of investment in, and operation of, electricity system resources which minimises the overall electricity system cost. WeSIM has been widely used to investigate the future of the electricity system, with a focus on power sector decarbonisation.

The Systems Value of Smart Technologies in WeSIM

Like ESME, WeSIM is a whole energy system model that generates lowest-cost energy system transition pathways meeting user-defined constraints. These technology options are characterised in cost, performance, and other terms out to 2050, with associated ranges of uncertainty.

‘Smart’ itself is not modelled within WeSIM, rather there are a range of technology options within WeSIM that can be classified as falling under the umbrella of Smart. The technologies classified and modelled in the EINA analysis in this way are shown in Table 16.

Table 16. **Smart technologies in WeSIM**

WeSim smart technology list
EV smart charging and V2G
Smart appliances (load shifting and provision frequency response)
Electric heating (heat pumps, resistive heating)
Industrial and Commercial flexible demand
Thermal storage
Bulk electricity storage (super-capacitors, batteries, compressed air, pumped hydro, etc.)
Distributed electricity storage
Voltage control technologies in distribution networks
Electricity network technologies
Generation with enhanced flexibility

Source: *Vivid Economics*

The net value of these technologies in WeSIM is between £17-40 billion (cumulative savings to 2050 discounted at 3.5%).[104] This estimate considers a range of different scenarios for demand, energy storage cost, DSR cost, and future deployment levels of interconnection. This is a different calculation to ESME, which estimates the value of improved technologies, whereas WeSIM is estimating the value of the technologies compared to not having them.

Discussion

A common finding across the models is that the smart family of technologies is highly significant in terms of its value to the energy system. However, the value of 'smart' in the two models differs greatly. ESME estimates the cumulative system cost value of these technologies to be £1 billion in 2050. WeSIM estimates the value to be £17-40 billion cumulative to 2050.

[104] Imperial College and Carbon Trust (2016) An analysis of electricity system flexibility for Great Britain https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/568982/An_analysis_of_electricity_flexibility_for_Great_Britain.pdf

There are four important drivers of the differences between the ESME and WeSIM results:

- **Different calculation basis.** The WeSIM study makes a different calculation to ESME. The WeSIM study estimates the value of smart technologies, compared to a system that does not have these technologies, whereas ESME estimates the value of innovation in smart technologies. This would, to some extent, explain why the WeSIM values are higher than ESME.

- **Time resolution:** A key feature of WeSIM is granular time and space resolution. WeSIM considers frequency regulation requirements. This includes system inertia (seconds timescale), reserve requirements (min-hours), energy dispatch and load shifting (hours), scheduling of storage (hours-months), and investment decisions (years). In another project comparing WeSIM with TIMES, it was found that granular time resolutions makes a significant difference to results. WeSIM is expected to place a higher value on flexibility, compared to a model with less granular resolution of time slices.

- **Technological coverage:** There is also a difference between the technologies in ESME and WeSIM. The scope of technologies related to smart systems is wider in WeSIM, enabling a broader value for flexibility to be generated.

- **Sectoral coverage:** ESME covers the whole energy system, whereas the version of WeSIM that was used in the 2016 study covered the electricity system and electrified heating and transport sectors. In 2017, WeSIM was enhanced to optimise multi-energy vectors in a coordinated way. This includes gas- and hydrogen-based heating, hybrid heating systems, district heating, combined heat and power generation technologies, hydrogen production and storage, and the transport and electricity sectors. This modelling was used to optimise the whole-energy system. It also quantified and analysed the implications and benefits of flexibility across different energy sectors.[105]

Overall, it is not possible to say, without a more detailed comparison and set of modelling runs, precisely what causes the degree of difference between these models. The first three factors would lead to a higher value of smart in WeSIM compared to ESME, whereas the third factor should lead to an offsetting lower value for WeSIM, compared to ESME. **In this report we use the WeSIM estimates as they better characterise the time resolution in the electricity system.**

[105] CCC (2018) Analysis of alternative UK heat decarbonisation pathways.

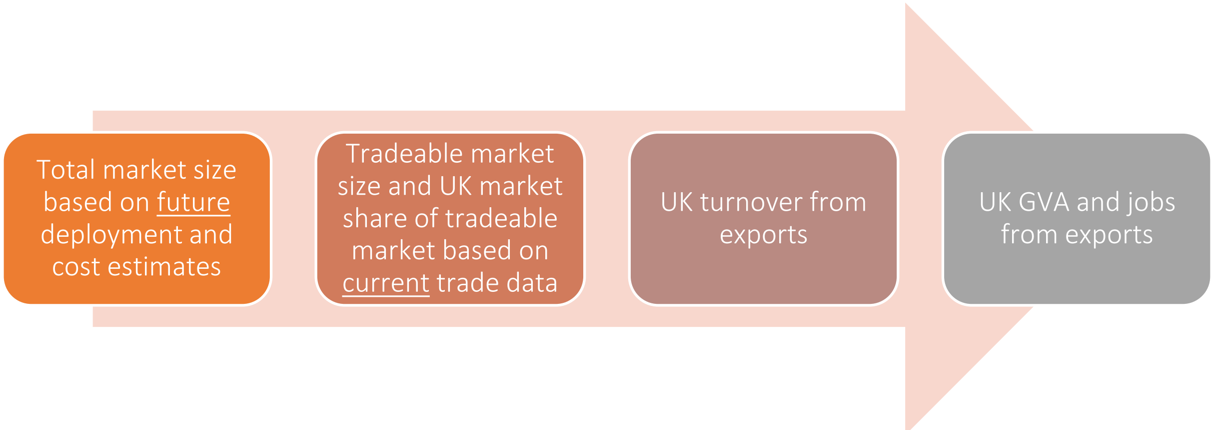
Appendix 3: Business opportunities methodology

Methodology for export business opportunity analysis

In identifying export opportunities for the UK, the EINA process uses a common methodology to ensure comparability of results:

- The **global and regional markets** to 2050 are sized based on deployment forecasts, which come from the IEA when available. For example, deployment of nuclear power is multiplied by costs to obtain annual turnover for the nuclear market.
- The **tradability** of the market is estimated based on current trade data, where available, and informed by expert judgement. This determines how much of the global market is likely to be accessible to exports and gives a figure for the tradeable market.
- The UK's **market share** under a high-innovation scenario is estimated based on current trade data, research, and expert consultation. The determination of these shares is discussed in more detail below.
- The tradeable market is multiplied by the market shares to give an estimate for **UK-captured turnover**.
- The captured turnover figure is multiplied by a GVA / turnover multiplier which most closely resembles the market to obtain **GVA**. The GVA figure is divided by productivity figures for that sector to obtain **jobs created**.

Figure 3 **Methodology for assessing export opportunities**



Source: *Vivid Economics*

For all EINA sub-themes, the assessment of the UK's future competitive position is informed by the UK's existing market share of goods and services, the market share of competitors, industry trends, and workshop feedback.

Export business opportunities for goods

- Current market shares of UK goods are evaluated based on existing trade data, where available. If the technology is immature or export levels are low, UK shares are based on trade data from trade in related goods.
- Based on the importance of innovation in unlocking markets, the UK is projected to reach a market share in the EU and RoW by 2050. The potential future market share is intended as an ambitious, but realistic, scenario. It is triangulated using:
    - Market shares of competitor countries, as a benchmark for what is a realistic share if a country is 'world leading'.
    - The maturity of the existing market, which affects the likelihood of market shares changing significantly.
    - The importance of innovation in the technology.
- Market share assumptions are validated at a workshop with expert stakeholders and adjusted based on stakeholder input.

Export business opportunities for services

- The EINA focus on service exports directly associated with the technology and innovations considered within the sub-theme. For example, this could include EPCm services around the construction of an innovative CCS plant, but it will not include more generic service strengths of the UK, such as financial services.
- The EINA methodology does not quantify opportunities associated with installation and operation and maintenance as these are typically performed locally. Exceptions are made if these types of services are specialised, such as in offshore wind.
- The key services to consider are based on desk research and verified through an expert workshop.
- The services considered in the CCUS EINA export analysis are EPCm services, transport and storage services.

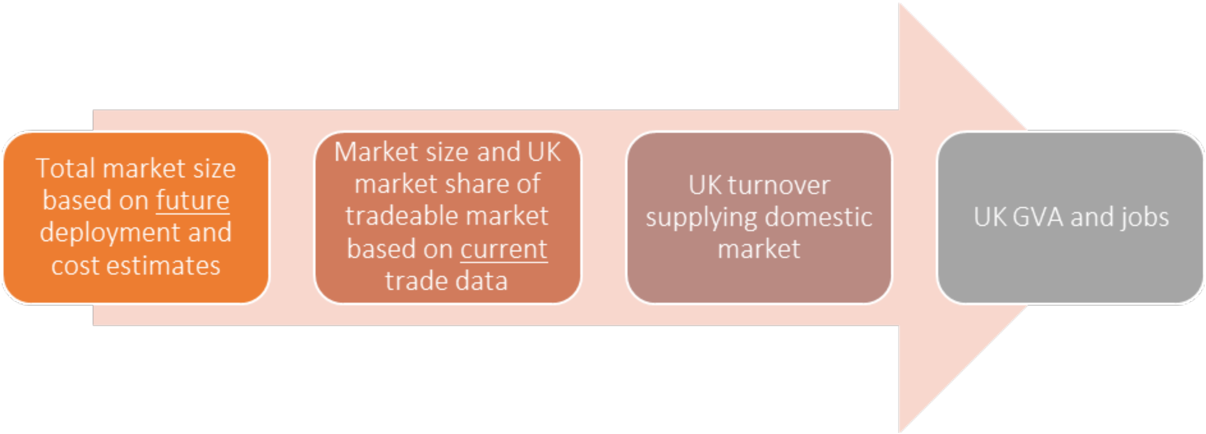
Methodology for domestic business opportunity analysis

To estimate the size of domestic business opportunities for the UK, the EINA methodology, as developed to size export opportunities, is adapted. The domestic analysis leans heavily on insight gleaned from the export analysis, particularly in estimating UK competitiveness and ability to capture market share in its domestic market. To estimate the domestic opportunity, the following methodology is used:

- The **domestic market** to 2050 is sized based on deployment and cost estimates. Deployment estimates are based on ESME modelling used for the EINAs and cost estimates are equal to those from the export work, and based on analysis for each of the EINA sub-themes.[106] For example, deployment of nuclear power is multiplied by costs to obtain annual turnover for the nuclear market.
- The **tradability** of the market is estimated based on current trade data, where available, and informed by expert judgement. This determines how much of the UK's market is likely accessible for foreign firms (e.g. electric vehicles), and how much is likely to be exclusively provided by UK companies (e.g. heat pump installation).
- For the traded share of the UK market, the UK's **market share** under a high-innovation scenario is estimated based on current trade data, research, and expert consultation. The determination of these shares is discussed in more detail below.
- To estimate **UK captured turnover** the traded and non-traded markets are summed.
  - The UK's captured turnover of the UK traded market is estimated by multiplying the tradeable market by the UK's market share.
  - The UK's turnover from the non-traded market is equal to the size of the non-traded market.
- The captured turnover figure is multiplied by a GVA / turnover multiplier which most closely resembles the market to obtain **GVA**. The GVA figure is divided by productivity figures for that sector to obtain **jobs supported**.

[106] For detail on cost estimates used, please refer to the Excel calculators provided for each sub-theme, and the individual sub-theme reports.

Figure 4 **Methodology for assessing domestic business opportunities**



Source: Vivid Economics

For all EINA sub-themes, the assessment of the UK's future competitive position is informed by the UK's existing market share of goods and services, the market share of competitors, industry trends, and workshop feedback.

Domestic business opportunities for goods

- Current market shares of UK goods are evaluated based on existing trade (import) and domestic production data, where available. If the technology is immature, UK shares are based on trade data from trade in related goods.
- Based on the importance of innovation in unlocking markets, the UK is projected to potentially increase its market share in its domestic market. This estimate is informed by the previously performed export analysis. It is triangulated using:
    - Market shares of competitor countries, as a benchmark for what is a realistic share if a country is 'world leading'.
    - The maturity of the existing market, which affects the likelihood of market shares changing significantly.
    - The importance of innovation in the technology.

Domestic business opportunities for services

- The EINA focus on service exports directly associated with the technology and innovations considered within the sub-theme. For example, this could include EPCm services around the construction of an innovative CCS plant, but it will not include more generic service strengths of the UK, such as financial services.
- The domestic assessment explicitly quantifies services such as O&M and installation, which are typically not traded but can support a large number of jobs associated with e.g. heat pumps. For these services, the estimate of potential service jobs supported is based on:
    - An estimate of the total turnover and GVA associated with the service

  - A ratio of GVA/jobs (adjusted for productivity increases) in analogous existing service sectors based on ONS data.
- The key services to consider are based on desk research, verified through stakeholder workshops.

Worked example

1. The **global and regional markets** to 2050 are sized based on illustrative deployment forecasts, which come from ESME when available.[107] For example, deployment of nuclear power (37 GW by 2050) is multiplied by O&M costs (~12% of total plant costs) to obtain annual turnover for the nuclear O&M market (~£2.5 billion by 2050).
2. The **tradability** of the market is estimated based on current trade data, where available, and informed by expert judgement. This determines how much of the global market is likely to be accessible to exports and gives a figure for the tradeable market. In the case of nuclear O&M, tradability is 0% being as it is not tradeable. For the domestic analysis, tradability does not directly feed into our model, but is vital to provide insight on the share of the domestic market UK firms will capture.
3. The UK's **market share** under a high-innovation scenario is estimated based on current trade data, research, and expert consultation. The determination of these shares is discussed in more detail below. For example, for nuclear O&M the UK domestic market share is 100% because the component is not tradeable and therefore foreign firms do not capture some of the value.
4. The tradeable market is multiplied by the market shares to give an estimate for **UK-captured turnover**. For nuclear O&M, market turnover (~£2.5 billion) is multiplied by the UK market share (95%) of O&M to obtain UK-captured turnover (~£2.5 billion by 2050).
5. The captured turnover figure is multiplied by a GVA / turnover multiplier which most closely resembles the market to obtain **GVA**. The GVA figure is divided by labour productivity figures for that sector to obtain **jobs supported**. For example, appropriate Standard Industrial Classification (SIC) codes are chosen for nuclear O&M. This leads to a GVA / turnover multiplier (49%) that is multiplied by market turnover (~£2.5 billion) to isolate GVA (~£1 billion by 2050), which is then divided by labour productivity (~70,000 GVA / worker by 2050) to isolate jobs supported (~16,000 jobs by 2050).

[107] If deployment information is not available from the IEA, alternative projections from, for example, Bloomberg are used. Please see individual sub-theme reports for further detail.

Additional notes

V2G and smart charger deployment estimates draw on detailed bottom up studies in place of ESME estimates as future deployment of EV charging and battery storage is partially dependent on spatial factors that ESME does not account for.

V2G and smart charger deployment: The deployment of public and private chargers is considered. For public chargers, deployment estimates are from Systra, Cenex and Next Green Car (2018), which estimates the need for 29,000 public chargers by 2030.[108] Public charger deployment outside of this year range are estimated using a linear rate of growth to 2050. Private charger deployment estimates rely on ESME EV deployment estimates and the 1.1 ratio of private chargers to EVs identified by the IEA.[109]

Electricity storage deployment: Electricity storage deployment estimates are drawn from Carbon Trust and Imperial College (2016).[110] This storage estimate includes 2.8 GW of pumped hydro, which is excluded to obtain a battery storage deployment estimate of 12GW in 2050.

[108] Systra, Cenex and Next Green Car (2018) Plugging the gap: An assessment of future demand for Britain's electric vehicle public charging network https://www.theccc.org.uk/publication/plugging-gap-assessment-future-demand-britains-electric-vehicle-public-charging-network/

[109] IEA (2018) Global EV Outlook https://www.iea.org/gevo2018/

[110] Carbon Trust and Imperial College (2016) An analysis of electricity flexibility for Great Britain https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/568982/An_analysis_of_electricity_flexibility_for_Great_Britain.pdf

Appendix 4: Assessment of business opportunities uncertainty

The assessment of business opportunities in the long term, associated with new technologies is uncertain. This assessment does not attempt to forecast what *will* happen. Instead, the business opportunity assessment attempts to provide a realistic and consistent assessment, based on current information, on the business opportunities that *could* be captured by the UK. Whether these opportunities are indeed realised depends on domestic and international developments, political decisions, macro-economic conditions, and numerous other complex variables.

As this assessment is not intended as a full forecast, a formal quantitative sensitivity analysis has not been performed. the below provides a high-level qualitative assessment of the uncertainty associated with the sized opportunity. Note, this is *not* an assessment of how likely the UK is to capture the opportunity, rather it is an assessment of the uncertainty range around the size of the opportunity. The assessment is based on three key factors driving the assessment

1. *The level of future deployment of the technology*. Technologies such as offshore wind are deployed at scale across different energy system modelling scenarios and hence considered relatively certain. In contrast, there is more uncertainty for e.g. hydrogen related technologies. The export analysis is based on 3 IEA scenarios (with numbers provided for the IEA ETP 2 degree scenario). Domestic analysis is based on a single ESME run used across the EINA process.
2. *The potential domestic market share* the UK can capture. This assessment attempts to estimate a plausible market share for the UK across relevant markets. Where this can be based on longstanding trade relationships and industries, this assessment is considered more robust.
3. *Future technology costs and production techniques* are a key driver of the future turnover, gross value added and jobs associated with a technology. For immature technologies for which manufacturing techniques may, for example, become highly automated in future, future costs and jobs supported by the technology may be significantly lower than assessed.

The ratings in the table below are the judgement of Vivid analysts based on the above considerations. The analysts have worked across all sub-themes and the ratings should be considered as a judgement of the uncertainty around the size of the opportunity relative to other sub-themes. As a rough guide, we judge the uncertainty bands around the opportunity estimates as follows:

- **Green**: Size of the opportunity is clear (+/- 20%). Note, this does not imply the UK will indeed capture the opportunity.
- **Amber:** Size of the opportunity is clear, but there are significant uncertainties (+/- 50%).
- **Red:** There are large uncertainties around market structure and whether the technology will be taken up at all in major markets. The opportunity could be a factor 2-3 larger or smaller than presented.

Table 17. **Assessment of uncertainty in business opportunities across sub-themes**

Sub-theme	Uncertainty rating	Comments
Biomass and bioenergy		• **Deployment**: Moderate deployment uncertainty; BECCS can produce negative emissions that have high value to the energy system under a deep decarbonisation pathway; there is moderate uncertainty as to whether BECCS will be used for hydrogen production, as in the ESME modelling, or for power generation. • **UK market share:** Speculative market share for immature traded equipment, but majority of business opportunities associated with certain untraded services and feedstocks. • **Costs and production techniques:** Relatively certain costs with most opportunities associated with labour input rather than immature technologies.
Building fabric		• **Deployment:** Depends on levels of retrofit that greatly exceed those seen to date. • **Market share:** Speculative for traded. However, majority of market untraded, highly likely captured domestically. • **Costs and production techniques:** High share of labour costs (independent of uncertain tech cost).
CCUS		• **Deployment:** Moderate deployment uncertainty; decarbonisation scenarios anticipate rapid uptake of CCUS, though there are few large-scale facilities today. • **Market share:** Moderate market share uncertainty; the UK is likely to be competitive in the storage of CO2 and EPCm services while component market shares are less certain given numerous technology choices and lack of clear competitors. • **Costs and production techniques:** Moderate cost uncertainty; the lack of large-scale facilities today makes estimating future costs difficult.
Heating and cooling		• **Deployment**: Expected to be deployed in most UK buildings by 2050. • **Market share:** some uncertainties, immaturity in markets such as for hydrogen boilers. • **Costs and production techniques:** Relatively certain given relative maturity of boilers and heat pumps. • **Deployment of hydrogen boilers or heat pumps** lead to similar opportunities for UK businesses, while heat networks present a 50 per cent smaller opportunity per household.

Hydrogen and fuel cells		• **Deployment**: Highly uncertain future deployment with a wide-range of 2050 hydrogen demand estimates across scenarios, particularly for export markets. • **UK market share**: Speculative market share for immature traded equipment, but majority of business opportunities associated with certain untraded services. • **Costs and production techniques:** Although deep uncertainty in future hydrogen production costs, for example electrolysis, most domestic costs are associated with labour input rather than equipment.
Industry		• **Deployment**: Relative certainty in deployment as it is based on the 2050 Roadmaps • **UK market share**: Some uncertainty due to poor quality of trade data that may not be representative of technologies within scope. • **Costs and production techniques:** Some uncertainty in costs, particularly for less mature technologies.
Light duty transport		• **Deployment**: Certainty in deployment; low-carbon vehicles will be required in any deep decarbonisation scenario. • **UK market share**: Speculative market share for a relatively immature market; a small number of uncertain future FDI investment decisions generates high uncertainty in overall business opportunities. • **Costs and production techniques:** Highly uncertain future costs, with substantial falls in battery costs a key enabler of BEV uptake.
Nuclear fission		• **Deployment**: Moderate uncertainty in future deployment with some proposed nuclear plants recently cancelled • **UK market share**: Relatively certain market shares based on robust estimates of current nuclear activity; market share growth is dependent on uncertain development of UK reactor IP; however, most business opportunities are associated with untraded activity or areas where the UK has existing strength • **Costs and production techniques:** Uncertain costs for nuclear new build, with dangers of construction overrun; deep uncertainty in costs for immature nuclear technologies, for example SMRs and AMRs.
Offshore wind		• **Deployment**: Offshore wind will be required in any deep decarbonisation scenario, with clear government commitments. • **UK market share**: Expected growth in current market shares given commitments and progress to date. • **Costs and production techniques:** Costs are relatively certain, with clear pathways to 2050.
Tidal stream		• **Deployment**: Global sites for tidal stream are relatively limited, and hence the potential market size well established. • **UK market share**: Although the market is immature, the UK has a an established (and competitive) position. • **Costs and production techniques:** Costs are relatively certain, although the impact of potential scale production is hard to anticipate.
Smart systems		• **Deployment**: High deployment uncertainty given immaturity of smart system market today and evolving business models and regulatory framework. • **UK market share**: Moderate uncertainty given immaturity of the market today and scalable nature of digital smart

		technologies, though there is UK leadership in aggregation services and V2G charging. • **Costs and production techniques**: Moderate uncertainty of cost reductions of batteries and V2G and smart chargers, though costs are expected to continue to fall.

Source: *Vivid Economics*

Appendix 5: Estimates of business opportunities from export and domestic markets supplement

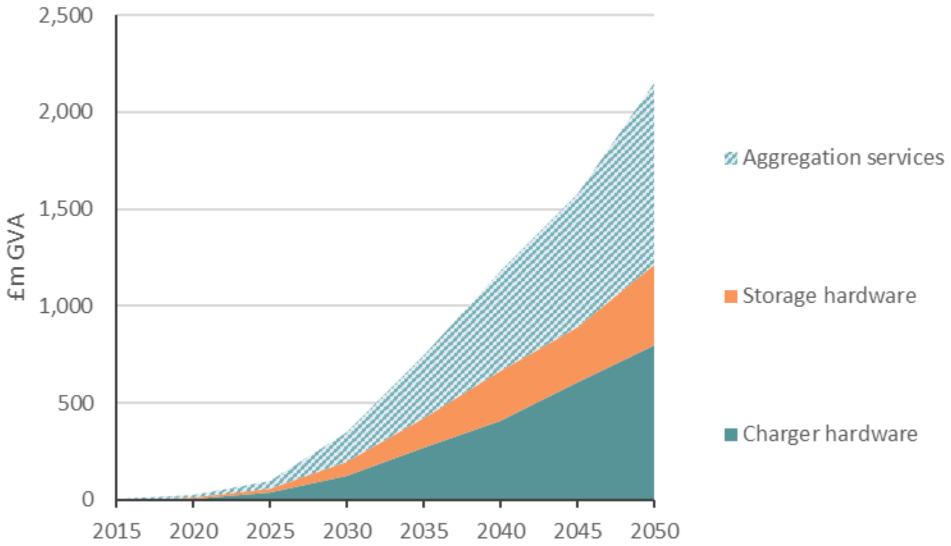
Table 18. **Export market shares and innovation impact – smart systems**

Technology	Tradeable market 2050 (£bn)	Current market share of related goods and services	2050 outlook with strong learning by research			
			Market share (%)	Captured turnover (£m)	GVA from exports (£m)	Rationale for the impact of innovation on domestic deployment of related equipment and services
V2G and smart charger manufacturing	**EU: 5.4** RoW: 19	**EU: 4.1%** RoW: 1.0%	**EU: 8.0%** RoW: 8.0%	**EU: 430** RoW: 1,500	World: 800	The UK market share grows to twice that of the current share in ICEs, as an EV push enables strong learning and innovation in EV chargers.
Battery storage manufacturing	**EU: 11.3** RoW: 19	**EU: 2.9%** RoW: 0.6%	**EU: 8.0%** RoW: 2.0%	**EU: 900** RoW: 380	World: 400	The UK market share grows to twice that of the current share in ICEs, as a battery push (e.g. Faraday challenge) enables strong learning and innovation.
Smart network equipment and services	**EU: 18.9** RoW: 53.2	**EU: 3.3%** RoW: 0.9%	**EU: 3.3%** RoW: 0.9%	**EU: 620** RoW: 500	World: 200	The UK market share remains constant in a growing international market.
Aggregation services	**EU: 17.2** RoW: N/A	**EU: N/A** RoW: N/A	**EU: 10%** RoW: N/A	**EU: 1,720** RoW: N/A	EU: 950	The UK market share of the EU rises to 10% by 2050 as the skills developed from offering domestic aggregation services are exported.

Note: ** Future market shares are not a forecast, but what UK business opportunities could be potentially in the context of the EINAs. The possible market share of the UK, and rationale for the impact of innovation, are based on stakeholder input gathered in 2 workshops.*

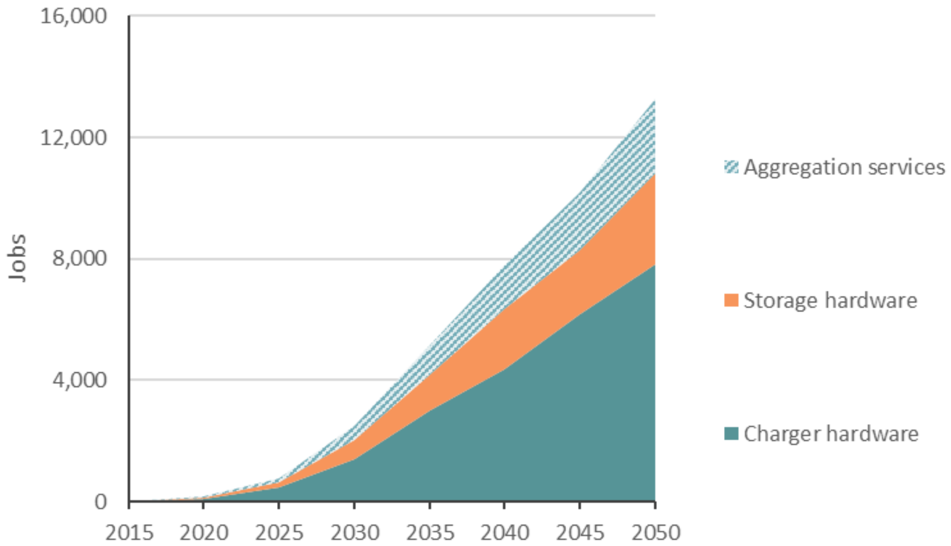
Source: *Vivid Economics*

Figure 5. **GVA from export markets by component – smart systems**



Source: *Vivid Economics*

Figure 6. **Jobs supported from export markets by component – smart systems**



Source: *Vivid Economics*

Table 19. **Domestic market shares and innovation impact – smart systems**

Technology	Domestic market (£m)	Current share of related UK market	2050 outlook with strong learning by research			
			Market share* (%)	Domestic turnover captured (£m)	GVA (£m)	Rationale for the impact of innovation on domestic deployment of related equipment and services
V2G and smart charger manufacturing	2030: 160 2050: 1,200	13.4% (ICE LDVs)	20%	2030: 30 2050: 240	2030: 10 2050: 100	The UK's share of V2G and smart charger hardware in the domestic market is assumed to be the same as the UK's share of the EV market as determined in the transport subtheme; 13.4% today, rising to 20.1% in 2050.
V2G and smart charger installation	2030: 110 2050: 810	N/A: not highly traded	95%	2030: 100 2050: 770	2030: 50 2050: 340	Innovation is unlikely to have a substantial effect on the UK's competitiveness as installation services are typically sourced from local construction companies.
V2G and smart charger O&M services	2030: 60 2050: 510	N/A: not highly traded	95%	2030: 50 2050: 490	2030: 20 2050: 220	Innovation is unlikely to have a substantial effect on the UK's competitiveness as operations and maintenance services are typically sourced from locally available labour.
Battery storage manufacturing	2030: <10 2050: 300	13.4% (ICE LDVs)	20%	2030: <10 2050: 60	2030: <10 2050: 20	The UK's share of electricity storage hardware in the domestic market is assumed to be the same as the UK's share of the EV market as determined in the transport subtheme; 13.4% today, rising to 20.1% in 2050.
Battery storage installation	2030: <10 2050: 60	N/A: not highly traded	95%	2030: <10 2050: 60	2030: <10 2050: 30	Innovation is unlikely to have a substantial effect on the UK's competitiveness as installation services are typically sourced from local construction companies.

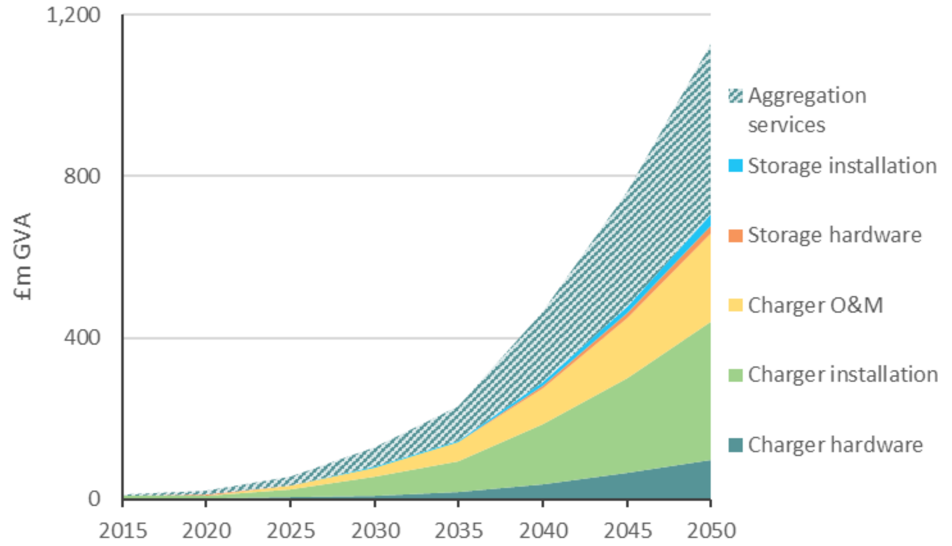
Technology	Domestic market (£m)	Current share of related UK market	2050 outlook with strong learning by research			
			Market share* (%)	Domestic turnover captured (£m)	GVA (£m)	Rationale for the impact of innovation on domestic deployment of related equipment and services
Smart network equipment and services	2050: 1,000	N/A	60%	2050: 600	2050: 210	60% of investment in smart network equipment and services is expected to accrue to UK firms[111]
Aggregation services	2050: 1,100	N/A	75%	2050: 800	2050:400	The UK is a leader in aggregation services and is expected to remain a leader to 2050

Note: * *Future market shares are not a forecast, but what UK business opportunities could be potentially in the context of the EINAs. The possible market share of the UK, and rationale for the impact of innovation, are based on PRODCOM analysis and additional market research. N/A indicates data is not available.*

Source: *Vivid Economics*

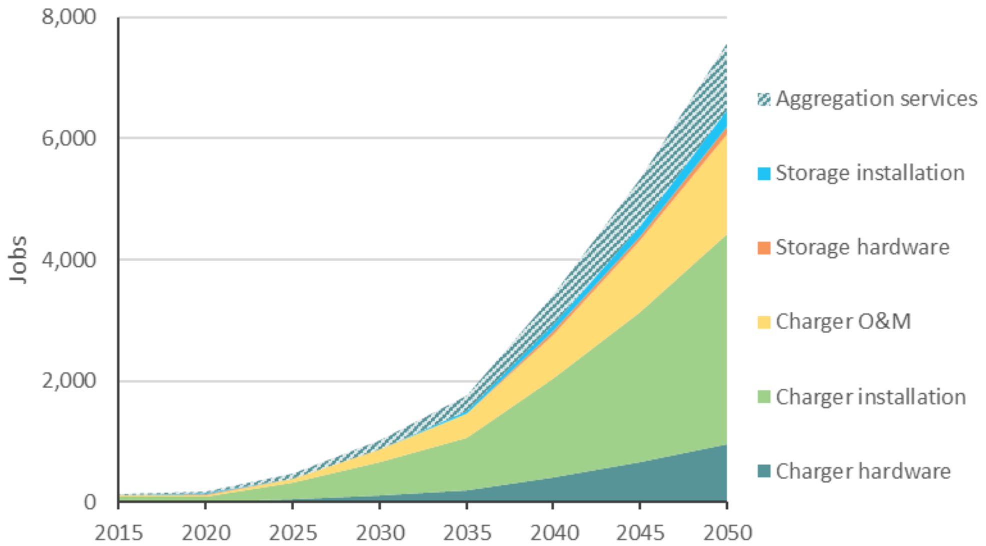
[111] Ernst & Young (2012) Smart Grid: a race worth winning? https://www.ey.com/Publication/vwLUAssets/Smart-Grid-A-race-worth-winning/$FILE/EY-Smart-Grid-a-race-worth-winning.pdf

Figure 7. **GVA from domestic markets by component – smart systems**



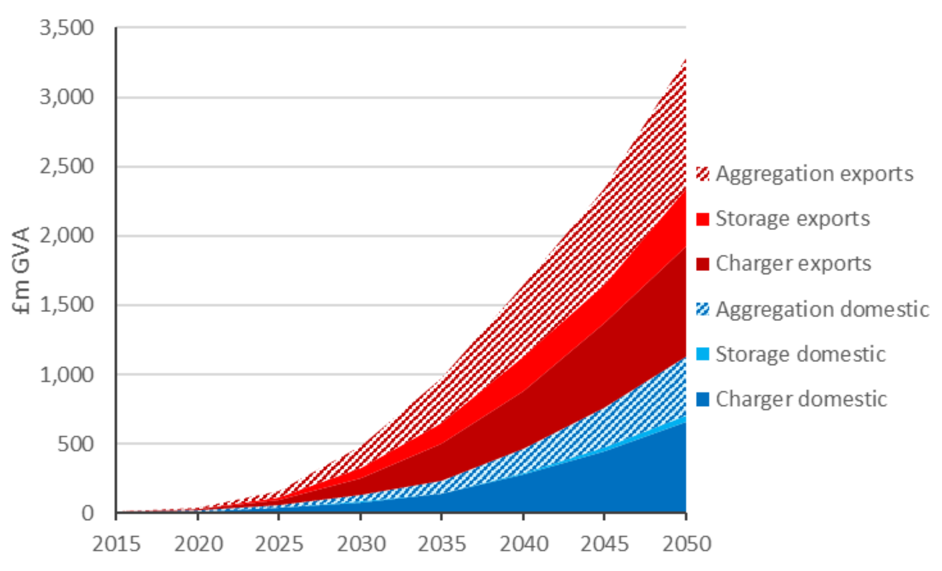
Source: *Vivid Economics*

Figure 8. **Jobs supported from domestic markets by component – smart systems**



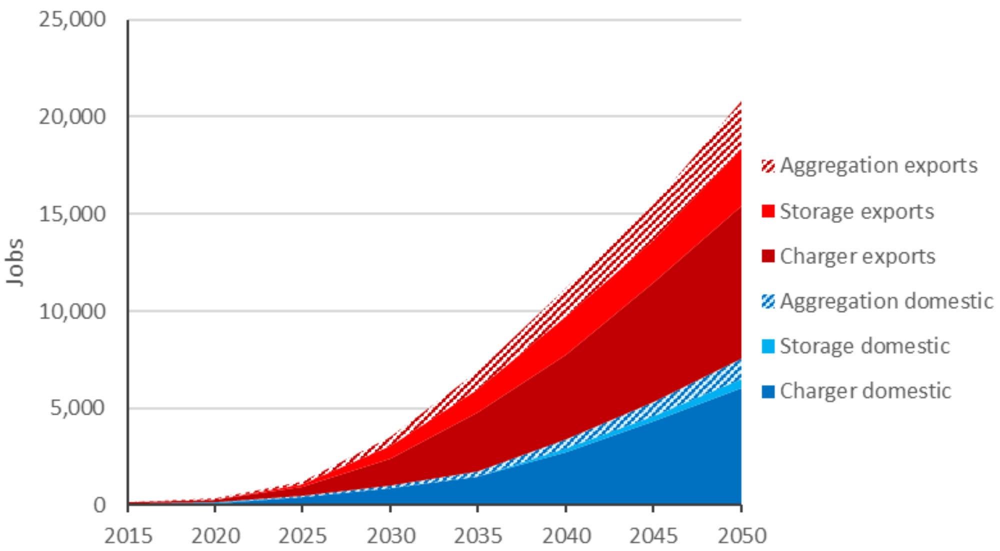
Source: *Vivid Economics*

Figure 9. **GVA from export and domestic markets – smart systems**



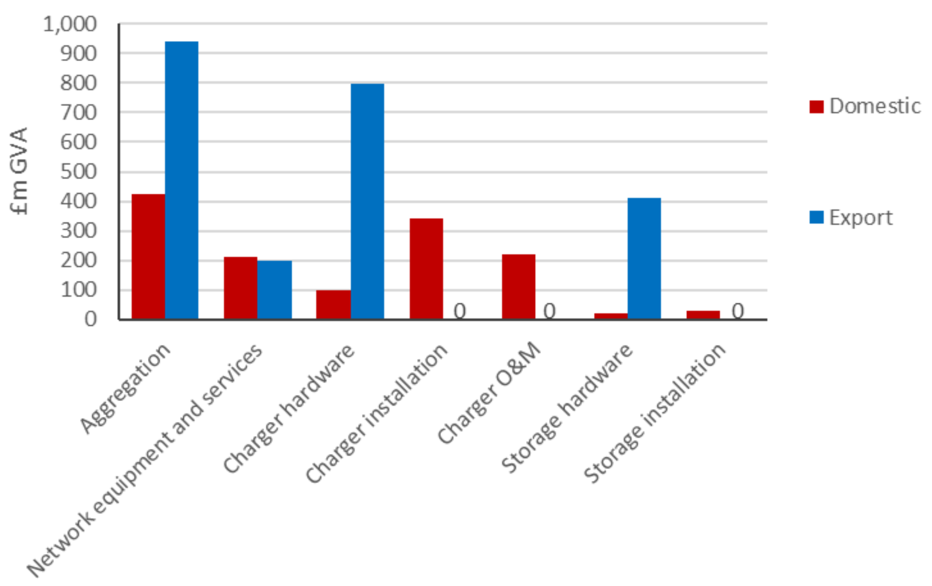
Source: *Vivid Economics*

Figure 10. **Jobs supported from export and domestic markets – smart systems**



Source: *Vivid Economics*

Figure 11. **GVA from export and domestic markets in 2050 – smart systems**



Source: Vivid Economics

Contact us if you have any enquiries about this publication, including requests for alternative formats, at:

Department for Business, Energy and Industrial Strategy
1 Victoria Street
London SW1H 0ET
Tel: 020 7215 5000

Email: enquiries@beis.gov.uk