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Smart energy - technology landscaping, Scotland's Energy Efficiency Programme

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Summary

This is one of three technology landscaping studies commissioned by Climate X Change, feeding into the Research and Development (R&D) workstream of Scotland's Energy Efficiency Programme (SEEP). It covers smart energy technologies with the concurrent landscaping studies looking at energy efficiency and heat. In co-ordinating this work, Climate X Change is working closely with the Scottish Government policy team working on delivering SEEP.

Our research has been focusing on the identification and application of market-ready smart energy technologies, specifically those at a Technology Readiness Level (TRL) of 8 or 9. They need to be relevant in the drive to reduce energy consumption and carbon in buildings. We have checked with practitioners if we have the right spread of technologies, and whether there is anything we have missed. Our finalised list of technologies has been run through a total of 30 assessment criteria to build up individual use profiles as well as a broader picture of smart energy's application.

Our starting point for categorising technologies is shown in the table below.

Technology categories	Domestic	Industrial / Commercial	Generation	Distribution Network
Monitoring and sensors	*Monitoring, data collection and in-built data analysis / controls*			
Platforms / data analytics	*Presentation and analysis of data on a digital platform*			
Communications	*Newer broadband technologies for transporting data*			
Control	*Technologies with a primary control function*			
Storage	*Electrochemical, heat and cold storage*			
Response	*Flexing energy consumption or output when signalled to do so*			

It is important to understand that this is a broad-brush assessment, intended to identify technologies relevant to SEEP. We have not assessed any technologies in detail, our scoring is largely a judgement call on a simple 1 to 5 scale to provide flavour and context to each technology. It is absolutely not an endorsement of otherwise of individual technologies or manufacturers.

Our database provides an ongoing resource for SEEP on smart technologies ready and able to make a contribution to energy savings. The assessment against criteria is only as good as the available data and knowledge base, but is provided

in a form that can be readily updated. We have made a number of broad observations on where and how technologies might be incorporated into SEEP, based on what we know about their application and the Scottish context.

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Introduction

The commission

This is one of three technology landscaping studies commissioned by Climate X Change, feeding in to the Research and Development (R&D) workstream of Scotland's Energy Efficiency Programme (SEEP). Climate X Change is working closely with the Scottish Government policy team working on delivering SEEP.

The three landscaping studies are:

- Smart energy (this report) – led by CAG Consultants in conjunction with Smarter Grid Solutions and Innovas.
- Energy efficiency – by the National Energy Foundation
- Heat – by BRE Scotland

Together the studies create a platform and common format for further developing and updating the suite of technologies. The focus for the moment is on technologies that are or will be 'ready' for commercial application under SEEP – the guideline for this being a Technology Readiness Level (TRL) of 8 or 9. Each shortlisted technology is assessed against an agreed set of criteria on technical, environmental, consumer, monetary, supply chain and policy grounds.

Scotland's Energy Efficiency Programme (SEEP)

SEEP is the "cornerstone" of Scottish Government's National Infrastructure Priority on buildings energy efficiency. It will combine existing energy efficiency and community energy programmes with new devolved powers over Supplier Obligations on energy efficiency and fuel poverty.

Alongside its draft energy strategy published in January 2017, Scottish Government is consulting on the SEEP framework[1]. A pilot phase is underway, with projects running to 2018/19. A development phase to 2022/23 will see implementation of advice and support services, an assessment and consumer protection framework. Thereafter will be a full-scale operation of SEEP, facilitated by new regulation as appropriate (e.g. of private sector rented sector).

The vision is a scheme which combines and consolidates interventions across all of Scotland's building stock – commercial, domestic and social – making use of delivery mechanisms shown to work and deliver value for money.

Report structure

All three studies use the same reporting structure, as follows:

- Technology area – explanation of the technologies involved as a group, with context for Scottish application
- Methodology – overview of the consultant's methodology
- Six separate sections covering a technology category (Monitoring and in-built sensors, Platforms / Analytics, Communication, Control, Response, Storage) each with a narrative on shortlisted technologies, trends emerging from the assessment, contextual observations and identification of key data gaps. A combined database of technologies and assessment scores accompanies the three reports.
- Conclusions and recommendations

[1] National Infrastructure Priority for Energy Efficiency – Scotland's Energy Efficiency Programme. January 2017. http://www.gov.scot/Publications/2017/01/2195/downloads#res-1

Smart energy

Context

There is not a lot that cannot be prefaced by the word 'smart' these days – smart homes, offices, factories, washing machines, TVs, phones, generators, networks, plugs and (with a "smart" device at their fingertips), consumers. Even the Birmingham section of the M6 is smart[2]. So how do we define and give substance to such a ubiquitous phenomenon?

Broadly speaking smart technologies are seen as enabling flexibility in parts of the energy (or any other) system that have previously been inflexible – for example flexing demand to low carbon generation patterns (as opposed to flexing fossil fuelled generation to demand patterns), or facilitating active participation of customers in understanding and controlling energy consumption, or letting intelligent devices do this for them.

The Scottish Government's draft energy strategy sets out a vision for 2050, when "new forms of flexible generation and demand management services are widespread" and "Scotland has achieved almost complete decarbonisation of the energy system." Faced with a more complex energy system, the Government says consumers will engage through the use of "smart technologies[3]." It goes on to say that, "There is ….great potential for investment in a range of smart, flexible and grid-friendly technologies that can provide a range of benefits to the energy system in Scotland. These technologies can maximise our renewable energy potential, use existing assets more fully, balance energy supply and demand, and enhance the efficiency of the energy system."

Flexibility is not an end in itself, it is the glue that binds and integrates other developments in energy efficiency, low carbon generation, heat utilisation, electrification and enhanced consumer response and engagement. Using less energy through more conventional energy efficiency measures can create challenges for a system that has grown up around seasonal and daily peaks. Successes in developing renewable energy resources can create periods of over-supply for which we need new ways of managing. Consumers still expect energy to be there when they want it, but are increasingly accustomed to using smart devices to improve utility, save money and, for some, to benefit the environment.

A key driver for smart applications is saving money. Network companies actively manage supply and demand to keep flows within safe limits, as an alternative to building more lines to passively provide for more demand. Motorway operators manage the traffic at pinch points to delay the need for new roads. When new power lines and motorways cost several billion pounds, investment in monitoring and control capabilities instead makes perfect economic sense. Growth in renewable energy accelerates the need to balance flow management against new investment as well as driving smart energy applications aimed at further decarbonising our energy use.

It is easy to see the logic at this macro scale of whole energy systems. But what about from the bottom up, at the buildings and consumer level? Well, in one sense it is exactly the same, but at a smaller scale with many, many more points of flex. Who is in control is a key question – it could, as for the macro level, be the System Operator (SO) sending signals into people's homes and controlling their appliances, without them even noticing. Or it could be the customer responding to time of use tariffs, or installing their own storage systems to smooth their own demand seen by the SO.

We don't yet know quite how smart a smart energy system will be. At the moment, it is very much in its evolutionary phase. We all have an idea of what it is, but very few of us actually use it. This technology landscaping exercise gives us an idea of what's on the horizon, what we actually might expect to see and experience over the next decade or so.

Parameters of the study

We are interested here in the bottom up applications, those smart energy technologies with the potential to enhance buildings and behavioural energy efficiency. This does not mean we are limited to technologies physically within buildings when you can have a chain of command from the transportable smart phone app controlling the smart

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[2] Smart motorway, https://en.wikipedia.org/wiki/Smart_motorway

[3] Scottish Government, 2017. "Scottish energy strategy: the future of energy in Scotland." http://www.gov.scot/Publications/2017/01/3414

thermostat monitored by the smart meter talking to the network's smart energy management platform controlling distributed generation. By way of imposing some structure, we start with buildings and people, and look outwards at their dependencies and interconnections. Inevitably it is just a beginning, and we fully expect it will be expanded and refined over time.

European standards organisations[4] use a Smart Grid Architecture Model (SGAM) to conceptualise the component parts of smart energy technologies, their application and use. Figure 1 below reproduces the three dimensional architecture. It basically serves as a map of the sector ("domain" in the model), place ("zone") and purpose ("interoperability layer") within which smart technologies operate.

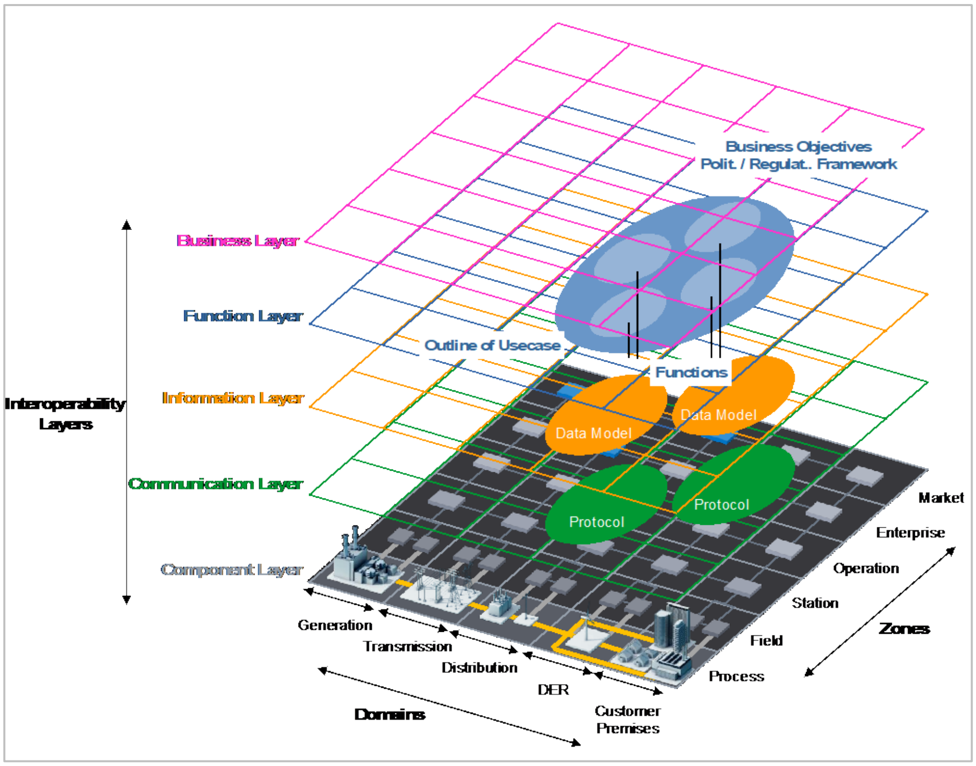

Figure 1 Smart Grid Architecture Model

This model is a little too complicated for our purpose, which needs a narrower scope of buildings- and people-focused applications. Therefore, we have employed a simplified two dimensional categorisation, defining purpose or function on one axis and sector / domain on the other, with very similar subdivisions (Table 1).

Technologies tend to be marketed by their primary function, but can encompass several technology components packaged together. These component technologies can span two or more categories, making it almost impossible to place some technologies definitively in just one category. Probably for this reason the SGAM shows categorisation visually, using shading to span several categories.

[4] CEN, CENELEC, ETSI, November 2012. Smart Grid Reference Architecture. Smart Grid Coordination Group. https://ec.europa.eu/energy/sites/ener/files/documents/xpert_group1_reference_architecture.pdf

Table 1 Technology categories	Domestic	Industrial / Commercial	Generation	Distribution Network
Monitoring and sensors	*Monitoring, data collection and in-built data analysis / controls*			
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Methodology

Overall approach

Our methodology is shaped around producing working deliverables which can be maintained as SEEP moves into development and implementation phases. Given the focus on TRLs of 8 or 9 we have looked for technologies being tested and used in the real-world, and asked practitioners to tell us if we have missed anything important. Long-listing to short-listing includes sense-checks against SEEP energy- and carbon-saving objectives and the focus on application to buildings and consumers.

Alongside this narrative report, our main output is an Excel spreadsheet cataloguing and referencing each short-listed technology, each with its own scorecard against 30 criteria.

Literature review

Casting the net in the broadest sense of the word "literature", we have consulted reports, presentations, websites and directories to identify technologies of interest. In the UK, excepting technology providers themselves, a good number of organisations work directly on smart energy research and development – from the 14 distribution companies (Distribution Network Operators, DNOs) through to government and government-backed R&D organisations (Energy Technologies Institute, Energy Systems Catapult, EPSRC – the Supergen initiative – and TechUK), charities, trade associations and the energy regulator Ofgem. Outwith the UK, continental Europe has many examples of good practice and Denmark and Germany in particular are very experienced in managing distributed intermittent generation and demand[5]. In the US some states are, notably, leading the way in domestic demand-side participation in energy markets.

References inevitably 'snowballed' onto new references, although we quite quickly found that the same technologies were coming up again and again. Whilst there were diminishing returns in identifying new technologies, we did put place-markers against references which could be useful for subsequent technology assessment.

We found that some historical smart energy initiatives had run out of steam, with workstreams having finished a number of years ago, and websites not updated. Other sources, notably the Energy Networks Association (ENA) smarter networks portal had a huge amount of historical and recent information. It is comprised of projects funded by money that the regulator awards network companies to spend on new and innovative ways of running the networks. We had to filter quite extensively for projects with a buildings component and for projects that met our definition of 'smart' (as opposed to new and experimental ways of doing things).

Our full list of references for the initial technology search can be found in Appendix A. Candidate technologies went forward to populate a technology database. Although it has not been our intention to single out particular technology providers, our literature review does include links to individual providers, some of which are carried through into the scorecards. We have found that this helps to crystallise understanding of the technologies and their often niche function.

Market testing

Following the literature review, we wanted to check whether we had a complete picture of the smart technology landscape. Key (UK-based) practitioners and researchers with an interest in and experience of smart energy were asked to comment on the technology database. We simply requested pointers as to any important omissions but any contextual comments were also gratefully received. A full list of stakeholders consulted is in Appendix B.

One stakeholder thought that our original categorisation was too broad, and suggested that we separate out web-based platforms which present and analyse data, and separately communication technologies, from a more general monitoring and data category. We agreed with this comment, although categorisation has remained difficult throughout the project.

[5] We have limited our search to English language publications and websites.

Two stakeholders emphasised heat storage as an important component of storage, and provided us with additional examples. One added light sensors as an additional technology. Overall a number of additional technology providers were put forward, but we found that broadly the literature had unearthed all of the main technology types. Contextual comments focused on privacy implications of some smart energy technologies, barriers to deployment – especially regulation, and the challenges of organising and deploying smart applications at scale.

We would like to thank all of the stakeholders who responded for their time and insightful input.

Assessment criteria

The final short-listed technologies have been assessed for their performance against a set of technical, economic, environmental, policy and consumer-based criteria.

Working closely with Climate X Change and the consultants for the energy efficiency and heat landscaping studies, we are using a common assessment framework. This has been developed through discussion and through trial and error, running technologies through a 'scorecard.' Each criterion is given a 1-5 score against an agreed high / low scale. Between studies, the technologies can differ substantially and some criteria may not apply – for example it is difficult to see how to assess the technical efficiency of a smart energy web-based platform. In this case we have recorded Not Applicable. The exception to a 1-5 score is the TRL, which is either 8 or 9 (all available TRL levels are shown in Appendix C). Where quantitative assessment is not appropriate we have made textual observations.

A blank scorecard is shown overleaf (Figure 2)

Data provided by Innovas has also allowed some detailed quantification of market value, employment and company numbers by market sector. Standardised business sectors[6] – which are disaggregated to the level of, for example "domestic power consumption monitoring equipment" – do not always precisely match our technologies but, more often than not, we are in a good position to rate economic impact. Innovas' full set of economic data by sector is reproduced in Appendix D, alongside the methodology used to derive the figures.

The scorecard exercise reveals both how readily deployable technologies are (for example on grounds of cost and practicality) as well as barriers to deployment. It gives a sense of the most promising technologies, as well as where policies need to concentrate. This is a relatively high-level exercise and, in some cases, highlights data gaps hindering reliable assessment.

The technologies

Our database has 26 technologies which have been run through the scorecard. The following sections provide a narrative for each category of technologies, to be read alongside the scorecards (separate document).

Likert				
1	2	3	4	5
Bad				Good

[6] definitions are consistent with (but not limited by) SIC and NAICS codes and extend down to the equivalent of a 6 digit classification. See Appendix D for details.

Technology here

Explanation here

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	9	
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	5	
Reliability	1 (low) to 5 (high) score	5	
(level of) Compatability with existing systems	1 (low/poor) to 5 (high/good) score	4	
complexity of systems/ their integration	1 (complex) to 5 (simple) score	4	
risk/severity of unintended consequences	1 (high) to 5 (low) score	4	
		31	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	3	
whole life environmental impact	1 (high) to 5 (low) score	5	
		8	

Policy / Regulation	Scoring	Score	Comments
compatability with Scottish policy	1 (low) to 5 (high) score	5	
compatability with current regulation	1 (low) to 5 (high) score	5	
compatibility with current assessment	1 (low) to 5 (high) score	5	
		15	

Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	2	
life cycle costs	1 (high) to 5 (low) score	5	
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	3	
(potential for) economy of scale (to drive	1 (low) to 5 (high) score	4	
		14	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	4	
existing Scottish capacity/skills	1 (low) to 5 (high) score	3	
Scottish content	1 (low) to 5 (high) score	3	
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	3	
scottish economic impact potential	1 (low) to 5 (high) score	3	
		16	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	4	
disruption	1 (high) to 5 (low) score	2	
customer aceptance	1 (low) to 5 (high) score	3	
savings on bills	1 (low) to 5 (high) score	3	
maintenance requirements	1 (high) to 5 (low) score	5	
health/wellbeing/comfort	1 (high -ve imapct) to 5 (high +ve	4	
existing consumer protection? (adequacy?)	1 (low) to 5 (high) score	3	
		24	

Opportunities / risks	Scoring	Score	Comments
Critical success factors/watch points	List/Describe		
other relvant considerations/risks/opportunities	List/Describe		
adaptability / future proofing	List/Describe		
		108	

Figure 2 Example scorecard

Interpreting findings

It is important to understand that this is a broad-brush assessment, intended to identify technologies relevant to SEEP. We have not assessed any technologies in detail; our scoring is largely a judgement call on a simple 1 to 5 scale to provide flavour and context to each technology. It is absolutely not an endorsement or otherwise of individual technologies or manufacturers.

We have included technologies at both TRL 8 and 9. Those at 9 are reasonable well established technologies, but are included where we feel that some signalling would aid policy makers in understanding where and how they fit in to the bigger picture.

There are some areas where data availability is excellent – for example economic impact – and others where we have struggled to find reliable and especially quantifiable data. This is important to bear in mind when interpreting our findings. By way of guiding reading of the scorecards, we have provided comments against the assessment criteria on how confident we are in our scoring, based on data availability and recorded use and experience of the technology (see Table 2).

Table 2 Confidence in assessment

Criteria	Confidence High, Medium or Low	Comments
Technical		
Technology readiness	High	Professional judgement based on nature of application
Efficiency	High where relevant	Not meaningful for ICT technologies; good data for most storage technologies
Reliability	Medium	Patchy data, reliance on demonstration project reports and customer reviews
Compatibility with existing systems	Medium	Qualitative assessment based on literature and professional judgement
complexity of systems/ their integration	Medium	Qualitative assessment based on literature and professional judgement
risk/severity of unintended consequences	Low	Not always known, especially for TRL 8
Environmental		
(in-use) carbon saving potential	Medium	Smart technologies do not always have direct carbon or energy savings, but where relevant data often available on energy savings which can translate to carbon savings
whole life environmental impact	Low	Environmental impact documented for some storage components, otherwise poor data availability
Policy / Regulation		
compatability with Scottish policy	High	Professional judgement based on existing and prospective policies
compatability with current regulation	High	Professional judgement based on existing prospective regulations
compatibility with assessment methodologies	High	Professional judgement based on existing and prospective Standard Assessment Procedure
Monetary		
capital costs	High	Good data generally but rather subjective scoring based on costs compared to nearest alternative.

life cycle costs	Low	Rarely complete data on lifecycle costs
carbon cost effectiveness (£ per tCO2 saved)	Low	Not particularly relevant to ICT or data not readily available, based on assessment of savings versus capital costs and maintenance requirements
economy of scale (to drive down costs)	Medium	Judgement based on current market penetration, potential for roll-out and economies
Capacity/ Supply Chain		
applicability	High	Professional judgement and drawing from literature, considering utility and potential Scottish buildings
existing Scottish capacity/skills	High	Use of Innovas data on Scottish companies and literature review for Scottish connections
Scottish content	Low	Limited data in literature, difficult to establish provenance of materials
potential for cross-sector involvement/benefit	High	Smart technologies ubiquitous in wider context of smart systems with lots of cross-sector involvement
Scottish economic impact potential	Medium	Use of Innovas data where applicable, but difficult to predict future potential
Consumer		
user friendliness / practicality	High	Mostly good information from pilot projects, customer reviews and research. Exception is very new-to-market
disruption	High	Mostly good information from pilot projects and manufacturers.
customer acceptance	High	Mostly good information from pilot projects, customer reviews and research. Exception is very new-to-market technologies.
savings on bills	Medium	Patchy data and often from manufacturers rather than independent assessments
maintenance requirements	Medium	Patchy data, often reliant on manufacturers information
health/wellbeing/comfort	High	Generally professional judgement
existing consumer protection? (adequacy?)	High	Based on established regulations and protections
Opportunities / risks		
Critical success factors/watch points	High	Literature has good information on barriers to future roll out
adaptability / future proofing	Medium	Generally professional judgement

Monitoring, sensors and in-built control

Many smart energy technologies will incorporate an element of monitoring, but few are marketed on the basis of this function alone. This is a recurring theme in categorising smart technologies, namely the outcome is the 'product' as opposed to its constituent part or parts. Often, the combination of constituents, and how they are used, *is* the technology – the sum being greater (smarter) than the individual parts.

Because we are assessing outcomes, our categorisation is outcomes-based. The consequence is a limited number of monitoring-focused technologies. Nonetheless, it is important to recognise that the monitoring or data acquisition function is an important feature of smart technologies, and we have attempted to distinguish this category from its close neighbours of communication, data analysis, control and response – taken in that order, each building on the previous functions.

Smart meters are primarily designed to collect and transmit data. In light of the UK's smart meter rollout, they are on the borderline of being classed as innovative or new. Nonetheless, we decided to keep them here and specifically to focus on the more advanced SMETS 2 meters, which integrate with the dedicated smart meter network, thereby providing enhanced security and significantly enhanced functionality compared to the foundation (SMETS 1) meters which have dominated the rollout to date.

Smart meters are being offered to all households and businesses within GB, as mandated by the UK Government[7]. Direct carbon saving potential is limited, as evidence suggests that interaction with the associated display devices is often short-lived[8]. However, the longer term potential arising from the DNOs and energy companies being better positioned to effectively manage the network and supply, is significant.

The UK rollout of smart meters largely precedes initiatives to harvest and use the data, beyond accurate billing. There are well-documented facilitatory actions which can be taken to improve this situation, including:

- For domestic customers, there is a need to move to what is called half-hourly settlement, meaning that half hourly energy prices are matched to half hourly energy consumption. At the moment, despite there being 'smart' half-hourly metering in many homes, energy suppliers still pay for the energy these customers consume based on an assumed domestic demand 24 hour profile. Clearly this in turn prevents domestic customers from moving to within-day time-of-use tariffs, something which industrial customers, who are settled half-hourly, have had – and mostly benefited from if they can be flexible – for many years.
- For all smart meter data, there are restrictions on access to the data in order to protect privacy. This is severely limiting its use by third parties such as DNOs and technology providers and hence holding back innovation.

Thus the direct gains from smart meters are currently quite limited, especially in the context of domestic consumers, but they are part and parcel of a wider smart energy system.

Intelligent thermostats or 'self-learning' thermostats automatically adjust building temperature settings based on learned preferences and occupancy patterns. Such devices are now widely available from numerous different manufacturers and suppliers, including major players such as Google (with their Nest thermostat). They are compatible with a wide and expanding range of heating systems and are easily installed. Carbon savings vary significantly depending on the installation context but trials suggest savings are greatest in properties with electric heating[9], of which Scotland has a disproportionately high number.

[7] The smart meter network being developed by the Data Communications Company (DCC) will reach at least 99.5% of Scottish households. There will likely be a small number of remote communities that will not be able to access the benefits of this network.

[8] See DECC (2015) Smart Meter Early Learning Project, Consumer survey and qualitative research

[9] CLEAResult (2015) Smart Thermostats: A CLEAResult White Paper, prepared for Commonwealth Edison

Intelligent lighting incorporates daylight and motion sensors, as well as remote control. Whilst there may be carbon saving benefits in some circumstances, particularly commercial settings, the opportunity for this is likely to diminish over time as lighting installations themselves continue become more energy efficient.

Power quality monitoring and intelligence systems are devices and systems which provide information on power consumption at the local level and which monitor the impact of embedded power generation. They come part and parcel of a wider smart energy system and whilst reliable, are generally as good as the ability to use the real-time information. They facilitate more active local networks incorporating demand response, local energy supply and power matching, enabling power fluctuations and other power quality deviations to be detected and rectified.

Scorecards overview

It has been difficult to compile complete scorecards for technologies in this and in the following analytics and communications categories, simply because many of the criteria are not particularly relevant or often thought of in the context monitoring and ICT equipment.

Technically, all of the reviewed technologies are easily at TRL 9. Their role in future innovation will be in combination with other technologies such as building energy management systems. Technical efficiency is a little meaningless for these technologies given the lack of an energy conversion process and low energy consumption.

Technical compatibility has been an issue for earlier SMETS 1 smart meters. A common framework for communications infrastructure linking smart meters has lagged behind the rollout and left the older meters needing some modifications to be compatible. This is not an issue for SMETS 2 meters which we have reviewed, but it highlights an issue with many smart energy interventions which are reliant on a network of interconnecting technologies which need to be cross-compatible. This makes future-proofing particularly important, and, for large-scale roll-outs, planning and co-ordination.

Reliability and general consumer acceptance is largely good for meters and sensors (we took a straw poll of reviews on Amazon UK for intelligent lighting and thermostats). Costs are relatively low but that doesn't say much about value for money. There is very little data on carbon cost effectiveness, probably because energy savings are an indirect consequence of knowing more about energy consumption, and savings are often behaviourally-driven. Some commercial providers do however claim significant savings.

Power quality monitoring is not consumer-facing – even though it ultimately serves consumers – so we have been unable to assess the consumer criteria here.

Scottish economic potential is moderate for these technologies in isolation, greater clearly when combined within more complex smart energy systems. Because of the sheer volume of the rollout, smart meters offer the greatest potential for installers.

Platforms / analytics

Customer energy use platforms are both basic and diverse at the moment – anything from a simple display device to web-based presentation and analysis of energy use data, and energy saving suggestions. They are not particularly innovative, but the potential for future development and integration with other smart technologies is significant.

Gaming of energy saving involves householders offering large household appliances (dishwashers, washing machines etc.) for central network control in the form of a "game", i.e. householders are able to win points and prizes for making appliances available for control at times of high demand on the network. A feasibility trial is currently underway[10], with little data yet available, other than reports of difficulties in recruiting sufficient numbers of households. The longer term potential of such approaches may be enhanced by the greater interactivity between householders and the network which will be facilitated by the smart meter rollout. Participation is straightforward and non-disruptive, involving the installation of smart plugs and participation via a smartphone app.

Peer-to-Peer Energy Matching Platform is a term to describe a cloud-based system for matching business energy demand with local renewable energy resources. Such a platform is currently available to business consumers via Open Utility's Piclo product, in partnership with Good Energy. Whilst it allows individual businesses to reduce their own carbon footprint by specifying that a higher proportion of their energy comes from renewable sources, it does not directly reduce emissions from the network overall. Indirectly, through encouraging greater connections between consumers and the network, greater awareness of energy use may be achieved, as well as increasing the demand for renewables.

Our literature review revealed a number of additional smart energy enablers which fall under the Analytics heading, but which cannot yet be identified as a distinct technology. **High Performance Computing Technologies** is a catch-all term for the computing that needs to accompany smart energy expansion. Studies highlight that powerful computing is and will be required but specifics are hard to ascertain. There are a number of analytical processes that accompany an active local network, for example **Distribution State Estimation (DSSE)** which, as it sounds, uses real-time readings in one part of the network to estimate the state of the network in other parts. In network planning timescales, **Network Investment Modelling** compares reinforcement options against alternatives such as deployment of smart technologies to manage flows. Both DSSE and network investment modelling are pretty standard practice for DNOs, but there is nonetheless room for development and innovation (in particular, there is potential for improvement through greater monitoring of the network and better quality data). Both are mentioned in pilot projects as important tools in the context of smart energy.

Scorecards overview

Scoring for these technologies is comparable to that for the monitoring technologies. They are relatively low cost interventions, where energy and carbon saving is not the direct result, but, but which could contribute to longer-term behavioural changes. Their use and application is much less common than smart meters or intelligent sensing, and the potential for future development and uptake is there to be had.

Innovas' analysis shows the ICT sector to be particularly strong in Scotland – hitting well above its weight in market value. So the fit here with Scotland's existing economic make-up is strong with this category, with significant potential to add value.

[10] Northern Powergrid (2016) Network Innovation Allowance Progress Report

Communication

Getting communication channels right is a learning point from a number of the DNO innovation projects. A number of pilot projects experienced issues around communications infrastructure, finding that regular in-home wireless or the 4G network for town-wide communications were not always up to the challenge of the demands of the project. For example, during trials of Demand Side Response in Glasgow city centre buildings, Scottish Power found that "the 4G solution …. proved to have low reliability and considerable unpredictability, which was surprising in city-centre environment."[11]

Improved reliability and service-level for existing wireless solutions such as Wi-Fi and 4G is of course one course of action as smart applications become more commonplace. We also found a few projects trialling new, more novel methods of communication.

Whole home communication refers to Home Area Networks which can be utilised for per-appliance metering (as opposed to property-level metering provided by smart meters). A UK company (Xsilon) is developing the technology (technology readiness is unclear), which fits inside a standard plug, so can be retrofitted to any device. The technology would also allow remote control of individual appliances. No data is available on costs and carbon saving potential.

Internet of Things mesh refers to generic technology which enables smart devices to be interconnected. At a local level, commercial products are available which allow households and businesses with smart batteries installed to share their stored energy via the grid. At the scale of a town or city, the potential of the technology has been explored in terms of, for example, highways management, waste management and parking[12]. In terms of energy, Scotland's ambitious renewable energy targets mean that energy storage will be critical to the future energy network, and the capability to share stored energy will enhance the efficiency and resilience of the network. Due to the high costs of batteries, carbon cost-effectiveness if estimated to be low but there is longer term potential for significant cost reductions, including through economies of scale.

WiMax, so-called "Wi-Fi on steroids" is cited as having potential, as is **broadband across power lines**. We have undertaken a partial assessment of the former based on very limited information, the latter is probably of peripheral relevance to local buildings-focused projects. It is not yet clear if these technologies or others will be important for smart energy. However, better and high capacity communications infrastructure is an area that could see further development to cope with the huge data transfer demands of a smart energy future.

Scorecards overview

It is clear that we need more information and experience with novel ways of transmitting information, both within our homes and over longer distances. Our research revealed whole towns (Bristol, London, Milton Keynes) putting themselves forward for pilot projects, experimenting with the Internet of Things and cross-town communications technology. This is still very much at the pilot stage and our scorecards are only partially complete, reflecting the fact that the technology itself is only part of the bigger smart energy saving picture.

[11] Smart building potential within heavily used networks. http://www.smarternetworks.org/Project.aspx?ProjectID=1678#downloads
[12] See, for example, http://www.hypercat.io/use-cases.html

Control

Control technologies are those which provide an enhanced level of control and configurability over demand and generation technologies.

Smart plugs are plugs for appliances that can facilitate control either by the grid operator or by the customer themselves. They are a relatively low cost and modular solution that can be purchased by the customer. They are not widely deployed at the moment and the technology is still in development. However, wide scale uptake of this technology has the potential to provide grid operators with a high level of flexibility on the system. Smart plugs can be a way of 'upgrading' regular appliances e.g. as an alternative to replacing existing appliances with 'smart appliances' (see below in Response technologies)

Home voltage regulation technologies control the voltage of residential properties. The purpose of this is to improve the energy consumption of a device. It works by maintaining the voltage at a set point to avoid having excess energy lost as heat e.g. incoming voltage for residential demand is typically 245V but appliances generation use 220V. It is possible to retrofit this solution to existing devices.

Building Management Systems (BMS) for residential, commercial and industrial scale buildings can help to optimise energy use, reduce energy consumption at peak times and provide savings on energy bills. There is currently a wider scale of deployment for BMS at commercial and industrial scale due to the potential for savings involved. BMS provides a route to participation in Demand Response markets. For domestic BMS, there are more simplified controllers available, including for smart thermostats. The graph below (Figure 3) demonstrates that the uptake in smart devices for home energy control is still low compared with audio/visual technologies and wearable technologies.

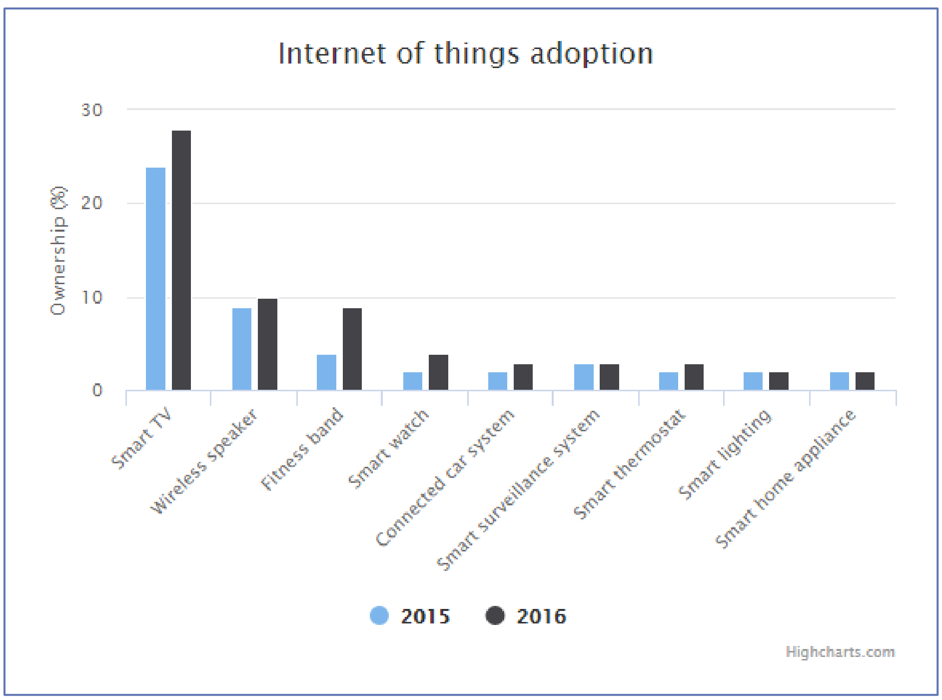

Figure 3 UK uptake of 'smart devices'[13]

[13] http://www.telegraph.co.uk/technology/2016/08/27/internet-of-things-struggles-as-use-of-smart-home-gadgets-flatli/

Control of generation and demand is available in various levels of complexity. At the basic level, **Generation router** devices can communicate with an energy management platform and instructs generation response. Technologies for this include Broderson RTU32 or the Origami Energy Router. Origami's Energy Router is a two-way hardware module that is connected to individual distributed energy assets and communicates data back to Origami's Energy Technology Platform for analysis and instruction. Every router contains a processor that is capable of measuring (energy, voltage, frequency), communicating (both locally as well as back to the platform) and controlling (by turning power up/down, on/off) the asset to which it is attached. The Broderson RTU32 provides an open and adjustable platform with both the power and functionality required to control advanced industrial applications.

A generation router is one of the key components of **Active Network Management** (ANM) systems. ANM schemes can control generation and demand in real time against constraints on the energy network. It provides an alternative method of connection of local energy to the distribution network, as opposed to traditional reinforcements. ANM can facilitate connections to the network in faster timescales and at a lower cost. A summary of ANM schemes in the UK is shown in Figure 4.

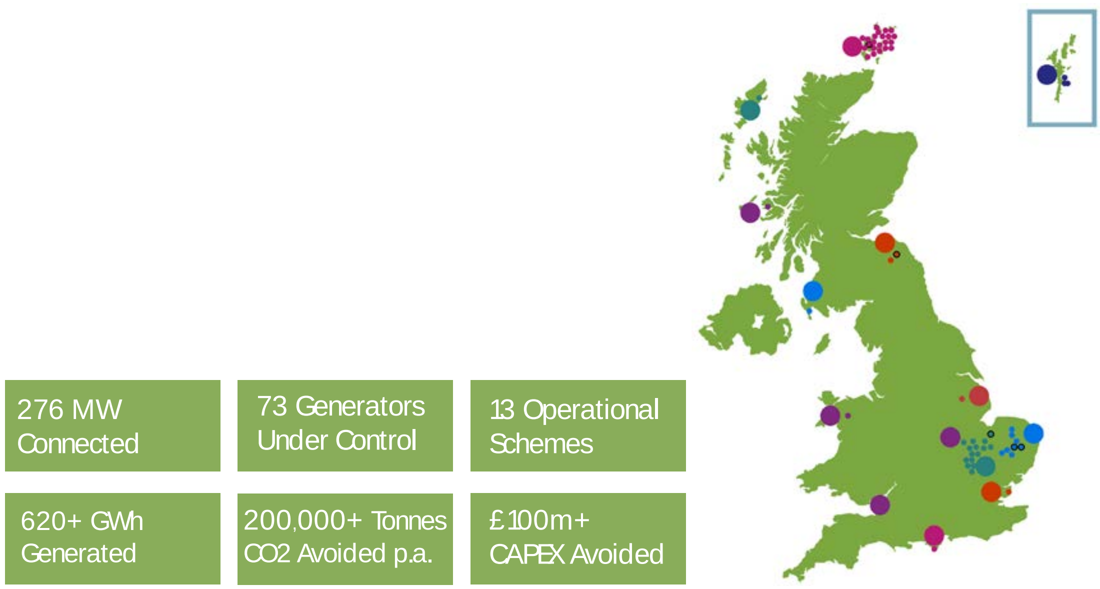

Figure 4 Summary of Active Network Management Schemes in the UK[14]

Microgrid controllers are local controllers that would allow an islanded network to be created following disconnection from the main grid. This would require the control platform to balance supply and demand within the islanded network to maintain power supply to critical infrastructure within the islanded grid. This can apply to industrial estates or within neighbourhoods e.g. domestic scale. It is similar in concept to ANM schemes, but in this case the constraint would be balance of supply and demand behind a single point of connection to the wider electricity network. Demonstration of Microgrids have been more common outside of the UK, and discussed by Xero Energy in a report for Highlands and Islands Enterprise[15]. They note only one true microgrid system in the UK, located at the Centre for Alternative Technology in Wales.

[14] http://www.smartergridsolutions.com/resources/knowledge-centre/anm-enabled-zones/

[15] http://www.hie.co.uk/common/handlers/download-document.ashx?id=5af49f92-d359-4180-9eef-08402a186319

Scorecards overview

As with some of the previously mentioned technologies, technical efficiency is not particularly applicable to control technologies, rather they contribute to the efficiency of the device or system being controlled. The consumer angle is important for consumer-facing technologies like Building Management Systems (BMS) and indeed they scored well here. Home voltage regulation had a slightly lower score due to its lower adoption profile and general lack of familiarity.

After ICT, "monitoring and control systems for energy management" is the second largest of the sectors analysed by Innovas, with 64 Scotland-based companies and over 15,000 employees. Some of these companies will be built around the renewables sector in Scotland, and there are others which focus on buildings management. There are strong linkages to work at Scottish universities and commercial spin-offs. Like ICT, this could be a sector with good synergy with existing capacity and skills in Scotland.

Costs are relatively low for controllers and generally integrate well within buildings and networks. Grid controllers are an order of magnitude up from building and device controllers, and necessarily are much more complex. Nonetheless, the incentive to install network-level controls is strong due to the rapid rise of renewables and the need for more flexibility from both generation and demand. As such, network operators are reasonably familiar with these technologies and open to further innovation.

Response

Response solutions are those which can be installed in consumer properties and respond automatically to instructions from either building management systems, local controllers or central control from the grid operator.

Smart appliances include washing machines, electric hot water heaters, air conditioning, dishwashers, tumble driers, fridges and freezers and electric space heaters. There are varying degrees of 'smart' capability with some more flexible than others. Reports in recent years have calculated the potential of smart devices on a nationwide level. If all fridges in the UK were replaced by dynamic demand units i.e. smart devices, the response level available to National Grid would be between 728 and 1,174 MW. This would have the potential to manage demand spikes on the network and reduce reliance on conventional spinning reserve plant – an expensive and high CO2 emitting option.

Demand response enables reduction or shift of electricity load from buildings through their existing building management systems (BMS) in response to signal from the DNO or energy management platform. To facilitate this, there is a requirement for aggregation of load shedding and communication between DNO and BMS. Developments in responsive technologies have come on significantly in recent years, however the uptake of such devices has been slow due to lack of incentives. In particular, demand response at residential and domestic scale has great potential to support the energy network and reduce customer bills, but without the right incentives for customers, they are not willing to adjust behaviour or to install the necessary technology to be able to participate in such schemes.

Sustainability First has looked at how demand-side innovation serves customers in the longer term, focusing on automation in terms of a customer consenting to remote control by a third party of their appliance.[16] As controls become intelligent, they suggest that it could become the norm for customers to control their own load in such a way that it responds in a pre-programmed and/or 'intelligent' way to cost-optimise.

Automated control could deliver a demand-side customer benefits at the level of the electricity system – matching patterns of electricity and network usage; at the customer level – matching consumer preferences with energy prices; turning individual customers and/or communities into 'prosumers' consuming and producing; and at the building level – by linking response into the BMS.

Sustainability First think that we may be 10-15 years away from commonplace usage of automated applications for electricity demand side at the home level but identify significant immediate potential for DSR integration with BMS.

Smart Inverter or 'Virtual Oscillator' is a relatively new technology, and one being developed in the US market. The National Renewable Energy Laboratory in the US[17] is investigating the potential for smart solar invertors which can enable PV units to remain connected to the network during faults, and therefore increase energy export. Smart inverters can also be used to provide grid services such as voltage and frequency regulation, fault ride-through, and anti-islanding functionality.

As with the smart appliances above, being able to provide more grid services via existing local energy connected to the network will provide greater flexibility and the potential to reduce the cost of balancing supply and demand on the network.

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[16] (Sustainability First and Frontier Economics, 2014)

[17] https://www.nrel.gov/grid/power-electronics-inverters.html

Scorecards overview

Demand-side response solutions are not very common, in particular in the domestic setting. For this reason the consumer-related criteria are scored slightly lower than for better-known control technologies. Really demand side response needs a time of use tariff in order to incentivise participation in response schemes, and these are not yet available to domestic consumers – in turn this is because domestic consumers are currently "settled" (billed) based on a standard time of use profile rather than their actual half hourly profile[18].

Adding smart response functionality to an existing device might add 15-20% on to the price, which would likely pay back through accessing time of use tariffs. (However this does not include the cost of aggregating a demand response scheme from hundreds or thousands of appliances).

On smart appliances, the scorecard cites BEIS consumer panel research which found that, of their existing non-smart appliances, people would be most willing to use washing machines (79%), tumble dryers (71%), dishwashers (68%), and chargers (68%) flexibly with a smart tariff. The public are less willing to use fridges (45%) and freezers (43%) flexibly, largely due to a view that they need to run constantly to ensure food safety.

Technically speaking, the technology works and demand response in the commercial and industrial sector has a reasonable track record. Energy savings are largely in the form of peak demand-lopping – i.e. shifting a customer's demand rather than reducing it. This can lead to significant savings down the line by avoiding building new, expensive and CO2-emitting peaking plant.

[18] The industry is working towards half hourly settlement for domestic customers.

Storage

Storage solutions are a tool used in smart energy systems to better match energy supply with energy demand. In particular, for uncontrollable energy sources – weather-driven renewable energy – excess generation over demand can be stored and used when demand is higher than supply. This reduces wastage or curtailment of carbon-free generation. Storage can be used at any scale from the capacity of a small power station to a battery in a residential setting.

Batteries storing electrical energy as chemical energy are the most well-known form of storage in the context of buildings and industrial settings. Technologies in TRL 8-9 are summarised in the Table 3 below, each with advantages and disadvantages depending on size, use (selected for amongst other things how long the battery can hold its charge, how fast in can charge / discharge, depth of discharge), environmental conditions, space, availability and cost.

Table 3 Battery technologies[19, 20]	Advantages	Disadvantages
TRL 9		
Lead acid	Established technology, relatively low cost, highly recyclable	Large and heavy, short life, poor depth of discharge
Lithium ion	High energy density, high depth of discharge, high efficiency, long life	Higher cost (but downwards cost trajectory), overheating is fire risk
Sodium sulphur	Established technology, relatively low cost for long discharge times, long life	Come as relatively high capacity units (1MW), high temperature application fire risk
Nickel cadmium	High energy density, modular	Higher cost, hazardous chemicals with poor recycling infrastructure, loses capacity with shallow discharge.
TRL 8		
Advanced lead acid	Evolution of lead acid – longer life and durability	Less proven
Vanadium redox flow	No degradation of storage capacity, scalable, long life	Large and complicated system
Zinc bromide flow	Modular, very long life	Large and complicated system, no established manufacturing process
Sodium nickel chloride	Evolution of high temperature sodium – long life, relatively low cost.	No established manufacturing process

[19] NYSERDA, 2014. "Behind-the-meter battery storage: technical and market assessment" Final Report. Report number 15-02.
[20] Lazard, 2016. "Lazard's levelized cost of storage" Version 2.

At the domestic scale, most of the examples in the literature use lithium ion – chosen for compactness and longer life. One provider offered both lithium ion and a cheaper, but shorter-lived, lead acid option.

The most common residential batteries do not provide power during a black-out at all, or, if they do, it is not sufficient for the entire home's needs. A BRE consumer guide says that "a fully-charged medium-sized system could store sufficient energy to power during the evening your lights and lower-powered items like your fridge-freezer, TV and laptop" but will "quickly run out if you put on heavy energy users like the washing-machine."[21]

There are batteries suitable for full back-up power but they need to be rated at a higher power (taking up more space) and wired correctly to do so. In the US there is increasing interest in back-up power in the home, following natural disaster related power failures[22]. As well as larger lithium ion applications, the literature cites other options, namely zinc bromide and a fridge-sized residential fuel cell (available to buy in Australia and the US respectively).

Electrical storage costs are quoted as $ per kWh and in the literature we have found these subdivided into costs as a function of the usable kWh in a fully charged to discharged battery, or, on the basis of KWh usage rather than maximum capacity. The benefit of the latter is that it is a better reflection of real-life, but is very specific to the regulatory and commercial environment in question. "Single use" cases are more expensive than where batteries can be put to multiple uses (for example peak lopping, demand side response, management of renewable energy).

Smart storage heaters are and new and improved versions of the well-established brick and water-based storage heaters found in households throughout the UK. The literature cites some 6.5 million night storage heaters and 13.7 million hot water storage cylinders currently installed in the UK[23], and around 7% of domestic customers relying on storage heaters for warmth[24]. By size this exceeds pumped storage capacity, although it cannot hold the store for more than a few days. Scotland has a disproportionate share of electric storage heaters, and in particular of those with dynamically teleswitched meters (heating controlled remotely). The new generation of smart storage heaters are more efficient (better insulated, able to hold heat for longer) and can be programmed by the user for optimum temperature and heating schedule.

Heat batteries using Phase Change Materials are based on the same technology used in portable hand warmers. A company in East Lothian markets batteries for domestic use in conjunction with PV, to larger installations sized to work with heat pumps, micro CHP and waste heat. It is also working on mobile storage taking waste heat from one location to be used at another. The company claims it is around six times cheaper and takes up around a sixth of the space of a comparable electric battery. Demonstration projects promise some impressive bill savings, principally by increasing self-consumption of self-generation. It is early days for the technology and economics will change with the reduction in PV incentives in the UK.

Ice batteries can be fitted in place of the condenser in an air conditioning unit. We found one trial project in the south east of England[25] where 7kW units were funded by the DNO and fitted to three buildings with a cooling load (a gym, office and school IT suite). The main benefits accrued to the DNO by way of demand shifting delaying the need for peak-demand driven network reinforcement. The benefits to end-users were moderate (compared to a typical Californian

[21] BRE, 2016. "Batteries and solar power. Guidance for domestic and small commercial users."

[22] DNV KEMA, 2013. "Residential solar energy storage analysis." Prepared for NYSERDA.

[23] DNV GL, 2016. Energy Storage Use Cases. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/554467/Energy_Storage_Use_Cases.pdf

[24] Darby, SJ, 2016. Balancing the system comfortably? Electric storage heating and residential demand response. BEHAVE 2016 4th European Conference on Behaviour and Energy Efficiency Coimbra, 8-9 September 2016. http://www.realvalueproject.com/images/uploads/documents/Darby-coimbra_916.pdf

[25] Scottish and Southern, undated. New Thames Valley Vision. Learning outcome report. Cold thermal LV network energy storage. http://www.thamesvalleyvision.co.uk/wp-content/uploads/2017/05/NTVV-Learning-Outcome-Report-LV-Network-Storage-Cold-Thermal-Storage.pdf

application) in large part because UK buildings do not have a high and consistent cooling need, and hence energy savings available are limited.

Scorecards overview

Batteries storing electrical energy as chemical energy are the most well-known storage technology. The scorecards differentiate between domestic and commercial-scale batteries. The former are only in their infancy in the UK and tend to be used to get the most on-site usage of domestic generation. Applicability is therefore limited and linked to renewable energy incentives. We do not yet have a drive for batteries to support power requirements in a black-out. At the commercial level there are economies of scale, and batteries may also be put to multiple uses such as back-up power and even participation in demand response schemes.

Lithium ion batteries are the most common, and are also deployed in vehicle technology. Environmental impact and life cycle costs could be improved by better recycling infrastructure for some of the materials used in manufacture.

Storage of heat is a less well known but potentially interesting prospect in the Scottish context. Storage heaters are of course well understood but the potential for enhanced demand-response using aggregated domestic smart storage less so. Consumer confidence in the old style, inflexible storage heaters is moderate at best, but smart upgrades offer much improved utility and flexibility. This is a technology to watch in the Scottish context.

Heat batteries using Phase Change Materials show early promise as a cheaper and more efficient energy store than conventional batteries. Multiple applications are in the pipeline from storage of excess PV and waste heat to a heat buffer in Electric Vehicles. We found limited information from demonstration projects so the scorecard relied heavily on one manufacturer's claims.

Conclusions and recommendations

Applicable context

Our database provides an ongoing resource for SEEP on smart technologies ready and able to make a contribution to energy savings. The assessment against criteria is only as good as the available data and knowledge base, but is provided in a form that can be readily updated. We can already make a number of broad observations on where technologies might fit under SEEP.

Smart meters

The smart meter rollout is a UK government initiative and is well underway – it seems unlikely that direct support for smart meters will be relevant to SEEP. However, there are some big questions around the utility of smart meters and, related to this, their interoperability within a smart home and wider smart energy system. Scotland is trialling access to smart meter data (with consent) for Home Energy Scotland (HES) advisors, with the potential for much more tailored advice and enhanced energy savings. This is just one of many ways in which smart meters could be put to work on behalf of energy savings, and an area where SEEP could make a real difference by leveraging UK investment in the meters themselves.

Consumer-facing devices, apps and platforms

There are a number of consumer-facing products which are already readily accessible, and which can be adopted and / or installed with minimum disruption. These are intelligent upgrades on existing controls such as lighting and heating, and consumer platforms and apps to manage and even to "game" energy saving and microgeneration. There is plenty of scope for innovation here, especially in integrating functions together into whole-house, whole-street or even whole-community systems.

We did not find any Scottish-based suppliers of particular technologies, but Scotland has a strong ICT sector and so there is a good match with existing skills. Where we don't have a lot of information is on how worthwhile these interventions are in terms of energy savings and carbon cost effectiveness. For the most part our assessment has relied on claims by manufacturers. SEEP could make a difference here by working with consumer organisations to understand how to get the most from these technologies.

An unintended consequence of greater knowledge and control may be privacy concerns – for example an intelligent thermostat that knows when you are home. This was highlighted by one of our stakeholders, but with the exception of smart meters privacy is not something that is discussed in the literature.

Supervisory buildings control

There are a range of products which allow either the consumer or a third party to control energy consumption in buildings. Industrial and commercial sectors are already well acquainted with Building Management Systems (BMS) but they are still to have any discernible impact in the domestic setting.

Consumers are more likely to accept control where they are doing the controlling. Third party control through a smart plug or through supervisory control of groups of BMS' is in its infancy. Trials have been mixed in their ability to recruit participants, although this is likely to be due to a number of issues including system compatibility. Consumer acceptance of third party control has yet to be tested in earnest, and again is something that SEEP could usefully address in conjunction with consumer organisations.

Comparable to the evolution of smart add-ons to existing TVs through to off-the-shelf smart TVs, we might expect control technologies to be increasingly integrated into devices. So rather than a smart plug on a washing machine we will simply purchase a smart washing machine. This will likely be driven by development of standards and care will be needed to avoid devices which are quickly made redundant by future developments.

Response – domestic / commercial

Suspicion of energy companies exercising control over our fridges shows that there is some way to go before demand-side response becomes mainstream[26] in the UK. This is even though users could benefit from lower bills and may not even notice the interruption.

In domestic households, the large domestic loads include washing machines, dishwashers, ovens, electric showers, electric hot water and space heating. While some of these devices could offer a great deal of demand response capability, it should be noted that there are certain devices which are used on an ad hoc basis, and only customers who are energy conscious and willing to change consumption patterns will respond to any form of demand response incentive. For example, it is unlikely that ovens have potential for wide scale demand response because the desired time of use is between 4-7pm – the same period of high demand on the UK energy system.

The benefits of utilising items such as fridge/freezer or hot water/space heating is that it remains on for long periods of time, and with the use of automatic response technology, the user may not be aware when demand response actions are taking place.

Smart functionality is not yet widely available in standard home appliances and energy suppliers do not yet offer time of use tariffs which would incentivise demand response. However these developments are on the horizon, with half hourly settlement (half hourly billing) for domestic customers making its way through the GB energy regulations and manufacturers starting to market fully integrated smart appliances.

Demand response is part and parcel of a more flexible energy system and a necessity for Scotland's low carbon agenda. Whilst reasonably well established at the commercial and industrial level, much more experience is required at the domestic level and fits well within SEEP.

Storage

Conventional electrical batteries are increasing in popularity as a storage medium for excess renewable energy, and, at the commercial / industrial scale as a means of providing demand response. They are becoming more cost competitive but are still more expensive in capital terms that say the cost of a new fossil fuelled power station. The future of batteries lies in multiple uses and in the value associated with making the most of low carbon generation. The regulatory and policy environment still needs improvements properly realise this value.

The use of electric heating devices has shown great potential in a number of innovation projects in the UK. For example, Dimplex Quantum Storage Heaters and Hot Water tanks have been integrated with the Active Network Management system on the Shetland Islands in order to help minimise peaks and troughs in energy consumption on the island[27]. These 'smart' devices replace older electric heating units controlled by radio tele-switching (they were set to charge from 11pm to 7am). The new units are scheduled based on forecasted outside temperature and wind forecast to optimise the utilisation of renewables on the network and minimise reliance on existing diesel generation. Given existing familiarity with electric storage heaters in Scotland, upgrades to smart versions would be a good contender for energy efficiency measures, especially in off-gas areas.

Network-facing technologies

We have included power quality monitoring and intelligence systems in our technology review, even though these systems are not directly relevant to buildings energy efficiency. However, they are an important part of projects looking to introduce more energy flexibility at the buildings level and are often wrapped into demonstration of demand response and buildings-integrated microgeneration. Even if not directly supported by SEEP, knock-on effects on local networks nonetheless need to be identified and managed. Like smart meters, innovative network interventions do have

[26] Hand over control of my fridge to an energy company? No thanks, say Brits. The Guardian, April 2015. https://www.theguardian.com/environment/2015/apr/27/hand-over-control-of-my-fridge-to-an-energy-company-no-thanks-say-brits

[27] http://www.hjaltland.org.uk/nines-project

separate and distinct funding arrangements[28] and so there is the potential to leverage this funding with SEEP funds on the buildings side.

Closing remarks

This study is a bottom-up approach, starting with the technologies already on the ground that can make a difference to energy efficiency, and assess their potential to grow and their impact on people and the environment. Other studies have taken a more top-down approach looking at the conditions favourable to seeding new smart technologies.

Our literature review found that a number of strategic approaches to facilitating smart energy are at the city or local level – for example Bristol's "smart energy city collaboration"[29] or the "Smart London plan"[30]. In the Netherlands a street in Groningen is a microcosm of what whole cities are working towards – generating energy, sharing energy and matching demand with supply (the "power matching city"[31]).

Questions of scale arise when looking at wholesale smart energy roll-out. We are expanding both outwards and inwards in efforts to increase our options and hence flexibility for meeting energy needs. On a grand scale, subsea interconnectors link the UK to different markets and continents, facilitating power matching between different weather systems and natural resources.

At the same time network companies are making plans to move towards a Distribution System Operator (DSO) model where they will play a key role in facilitating local energy balancing markets. This represents a significant shift from the traditionally passive distribution networks acting as a conduit for centralised control actions from a nation-wide system operator.

ScottishPower Energy Networks have published their 'DSO Vision' document, highlighting the key role smart technology can play in enabling a DSO to become a reality. Central to the DSO is the increased visibility of network behaviour – which is provided through solutions such as smart meters, monitoring, controllers (demand, generation, microgrid, ANM) etc.

The role of large-scale energy transmission could fundamentally change if countries, cities, streets and houses smarten up their energy supply and demand. But how it will change is difficult to predict given the huge variety of technologies and possibilities out there.

A recent consultation by Ofgem and BEIS called for evidence on a Smart, Flexible Energy System in order to better understand how they can support the development of greater flexibility within GB[32]. This call for evidence discussed areas such as removing policy and regulatory barriers to owning and operating storage, clarifying the role of aggregators in the future energy system, providing price signals for flexibility, smart appliances, demand side response and electric vehicles. These are all areas that have been discussed in this report and, just as this report has been finalised, Ofgem and BEIS have jointly published their response and "plan."[33] Proposed actions include a formal classification and licensing system for storage which would avoid it being charged final consumption levies (such as the Renewables Obligation), and re-confirmation by Ofgem of storage-related network charging reforms. Government also intends to consult on common standards for smart home appliances to promote "interoperability." These and other changes clearly signal a paving the way for a smarter energy future.

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[28] Principally Network Innovation allowances agreed by the energy regulator. https://www.ofgem.gov.uk/network-regulation-riio-model/network-innovation

[29] Centre for Sustainable Energy, 2015. Bristol Smart Energy City Collaboration. Towards a smart energy city: mapping a path for Bristol. https://www.cse.org.uk/projects/view/1296

[30] Introduction to Smart London and our Progress. https://www.london.gov.uk/what-we-do/business-and-economy/science-and-technology/smart-london/future-smart/introduction-smart

[31] Power matching city – smart energy system https://www.dnvgl.com/energy/video/watch/powermatching-city.html

[32] https://www.gov.uk/government/consultations/call-for-evidence-a-smart-flexible-energy-system

[33] Ofgem, BEIS. July 2017. Upgrading our energy system. Smart systems and flexibility plan. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/631724/upgrading-our-energy-system.pdf

Appendix A – Literature Review

Source	Title
Ofgem / BEIS	Smart grid forum, WS 9 Supply chain and standards
	UK Smart grid forum portal
	UK smart grid directory (with TechUK)
	Call for evidence, smart, flexible energy system
EPSRC, Supergen	Energy networks hub
Energy Technology Institute (ETI)	Smart systems and heat
Energy Systems Catapult	Future Power Systems Architecture
Regen SW	Smart Energy marketplace
Sustainability First	GB electricity demand project
Energy Networks Association	Smarter networks portal
Sustainability First	GB electricity demand project
LCNI trial focused on domestic sector domestic	Customer Led Network Revolution (Northern Powergrid)
LCNI trial focused on domestic sector	Ashton Hayes Smart Village (SPEN)
Danish Smart Energy Networks programme	Smart energy networks
Joint Research Centre	Smart electricity systems and interoperability
NYSERDA	NY REV – Reforming the Energy Vision
Con Edison (NY)	Energy Saving Programs
National Renewable Energy Lab (NREL)	Energy Systems Integration Facility
US Department of Energy	Sunshot ENERGISE
European Council for an Energy Efficiency Economy	Summary Study 2015: panel 5 Energy Use in Buildings
American Council for an Energy Efficiency Economy	Summary Study 2016, 1 – Residential Buildings

Appendix B – Stakeholders

Ashden

The Department for Business, Energy and Industrial Strategy

Centre for Sustainable Energy

Energy Networks Association

Energy Systems Catapult

Appendix C – Technology Readiness Levels

European Commission

Technology Readiness Levels

TRL 0: Idea. Unproven concept, no testing has been performed.

TRL 1: Basic research. Principles postulated and observed but no experimental proof available.

TRL 2: Technology formulation. Concept and application have been formulated.

TRL 3: Applied research. First laboratory tests completed; proof of concept.

TRL 4: Small scale prototype built in a laboratory environment ("ugly" prototype).

TRL 5: Large scale prototype tested in intended environment.

TRL 6: Prototype system tested in intended environment close to expected performance.

TRL 7: Demonstration system operating in operational environment at pre-commercial scale.

TRL 8: First of a kind commercial system. Manufacturing issues solved.

TRL 9: Full commercial application, technology available for consumers.

Appendix D – Economic impact data

Summary Figures for the Smart Technologies Report for Low Carbon Scotland – 2015/16

Energy Management	UK			Scotland			
	Market Value	Companies	Employment	Market Value	Companies	Employment	% UK market
	£'millions		FTE	£'millions		FTE	
Production of Energy Saving Industrial Heating Control Systems	13.58	7	146	0.37	0	6	2.7
Production Of Industrial Energy Saving Heating Equipment	61.39	25	591	2.75	0	37	4.5
Production of Energy Saving Industrial Ventilation Systems	17.43	8	118	0.87	0	8	5.0
Production Of Industrial Energy Saving Ventilation Equipment	29.89	13	230	1.40	0	13	4.7
Production of Energy Saving Domestic Heating Control Systems	11.58	6	97	0.56	0	7	4.8
Production Of Domestic Energy Saving Heating Equipment	300.79	124	2125	14.89	7	111	5.0
Production of Energy Saving Domestic Ventilation Control Systems	4.77	1	41	0.22	0	1	4.5
Production Of Domestic Energy Saving Ventilation Equipment	8.99	3	72	0.38	0	3	4.3
Building Control Systems	242.07	107	2213	10.75	5	94	4.4
Industrial Power Consumption Control & Monitoring Equipment	63.76	28	465	2.61	0	25	4.1
Domestic Buildings Control Equipment	5.26	1	52	0.23	0	3	4.4
Domestic Power Consumption Monitoring Equipment	10.24	6	105	0.49	0	7	4.8
Totals	**769.76**	**329**	**6255**	**35.51**	**12**	**316**	**4.6**

Design of Energy Management Systems	UK			Scotland			
	Market Value	Companies	Employment	Market Value	Companies	Employment	% UK market
	£'millions		FTE	£'millions		FTE	
Design Of Energy Management Systems New Build	26.60	10	186	1.06	0	8	4.0
Design Of Energy Management Systems Retro Fit	26.67	13	123	1.08	0	7	4.0
Totals	**53.27**	**23**	**309**	**2.13**	**0**	**15**	**4.0**

R & D of Energy Efficient Technologies and Management Systems	UK			Scotland			
	Market Value	Companies	Employment	Market Value	Companies	Employment	% UK market
	£'millions		FTE	£'millions		FTE	
New Lighting Technologies	41.06	19	371	1.88	0	20	4.6
Power Management Software	17.19	8	196	0.85	0	11	4.9
Infra Red Detection Systems	8.79	4	57	0.39	0	5	4.5
Development of Energy Management Software	10.94	5	126	0.53	0	7	4.9
Development of Advanced Energy Management Systems	28.12	12	284	1.42	0	17	5.0
Development of High Efficiency Lighting	28.09	12	245	1.25	0	14	4.4
Development of High Efficiency Power Systems	21.88	8	149	0.89	0	5	4.1
Development of High Efficiency Heating & Ventilation Systems	31.09	13	234	1.40	0	14	4.5
Totals	**187.16**	**81**	**1662**	**8.61**	**0**	**92**	**4.6**

Monitoring and Control Systems for Energy Management	UK			Scotland			
	Market Value	Companies	Employment	Market Value	Companies	Employment	% UK market
	£'millions		FTE	£'millions		FTE	
Motorized Valves and Actuators	706.57	223	4265	54.69	15	380	7.7
Sensing Devices	241.77	51	1423	21.19	5	137	8.8
Inter Building Electronic Control Systems	272.98	101	1826	22.07	10	156	8.1
Balanced Inter Building Heating Systems	703.58	269	4401	61.25	22	348	8.7
Energy Management Software	154.80	55	1196	14.27	5	101	9.2
Energy Analysis Software	71.90	25	361	6.15	0	22	8.6
Energy Monitoring Systems	202.84	78	1358	16.29	6	100	8.0
Distributed Energy Management Software	48.26	19	408	4.24	0	30	8.8
Distributed Energy Analysis Software	33.34	12	213	2.56	0	16	7.7
Distributed Energy Monitoring Systems	16.98	7	152	1.36	0	12	8.0
Totals	**2453.02**	**839**	**15603**	**204.08**	**64**	**1304**	**8.3**

Batteries	UK			Scotland			
	Market Value	Companies	Employment	Market Value	Companies	Employment	% UK market
	£'millions		FTE	£'millions		FTE	
Batteries	471.31	177	3353	54.65	29	395	11.6
Totals	**471.31**	**177**	**3353**	**54.65**	**29**	**395**	**11.6**

ICT	UK			Scotland			
	Market Value	Companies	Employment	Market Value	Companies	Employment	% UK market
	£'millions		FTE	£'millions		FTE	
ICT in Manufacturing	329.85	109	2270	56.66	19	479	**17.2**
ICT In The Process Industry	300.72	106	1921	16.83	6	85	**5.6**
ICT In The Energy Sector	1213.57	423	8409	91.30	33	692	**7.5**
ICT in The Water Management Sector	106.34	34	786	10.88	3	170	**10.2**
ICT in Environmental Control	1097.55	391	7778	117.67	44	557	**10.7**
ICT In The Logistics Sector	270.85	100	2577	31.17	12	272	**11.5**
Totals	**3318.87**	**1163**	**23743**	**324.51**	**117**	**2255**	**9.8**

ICT	UK			Scotland			
	Market Value	Companies	Employment	Market Value	Companies	Employment	% UK market
	£'millions		FTE	£'millions		FTE	
Smart Electricity Grids	288.87	100	1835	36.53	11	179	**12.6**
Totals	**288.87**	**100**	**1835**	**36.53**	**11**	**179**	**12.6**

Voltage Reduction		UK			Scotland			
		Market Value	Companies	Employment	Market Value	Companies	Employment	% UK market
		£'millions		FTE	£'millions		FTE	
Manufacturing Sector	Manufacture of Energy Efficient Drives & Couplings	211.72	156	2,243	8.54	8.42	79	**4.0**
Manufacturing Sector	Supply of Energy Efficient Drives & Couplings	94.40	69	971	3.77	3.64	34	**4.0**
Manufacturing Sector	Manufacture of Voltage Regulation Systems (220v) for Reduced Power Consumption	33.77	24	352	1.36	1.34	12	**4.0**
Manufacturing Sector	Supply of Voltage Regulation Systems (220v) for Reduced Power Consumption	16.66	12	175	0.72	0.62	6	**4.3**
Manufacturing Sector	Manufacture & Supply of Other Power Reduction Equipment for Retro Fit	51.26	39	535	2.19	2.16	19	**4.3**
Process Sector	Manufacture of Energy Efficient Drives & Couplings	269.66	169	2,773	23.53	17.03	217	**8.7**
Process Sector	Supply of Energy Efficient Drives & Couplings	117.92	76	1,201	11.22	7.34	96	**9.5**
Process Sector	Manufacture of Voltage Regulation Systems (220v) for Reduced Power Consumption	43.28	27	450	3.96	2.54	35	**9.1**
Process Sector	Supply of Voltage Regulation Systems (220v) for Reduced Power Consumption	21.27	13	216	1.94	1.29	16	**9.1**
Process Sector	Manufacture & Supply of Other Power Reduction Equipment for Retro Fit	66.90	41	680	6.11	4.15	51	**9.1**
Automotive Sector	Manufacture of Energy Efficient Drives & Couplings	157.04	145	1,598	12.60	8.01	157	**8.0**
Automotive Sector	Supply of Energy Efficient Drives & Couplings	69.05	63	690	5.93	3.72	73	**8.6**
Automotive Sector	Manufacture of Voltage Regulation Systems (220v) for Reduced Power Consumption	25.17	23	257	2.10	1.42	26	**8.3**
Automotive Sector	Supply of Voltage Regulation Systems (220v) for Reduced Power Consumption	12.55	12	123	1.08	0.67	12	**8.6**
Automotive Sector	Manufacture & Supply of Other Power Reduction Equipment for Retro Fit	39.02	35	380	3.20	2.05	38	**8.2**
Engineering Sector	Manufacture of Energy Efficient Drives & Couplings	303.02	217	2,928	28.29	18.17	265	**9.3**
Engineering Sector	Supply of Energy Efficient Drives & Couplings	133.15	94	1,316	12.00	7.75	111	**9.0**
Engineering Sector	Manufacture of Voltage Regulation Systems (220v) for Reduced Power Consumption	49.22	35	469	4.53	2.82	42	**9.2**
Engineering Sector	Supply of Voltage Regulation Systems (220v) for Reduced Power Consumption	24.15	17	233	2.17	1.39	19	**9.0**
Engineering Sector	Manufacture & Supply of Other Power Reduction Equipment for Retro Fit	75.99	53	751	7.13	4.04	67	**9.4**
	Totals	**1815.20**	**1320**	**18341**	**142.37**	**99**	**1378**	**7.8**

Smart Power Consumption	UK			Scotland			
	Market Value	Companies	Employment	Market Value	Companies	Employment	% UK market
	£'millions		FTE	£'millions		FTE	
Smart Electronic Devices for the Reduction of Power Consumption	396.02	352	4094	30.13	22	257	**7.6**
Software for Ultra Low Current Systems	325.30	253	3174	25.28	15	260	**7.8**
Totals	**721.32**	**606**	**7268**	**55.41**	**37**	**517**	**7.7**

Wind Energy System Component Manufacture	UK			Scotland			
	Market Value	Companies	Employment	Market Value	Companies	Employment	% UK market
	£'millions		FTE	£'millions		FTE	
Manufacture of Small Wind Energy System Control Components	374.01	110	1402	31.11	11	101	8.3
Manufacture of Small Wind Energy System Power Distribution Components	1394.14	462	6666	165.67	32	983	11.9
Totals	**1768.14**	**573**	**8068**	**196.78**	**43**	**1083**	**11.1**

Energy Storage	UK			Scotland			
	Market Value	Companies	Employment	Market Value	Companies	Employment	% UK market
	£'millions		FTE	£'millions		FTE	
Flywheel Energy Storage	15.84	6	111	0.90	0	7	**5.7**
Hydrogen Produced by Electrolysis	377.50	140	2525	34.53	12	290	**9.1**
Hydraulic Accumulator	121.57	56	984	11.93	5	84	**9.8**
Superconducting Magnetic Energy Storages	61.21	25	292	5.48	4	22	**9.0**
Compressed Air in Cylinders and in Caverns	57.10	25	675	5.31	2	67	**9.3**
Energy Storage Research	29.14	13	398	2.80	1	40	**9.6**
Fuel Cells	247.38	102	2270	24.24	10	225	**9.8**
Thermal Mass	73.32	29	464	6.81	3	45	**9.3**
Totals	**983.06**	**395**	**7720**	**92.00**	**37**	**779**	**9.4**