SMART ENERGY – TECHNOLOGY LANDSCAPING, SCOTLAND'S ENERGY EFFICIENCY PROGRAMME

Helen Snodin, CAG Consultants;

July 2017

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.

Table of Contents

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.

---

[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

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 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.

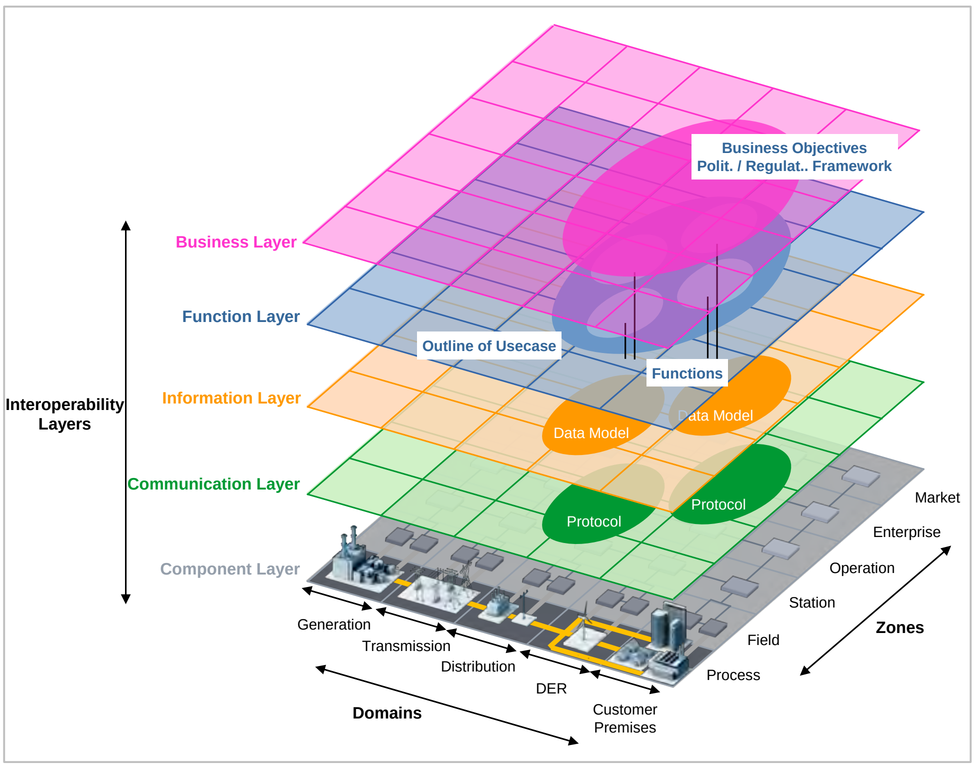


Figure 1 Smart Grid Architecture Model

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

[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

place some technologies definitively in just one category. Probably for this reason the SGAM shows categorisation visually, using shading to span several categories.

Table 1 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*			

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

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

and data category. We agreed with this comment, although categorisation has remained difficult throughout the project.

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. Final scorecards can be found in printable form in Appendix E.

[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.

Likert				
1	2	3	4	5
Bad				Good

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.

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.

---

[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

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.

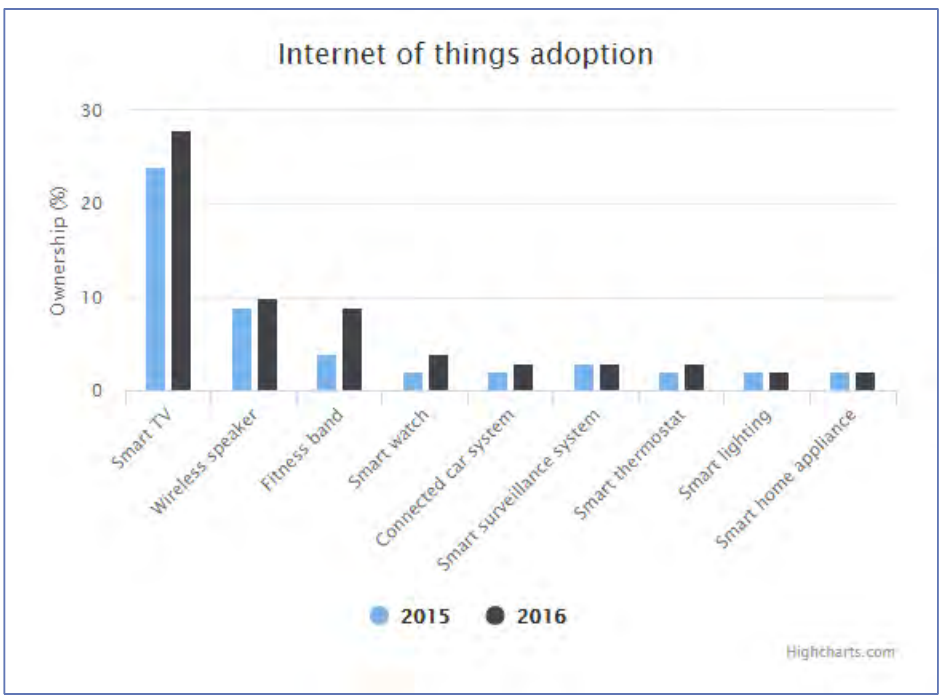


Figure 3 UK uptake of 'smart devices'[13]

[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.

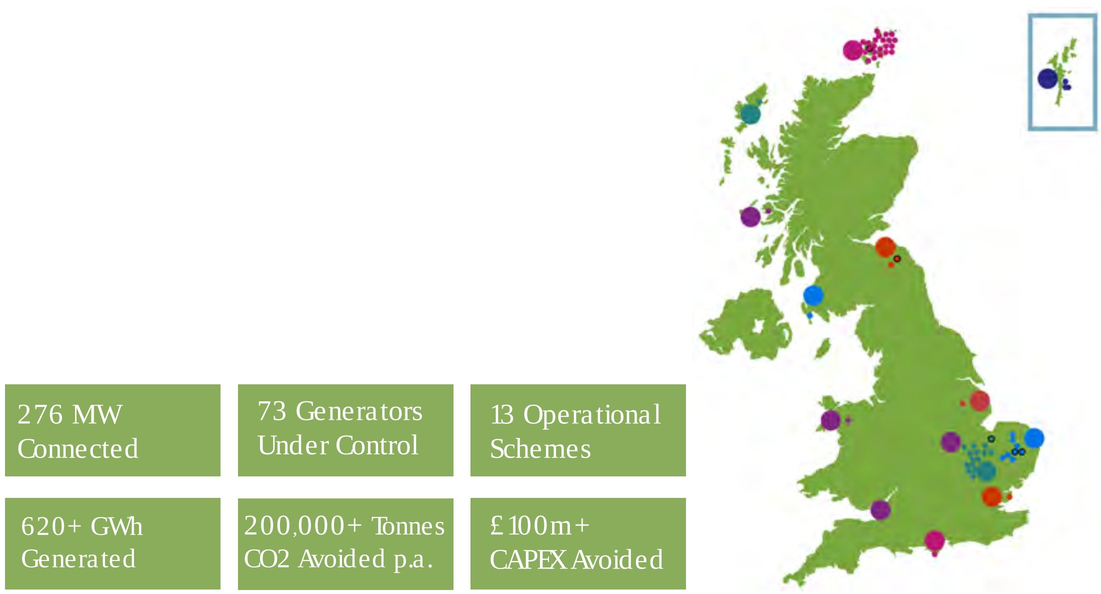


Figure 4 Summary of Active Network Management Schemes in the UK[14]

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.

---

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

[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

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.

---

[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**

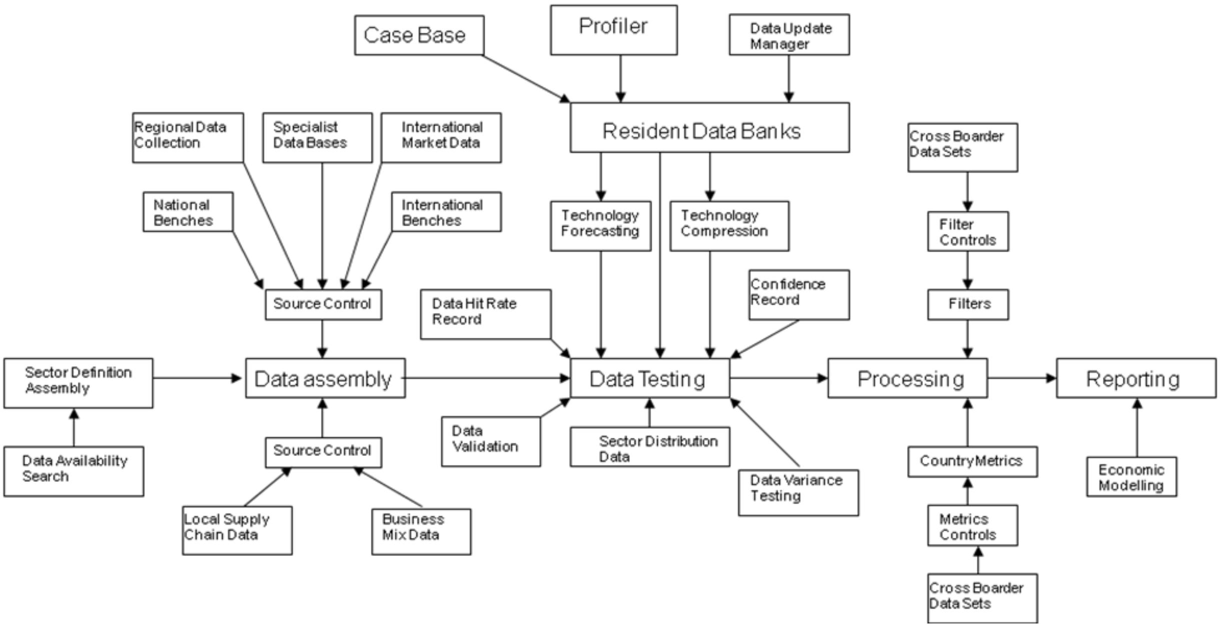
Wind Energy System Component Manufacture	UK			Scotland			
	Market Value	Companies	Employment	Market Value	Companies	Employment	% UK market
	£'millions		FTE	£'millions		FTE	
Manufacture of Small Wind Energy System Control Components	374.01	110	1402	31.11	11	101	8.3
Manufacture of Small Wind Energy System 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**

3. Environmental, Renewable Energies and Low Carbon Sectors Methodology

Full Sector Analysis Model

The full sector analysis research model is shown below. This will not be described in detail here, but the model has been demonstrated in detail to members of the BERR research team.

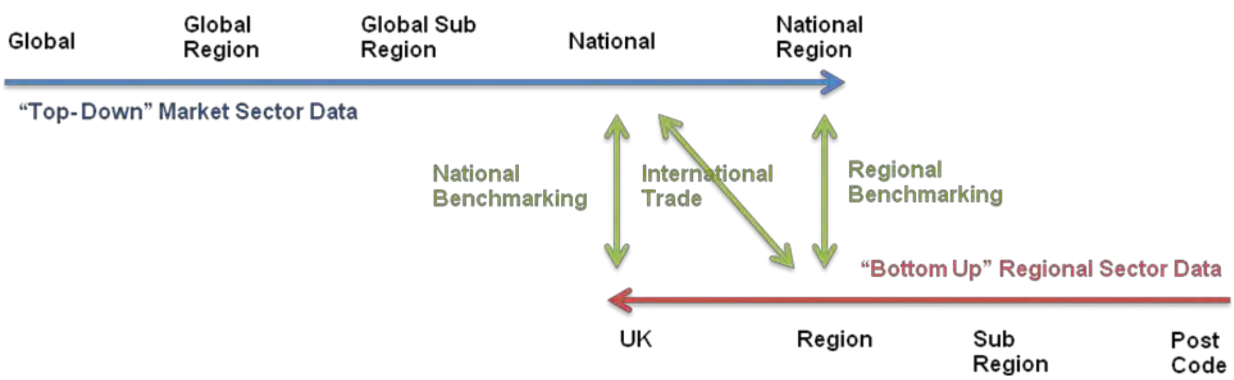


The salient points of the model are that it:

- Is a multi- staged process that uses multiple econometric techniques, sources and methods (like data triangulation) to verify and enrich source data
- Has been validated across multiple sectors and multiple regions of the world
- Relies upon multiple data sources, all of which have been verified for accuracy over time
- Adds unique data from actual, live and accumulated business cases
- Computes confidence levels for final reported numbers, based upon a rigorous assessment of the source data

Reporting and analysis are conducted using standard data templates that enable:

- Comparison of activities within the same sector
- Comparison of activities over time
- Comparison of activities across regions/ countries
- Comparison of activities across sectors.



Some of the more important features of the model/ methodology are explained below.

Sector Definition and Segmentation

Our approach to defining sectors is to reference a wide variety of international, national, institutional and academic sources. Our definitions are consistent with (but not limited by) SIC and NAICS codes and extend down to the equivalent of a 6 digit classification. This hierarchy of sector- specific markets activities is built bottom-up from the product market level and then aggregated into higher level activities that were agreed in consultation with BERR.

The sector has been defined using 3 Sectors;

- Environmental – covering the sub sectors perceived generally as being the more mature ones and which formed the core of previous definitions
- Renewable Energies – previously a part of the above sector with micro generation being included but often the larger scale power and heat generating systems being included in the Energy sector
- Low Carbon – more of a construct to include alternative fuels, building technologies, nuclear power and carbon finance. Areas which until recently were considered on the fringe of the environmental sector. These additions are how certain other leading countries are now viewing the environmental sector

These 3 sectors are further split into 22 Sub Sectors (Level 2 markets). These are:

Environmental
- Air Pollution Control
- Environmental Consultancy
- Environmental Monitoring
- Marine Pollution Control
- Noise and Vibration
- Contaminated Land Remediation
- Waste Management
- Water Supply and Wastewater Treatment
- Recovery and Recycling

Renewable Energies
- Hydro
- Wave and Tidal
- Biomass
- Wind
- Geothermal
- Solar PV

Low Carbon
- Alternative Fuels
- Alternative Fuels for Vehicles
- Additional Energy Sources
- Carbon Capture and Storage
- Carbon Finance
- Energy Management
- Building Technologies

In turn, these 22 Level 2 markets have been divided into 100 Sub Sub Sectors (Level 3 markets). Most of the analysis in this report is conduct using Level 2 or Level 3 data.

Level 3 markets have been sub divided further into level 4 markets and then into level 5, creating a total of 2,489 discrete economic activities (Level 5 markets) for further and future analysis. A full listing of Level 5 markets for the Low Carbon Sector is included at Appendix X.

Included Activities

The activities included under each of these headings vary according to the structure of the industry/ sub sector. We have adopted an inclusive (rather than a specialist) approach that captures as much of the supply chain activity as possible. The activities that we have included are: - design/ development, manufacture, supply, distribution, installation, maintenance, operations, R&D, Consultancy, support services and retail.

The difference in reporting Specialist v. Supply Chain market value relates to the primary activities of the trading companies included in the analysis. For our Supply Chain analysis our numbers include:

- Companies that only provide end-use low carbon, renewable energies or environmental products and services
- Companies who are 100% providers of components or inputs into sub assemblies or final low carbon products
- Companies who (amongst other activities) provide components or inputs into sub assemblies or final assemblies of low carbon products and services.

Our threshold for including a company is if at least 20% of sales activity can be directly attributed to the Low Carbon, Renewable Energies or Environmental Sectors (as defined within this report). In the case of larger companies this can often be extricated from financial reports, cross referenced to industry sources. For much smaller companies we may have to extrapolate the percentage of sales based on product range and turnover, tempered by more detailed case materials that we hold about the market performance of similar businesses.

While this is not an exact science, it is as accurate a method as we have found for calculating the size and distribution of supply chain activity across a sector. However, because our methodology is not based solely on historical SIC listings etc. it does mean that our estimates of Sales Value, Company numbers and Employment will be higher than more traditional estimates.

Levels of Analysis

Our data model for the Low Carbon Sectors is built bottom-up. This means that economic activities are identified at the lowest possible level of analysis (at the equivalent of a six or seven digit SIC code) and then aggregated together so that they can be reported upon more conveniently. In this report we record Low Carbon Sector activities at five hierarchical levels but analyse the data at Levels 1 (Sector), 2 (Sub Sector) and 3 (Sub Sub Sector) only. Analysis is done to level 5 levels in specific instances to highlight interesting points in the supply chain.

Where necessary we can “drill down” further through the data to analyse the component parts of much larger constructs. An example of how this works is shown below,.

Level 1	Level 2	Level 3	Level 4	Level 5
Environmental	Waste Management			
	Recovery and Recycling			
	Water Supply and Wastewater Treatment	Consulting, Education and Training		
		Technology Research and Development		
		Engineering		
		Water Treatment and Distribution	Biological Odour and Corrosion Control	
			Oil-Water Separation	
			Water Disinfection	
			Water and Wastewater Engineering	
			Rotating Biological Contactors	Manufacture of Anaerobic and Aerobic Wastewater Treatment Systems
			Anaerobic and Aerobic Wastewater Treatment Systems & Operations	Supply of Anaerobic and Aerobic Wastewater Treatment Systems
				Installation of Anaerobic and Aerobic Wastewater Treatment Systems
				Maintenance of Anaerobic and Aerobic Wastewater Treatment Systems
				Operation of Anaerobic and Aerobic Wastewater Treatment Systems

Each Level of detail has it own analytical benefits and in this report we use Level 1 to select the Top 50 global countries and for sub national analysis, Level 2 for identifying market growth trends and Level 3 for analysing regional Low Carbon Sector performance in the UKt.

Key Measures

In our analysis we concentrate on four key measures. These are:

- Sales £m
- Companies
- Employment
- Growth

Sales is our estimate (in £m) of economic activity by identified companies in a defined region or country. Our estimate of Sales is based upon where economic activity takes place i.e. the location of the business rather than the location of the income earner. In the calculation of Sales value we consider:

- Turnover by sub sector within postcode sets
- Capital asset adjustment by sub sector within postcode sets
- ONS GDP calculations
- Supply chain procurement value sub sector by sub sector by postcode sets
- Sub sector specific sales reporting where available

Further adjustment is made on a sub sector basis for both head office activities and virtual working organisations so that, as far as is practical, we report upon where Sales is conducted rather than where it is reported.

Companies is a measure of the total number of companies in the region that match (or fit within) the activity headings for the Low Carbon Sector. Because of the limitations in using traditional SIC codes to identify high technology and "new economy" businesses we have used our own unique analytical process to allocate companies to the Low Carbon activity headings. The total number of companies in this report has been arrived at by a bottom-up analysis of company stock within the country/ region using such sources as: Companies House, European credit agencies, British Telecom, Institutional listings and UK credit agencies.

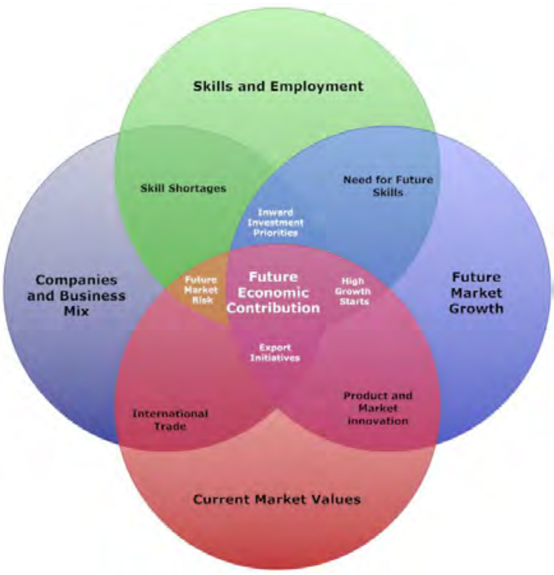
Having identified the total company stock in the region, product and service outputs have been identified and verified by accessing further databases that include: Institutional data sets, Yellow Pages, kMatrix proprietary databases, Euromonitor, Dun and Bradstreet and Thompson.

Employment is a measure of the estimated employment numbers across all aspects of the supply chain. National, regional and other economic data sources have been used to estimate current employment levels for each Low Carbon Sector activity. Where employment information is scarce, or where we are estimating employment for a proportion of a company's sales, we rely on our comprehensive case study materials to provide sensible industry- specific ratios and benchmarks.

Following national statistics, our employment figures are disaggregated into four streams- management, supervisory, Administrative and Other. Where we are commissioned for Skills analysis, these four streams are disaggregated into much more detailed occupational groupings.

Our employment figures for Low Carbon define the labour intensity of some market activiites over others and help to identify the economic activities that are generating the highest levels of employment (but not necessarily value or growth).

Market Growth is our forward looking indicator and has been measured for the short to medium term (five years) where we have a high level of confidence in the growth trend. This indicator enables us to identify the ongoing strength and potential of each economic activity relative to other sector activities within the region/ sub region and relative to growth rates across the UK and in other key country markets (See Calculating Market Values for more information on market forecasting).



Using these four key measures we are able to analyse sectoral and regional economic activity in terms of:

- Importance
- Impact
- Density and clustering, and
- Potential.

By combining these measures (and by including different levels of detailed analysis as well as geographical context) we are able to assess current and future activity in different economic policy contexts like future growth and economic contribution, export opportunity, inward investment needs and industry portfolio analysis .

Additional Measures

In addition to the above four measures, a wide range of industrial benchmarks are also included as part of our data templates. These typically include measures of:

- Innovation
- R&D Spend
- Return on Sales
- Critical Mass

These measures do not form part of our standard baseline analysis, but can be used for further research beyond the initial baseline into sectoral levels of demand for new product solutions (product adoption); industrial spend on R&D activity (as opposed to counting patents); industrial levels of new product introduction; product portfolios and success rates across different markets; profitability and the ability of companies within market niches to potentially re-invest in new technology/ markets.

Data Sources

We attempt to limit the risk and error behind the numbers that we publish (whether historical or forecast) by multi- sourcing and monitoring a wide range of reliable sources and then making the remaining range of uncertainty explicit.

For each market we track multiple sources of historical and forecasting data. From these sources we look to select at least seven that are current and that we have routinely tracked and verified (and, therefore, have built confidence in) over a number of years. Sources can be from company, industry, academic, public or market research sources and national statistics. The sources we reject may be out of date, unreliable, drastically under or overstated or too similar to other data sources.

When we have identified a minimum of seven acceptable sources we then take the “average” of the seven figures as our selected figure. We then look at the range of individual responses in relation to the selected figure and if the range of results is within +/- 20% of our selected figure we are generally satisfied. In some cases (where more than seven reliable sources are available) we may look to narrow the range of results by excluding the more extreme results. Where the range of results is greater than +/- 20% we then look for further sources that may be used, until we arrive within the accepted range.

The range within which our source values fall generally varies between +/- 10-20%. This range gives us a “confidence level” for each figure published in this report. Typically, we aim to provide a confidence level of 80% i.e. if we quote a figure of 10, this means that we are 80% certain that the answer is 10 but, given the range of uncertainty it might be between eight and 12. An example (chosen at random) is shown below to illustrate the range, age, tracking and verification of sources behind a single cell of data.

Source	Value £m	Year of data relevance	Hit Rate History	Number of times accessed	Accept	Reject	Track	Output	Comments
Petrol Retailers Association	869.27	2006	85%	35	1		Yes	869.27	
DTI	850	2004	60%	62		1	Yes		Old Data
Carbon_Info	1107.32	2005	25%	12		1	Yes		
Planetark	500	2006	48%	6		1	Yes		
Financial Times	604.37	2006	60%	24		1	Yes		
UK Peproliun Industry Association	799.24	2006	80%	47	1		Yes	799.24	
BP	904.51	2006	82%	29	1		Yes	904.51	
ACEA European Automibile Manufacturers Association	850.5	2006	85%	22	1		Yes	850.5	
British Association for Bio Fuels and Oils	915.18	2006	92%	19	1		Yes	915.18	
Bloomberg	850	2006	82%	31	1		Yes	850	
Flemming Bermann	904.51	2004	72%	1		1	Yes		Same ultimate source as BP
Market Watch London	850.27	2006	65%	26		1	Yes		
British Biogen	890.5	2006	85%	22	1		Yes	890.5	
Lloyds Environmental UK	962.71	2005	56%	12		1	Yes		
EXXON Research	900.26	2006	83%	17	1		Yes	900.26	
Range is within tolerance having removed lines 7 and 8	Data range is 962.71 to 850 and is 13% variance						Final Output	872.43	
There are no data warnings for this set									

A full list of sources will be provided at the end of the study, but within each data templates we have calculated and published the number of sources used to compile each of the 2,489 lines of market data. On average 85 sources (differing depending upon the market activity) are used for each line of data in the Low Carbon study. Typically a full list contains over 500 verified sources.

Appendix E – Individual Scorecards

Ref#	Class	Intervention	Technology	Min Performance Level/ Threshold	Notes	Application: Domestic	Industrial / commercial	Generation	Distribution network		Scorecard	Total score	Subtotals: Technical	Environmental	Policy / Regulation	Monetary	Capacity/ Supply Chain	Consumer	Opportunities / risks
	Scoring																		
M1	**Monitoring, Sensors and in-built controls**		Smart meters - SMETS2			✓	✓				Done	102	26	7	12	10	20	27	
M2			Intelligent thermostat			✓	✓				Done	104	28	7	12	13	16	28	
M3			Intelligent lighting			✓	✓				Done	100	31	6	12	11	13	27	
M4			Power quality monitoring and intelligence systems						✓		Done	81	33	6	11	15	16	0	
P1	**Platforms / Analytics**		Customer energy use platforms			✓	✓				Done	88	25	7	12	7	16	21	
P2			Gaming of energy saving			✓					Done	102	28	9	11	16	17	21	
P3			Peer-to-Peer Energy Matching Platform			✓	✓		✓		Done	98	31	3	10	7	17	30	
Cn1	**Communication**		Whole home communication			✓	✓				Done	44	9	0	9	5	8	13	
Cn2			Internet of things mesh			✓	✓	✓	✓		Done	18	18	0	0	0	0	0	
Cn3			WiMax				✓	✓	✓		Done	7	7	0	0	0	0	0	
Cl1	**Control**		Smart Plugs			✓	✓				Done	111	30	6	14	15	14	32	
Cl2			Home Voltage Regulation			✓	✓				Done	105	28	8	14	15	11	29	
Cl3			Home energy management systems			✓					Done	115	27	8	15	18	17	30	
Cl4			Building Management System				✓				Done	113	27	8	15	14	19	30	
Cl5			Active Network Management						✓		Done	116	31	9	13	14	22	27	
Cl6			Microgrid Controller				✓		✓		Done	114	27	9	11	17	23	27	
Cl7			Generation Router Device					✓			Done	113	27	9	13	15	20	29	
R1	**Response**		Smart Appliances			✓	✓				Done	115	25	10	13	19	19	29	
R2			Demand Response			✓	✓				Done	110	28	10	11	17	19	25	
R3			Smart Invertor' or 'Virtual Oscillator'			✓	✓				Done	99	26	10	9	16	14	24	
R4			DER providing grid services					✓			Done	111	29	10	10	18	16	28	
S1	**Storage**		Electric batteries, domestic			✓					Done	90	26	5	12	11	14	22	
S2			Electric batteries - commercial / industrial				✓				Done	82	16	6	11	13	16	20	
S3			Heat batteries based on Phase Change Materials (PCMs)			✓	✓				Done	91	27	4	11	9	13	27	
S4			smart conventional heat storage			✓	✓				Done	47	25	4	8	0	0	10	
S5			Ice batteries			✓	✓				Done	82	27	6	9	12	8	20	

Smart meters - SMETS2

Provide a high level of data for network operators to use for better managing the network, as well as providing consumers with 'live' data on usage and opportunities for greater control

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	9	Dedicated smart meter network now live so SMETS2 meters (2nd generation smart meters with full functionality) can be installed
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	3	Depends on user interaction; moderate efficiency gains are possible but require user action.
Reliability	1 (low) to 5 (high) score	4	Subject to extensive specification and testing but limited experience to date of interactions with Smart Data Communications Company (DCC)
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	3	Requires replacement of dumb meters. Smart DCC now in place. Installation in some properties can be problematic, e.g. solid-walled tenements.
complexity of systems/ their integration	1 (complex) to 5 (simple) score	3	Simple interfaces but system behind them is highly complex. System is now live and SMETS2 meters can be installed, although very few have been
risk/severity of unintended consequences	1 (high) to 5 (low) score	4	SMETS2 meters should overcome many of the concerns associated with foundation meters, e.g. switchability, security but some concerns regarding consequences of those who choose not to switch.
		26	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	3	Moderate projected savings for consumers but network management benefits could be more significant and longer term potential may be higher
whole life environmental impact	1 (high) to 5 (low) score	4	Not addressed in DECC/BEIS Impact Assessment. Unsure of direct environmental impact of meters, no information on this. Must be some impacts from disposal of old meters, replacing with smart meters.
		7	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	5	Currently being rolled out in Scotland
compatibility with current regulation	1 (low) to 5 (high) score	5	Directly compatible
compatibility with current assessment methodologies	1 (low) to 5 (high) score	2	Smart meters don't feature in RdSAP
		12	

Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	3	Total cost of the whole smart meter rollout including the new dedicated network and meter installations estimated at £11bn GB-wide but smart meters due to be freely available to all by 2020. Cost score - depends if we are talking about direct cost to consumer or overall costs of smart meter network? Consumers don't pay anything up front and in theory suppliers save by not having to pay for meter readers. However, the meters effectively cost around £200 each (£11B cost, 53M to be fitted; NB many households getting 2 meters, gas & electricity)
life cycle costs	1 (high) to 5 (low) score	4	Not addressed in DECC/BEIS Impact Assessments. Assume relatively low but that depends on level of future proofing and when they might need to be replaced.
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	1	Total cost of rollout c£11bn, carbon saving (traded and non-) potential 30mtC02e. Implies carbon cost effectiveness of £367/tCO2e. Carbon cost effectiveness at individual building level has not been calculated. (According to old Guardian, article, building new wind power capacity, which costs £50-£79 for each tonne of carbon saved; https://www.theguardian.com/environment/2008/feb/20/energyefficiency.smartmeters - but same article says smart meters are more cost effective than wind on carbon saving). Combined meter saving forecast to be £11 in 2020; combined meter costs would be over £400, giving savings of 2.5% of meter costs.
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	2	Economies of scale already being achieved - GB-wide rollout. BUT the lack of area-based approach (supplier-led rather than, e.g. DNO-led) misses economy of scale opportunities.
		10	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	4	Good applicability, although Scotland does have a higher proportion of problematic properties than the rest of GB
existing Scottish capacity/skills	1 (low) to 5 (high) score	5	Already being rolled out by the energy suppliers
Scottish content	1 (low) to 5 (high) score	2	Suspect that no smart meters are being manufactured in Scotland but supply chain for the rollout is extensive, which will benefit many Scottish companies
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	5	Potential for integration with demand-side (network management) and supply-side (greater consumer control)
Scottish economic impact potential	1 (low) to 5 (high) score	4	Implementation of rollout likely to generate significant impact, particularly for installers
		20	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	4	Smart meters incorporate user-friendly in-home controls but research demonstrates that interaction with these is often short-lived
disruption	1 (high) to 5 (low) score	5	Little disruption in most cases. Simple meter replacements
customer acceptance	1 (low) to 5 (high) score	3	Benefit from significant promotional campaign but weighed against concerns around privacy of data
savings on bills	1 (low) to 5 (high) score	2	Projected to reduce the average household energy bill by £11 in 2020 and by £47 in 2030. (= Data from most recent Cost Benefit statement). The average dual-fuel non-domestic property is expected to realise bill savings of approximately £128 in 2020 and £147 in 2030
maintenance requirements	1 (high) to 5 (low) score	5	None
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	3	Allow more informed control of energy use but some concerns relating to vulnerable households. Long-term potential is high through greater interactivity
existing consumer protection? (adequacy?)	1 (low) to 5 (high) score	5	Being rolled out by the energy companies with extensive consumer protections in place, including code of practice for meter installation that all energy suppliers must comply with
		27	

Opportunities / risks	Scoring	Score	Comments
Critical success factors/watch points	List/Describe		Level of future proofing and extension of applications to for example voltage limitation, time of use tariffs, real time information for distribution automation.
other relevant considerations/risks/opportunities	List/Describe		Some properties present technical challenges for installation. Smart DCC does not cover whole country
adaptability / future proofing	List / Describe		SMETS 2 meters have inbuilt functionality to talk to the DCC. Some concerns nonetheless that they won't be flexible enough for all potential uses.
		102	

References:

BEIS (2016) Smart meter rollout cost benefit analysis

CAG (2016) Smart Move: Taking stock of the smart meter rollout programme in Scotland Consumer Futures Unit Publication Series 2016: 1

Ofgem Factsheet - Smart metering - what it means for Britain's homes

Intelligent thermostat

Self-learning thermostats, adjust temperatures due to understanding of preferred temperatures, occupancy etc.

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	9	Already available, e.g. Nest thermostat gets to know the temperature you like when you're at home. And turns itself down when you're away. It learns how your home warms up or how draughty it is, so it only uses the energy it needs https://nest.com/uk/thermostat/meet-nest-thermostat; and Switchee http://switchee.co designed for social housing
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	3	In theory reasonably efficient with savings of >10% achievable.
Reliability	1 (low) to 5 (high) score	4	60 of 285 reviews on Amazon UK are critical
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	4	Compatible with a wide and expanding range of heating systems. See, for example, https://nest.com/uk/support/article/Which-heating-systems-are-compatible-with-the-Nest-Learning-Thermostat
complexity of systems/ their integration	1 (complex) to 5 (simple) score	4	Nest recommend professional installation
risk/severity of unintended consequences	1 (high) to 5 (low) score	4	Low risk, although Amazon reviews indicate operational problems in some instances with customers reporting control issues and cold homes as a result. Risk of breach of privacy - can indicate when someone is at home.
		28	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	3	One manufacturer (Tadoo) claim that consumers can save 27% on their heating bills. Nest trial across 42 US states showed on average the Nest Thermostat saved 10% to 12% on heating and 15% on cooling. Based on typical energy costs, they estimated average savings of $131 to $145 a year. However, savings will depend on baseline - CLEAResult report below suggests savings vary from 114kwH p.a. when replacing manual controller in gas heating system with no cooling, compared with 58kwH p.a. when replacing programmable controller.
whole life environmental impact	1 (high) to 5 (low) score	4	No data but can infer should be low due to adaptation of an existing function.
		7	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	5	No conflict
compatibility with current regulation	1 (low) to 5 (high) score	5	No conflict
compatibility with current assessment methodologies	1 (low) to 5 (high) score	2	Doesn't feature in RdSAP
		12	

Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	4	£200-300
life cycle costs	1 (high) to 5 (low) score	3	CLEARResult paper below suggests 10 year lifespan
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	4	Relatively high given low capital cost and assuming c.5-15% savings on energy bills
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	2	There are already an array of manufacturers and suppliers
		13	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	4	Good applicability - CLEAResult report suggests highest savings likely to be achieved in homes with electric heating, of which Scotland has a disproportionately high number
existing Scottish capacity/skills	1 (low) to 5 (high) score	4	Installation is not complex and can be carried out by competent plumber or electrician who is familiar with the product. E.g. Nest installer directory suggests 109 installers registered in Glasgow area and 8 in Inverness area.
Scottish content	1 (low) to 5 (high) score	2	Monitoring and control has reasonable share of UK market, according to Innovas data
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	3	Potential integration with other intelligent controls
Scottish economic impact potential	1 (low) to 5 (high) score	3	Principal benefit would be to local installers
		16	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	4	User-friendly interfaces, most linking to smartphone control
disruption	1 (high) to 5 (low) score	4	Requires some additional wiring at the boiler but low level of disruption overall
customer acceptance	1 (low) to 5 (high) score	5	Design is a major focus and key to marketing efforts
savings on bills	1 (low) to 5 (high) score	3	Moderate. Estimate around 5-15% depending on baseline
maintenance requirements	1 (high) to 5 (low) score	5	None
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	4	Intelligent functionality is intended to help ensure that home heating is adapted to lifestyle and usage, thereby increasing comfort
existing consumer protection? (adequacy?)	1 (low) to 5 (high) score	3	Would only be covered by standard consumer protections/product warranties. Some systems have installer networks but this is unlikely to provide much additional protection, e.g. terms & conditions of Nest Installation excludes any liability for property damage during installation
		28	

Opportunities / risks	Scoring	Score	Comments
Critical success factors/watch points	List/Describe		
other relevant considerations/risks/opportunities	List/Describe		Consumer protection associated with installation appears limited
adaptability / future proofing	List / Describe		
		104	

References:

https://www.uswitch.com/gas-electricity/guides/how-much-can-a-smart.thermostat-save/

https://nest.com/thermostat/real-savings/

http://ilsagfiles.org/SAG_files/Meeting_Materials/2015/6-23-15_Meeting/CLEAResult_Smart_Thermostat_WhitePaper_20150505.pdf

Intelligent lighting

Daylight and motion sensors connected into lighting controls, often combined with personal remote control from mobile phone / tablet

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	9	Commercially available, e.g. Phillips Hue
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	3	Efficiency will presumably depend on user interaction and correct initial configuration. Marketing data refers to the potential for saving electricity through automatic dimming schedules.
Reliability	1 (low) to 5 (high) score	4	The Phillips Hue Starter Kit attracts 13 critical reviews of 153 total reviews on Amazon UK. Small number of these refer to reliability issues
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	5	Can be installed anywhere with electric lighting and wi-fi
complexity of systems/ their integration	1 (complex) to 5 (simple) score	5	Straightforward DIY installation
risk/severity of unintended consequences	1 (high) to 5 (low) score	5	No obvious potential unintended consequences
		31	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	2	Not really part of the marketing of these products. As lighting becomes more efficient anyway, this diminishes the potential savings associated with smart controls. Ease of control and variety of settings available may also lead to increased use. However, an interview with Todd Manegold, senior director of Hue product marketing, by 'Slashgear' states that there is potential to reduce electricity use/carbon by automatically adjusting lighting depending on ambient light, avoiding unnecessary over-illumination, or tweaking the settings according to peak and off-peak energy periods. Research Philips has cited earlier even suggested that, by making the lighting temperature warmer, residents delayed turning up their physical thermostat.
whole life environmental impact	1 (high) to 5 (low) score	4	No data but can infer should be low due to adaptation of an existing function.
		6	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	5	No conflict
compatibility with current regulation	1 (low) to 5 (high) score	5	No conflict
compatibility with current assessment methodologies	1 (low) to 5 (high) score	2	Don't feature in RdSAP
		12	

Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	4	Starter pack, including three bulbs retails at c£250
life cycle costs	1 (high) to 5 (low) score	3	Bulbs have limited lifespan (15,000 hours) compared to other LED products
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	1	No data available but likely to be fairly small in most cases.
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	3	Likely to be potential for economies of scale as this appears to be still an emerging market in the domestic sector
		11	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	5	Applicable in all buildings with electricity and wifi
existing Scottish capacity/skills	1 (low) to 5 (high) score	3	As per intelligent thermostat, assume there are Scottish installers
Scottish content	1 (low) to 5 (high) score	2	Monitoring and control has reasonable share of UK market, according to Innovas data
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	2	Potential integration with other intelligent controls
Scottish economic impact potential	1 (low) to 5 (high) score	1	No data but unlikely, particularly given no professional installation required in domestic context
		13	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	5	Controlled via smartphone or other device
disruption	1 (high) to 5 (low) score	5	No disruption for basic system in domestic setting
customer acceptance	1 (low) to 5 (high) score	4	
savings on bills	1 (low) to 5 (high) score	2	As lighting becomes more efficient anyway, this diminishes the potential savings associated with smart controls. Ease of control and variety of settings available may also lead to increased use. However, an interview with Todd Manegold, senior director of Hue product marketing, by 'Slashgear' states that there is potential to reduce electricity use/carbon by automatically adjusting lighting depending on ambient light, avoiding unnecessary over-illumination, or tweaking the settings according to peak and off-peak energy periods. Research Philips has cited earlier even suggested that, by making the lighting temperature warmer, residents delayed turning up their physical thermostat.
maintenance requirements	1 (high) to 5 (low) score	5	None
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	3	May be limited benefits in terms of security and comfort
existing consumer protection? (adequacy?)	1 (low) to 5 (high) score	3	Would only be covered by standard consumer protections and warranties on individual products
		27	

Opportunities / risks	Scoring	Score	Comments
Critical success factors/watch points	List/Describe		
other relevant considerations/risks/opportunities	List/Describe		
adaptability / future proofing	List / Describe		
		100	

https://www.slashgear.com/with-energy-star-nod-philips-hue-unlocks-smart-bulb-rebates-24461314/

Power quality monitoring and intelligence systems

Distributed monitoring systems to measure consumption at the local level and monitor the impact of low carbon technologies, allows higher integration of smart technologies as part of active management of networks

Technical	Scoring	Score	Comments	
Technology readiness	TRL score 1-9	9	This is a well established technology	
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	5	Not really relevant but assume low energy consumption translates to high efficiency	
Reliability	1 (low) to 5 (high) score	4	monitor will capture information where possible, but the interpretation of that data is down to the engineer which can impact reliability. Restarts automatically, weather proof, low repair rates	https://w
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	5		
complexity of systems/ their integration	1 (complex) to 5 (simple) score	5	Industry standard bit of kit, can be easily integrated on to system for monitoring period and then uninstalled	
risk/severity of unintended consequences	1 (high) to 5 (low) score	5	only risks are interpreting the data incorrectly	
		33		

Environmental	Scoring	Score	
(in-use) carbon saving potential	1 (low) to 5 (high) score	2	monitoring does not lead to carbon savings, but better understanding of the network can make better utilisation of the network
whole life environmental impact	1 (high) to 5 (low) score	4	Should be low impact
		6	

Policy / Regulation	Scoring	Score	
compatibility with Scottish policy	1 (low) to 5 (high) score	5	Already in use by DNOs in Scotland
compatibility with current regulation	1 (low) to 5 (high) score	5	Already in use by DNOs in Scotland
compatibility with current assessment methodologies	1 (low) to 5 (high) score	1	Not applicable
		11	

Monetary	Scoring	Score	
capital costs	1 (high) to 5 (low) score	5	Reasonably low for the network operator
life cycle costs	1 (high) to 5 (low) score	5	Minimal
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	2	Not designed for savings per se, but can facilitate them
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	3	Devices are small and portable and can therefore be re-used on different areas of the network
		15	

Capacity/ Supply Chain	Scoring	Score	
applicability	1 (low) to 5 (high) score	4	Fits in with move to more active networks
existing Scottish capacity/skills	1 (low) to 5 (high) score	3	Not aware of any Scottish companies or manufacturers
Scottish content	1 (low) to 5 (high) score	3	Outram research have a close relationship with SP Energy Networks
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	
user friendliness / practicality	1 (low) to 5 (high) score		This is not something used by an energy consumer - it would be installed and used by the network operator
disruption	1 (high) to 5 (low) score		
customer acceptance	1 (low) to 5 (high) score		Customer is unaware
savings on bills	1 (low) to 5 (high) score		Does not lead to direct savings on bills although indirectly could reduce the need for system reinforcement
maintenance requirements	1 (high) to 5 (low) score		
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score		
existing consumer protection? (adequacy?)	1 (low) to 5 (high) score		
		0	

Opportunities / risks	Scoring	Score	
Critical success factors/watch points	List/Describe		
other relevant considerations/risks/opportunities	List/Describe		improved monitoring of the network can lead to improved modelling and analysis, and better understanding of what is happening in real life - when compared with assumptions made in design of the network
adaptability / future proofing	List / Describe		
		81	

Customer energy use platforms

Provide information on energy use and bills, make energy use suggestions

Used in conjunction with Smart Meters

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	8	the most basic platforms are at 9, but the full potential is yet to be reached
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	4	Not particularly relevant but low consumption
Reliability	1 (low) to 5 (high) score	3	Not reported, assume average
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	3	Needs to be compatible with smart meters, may need add-ons to do so
complexity of systems/ their integration	1 (complex) to 5 (simple) score	4	Not complex
risk/severity of unintended consequences	1 (high) to 5 (low) score	3	Too early to understand any unintended consequences. Main risk is that platforms are under-used.
		25	

Environmental	Scoring	Score	
(in-use) carbon saving potential	1 (low) to 5 (high) score	3	Could help to provide users with better understanding of energy use
whole life environmental impact	1 (high) to 5 (low) score	4	indirect savings over lifetime of use
		7	

Policy / Regulation	Scoring	Score	
compatibility with Scottish policy	1 (low) to 5 (high) score	5	
compatibility with current regulation	1 (low) to 5 (high) score	5	
compatibility with current assessment methodologies	1 (low) to 5 (high) score	2	Assessment methodologies do not take into account behavioural effects
		12	

Monetary	Scoring	Score	
capital costs	1 (high) to 5 (low) score	2	
life cycle costs	1 (high) to 5 (low) score	2	
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	2	
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	1	One device per user
		7	

Capacity/ Supply Chain	Scoring	Score	
applicability	1 (low) to 5 (high) score	4	would be applicable to Scottish energy consumers
existing Scottish capacity/skills	1 (low) to 5 (high) score	4	not aware of specific existing Scottish capacity or skills but strong ICT sector so potential for transferability
Scottish content	1 (low) to 5 (high) score	1	
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	3	
Scottish economic impact potential	1 (low) to 5 (high) score	4	Good, Scotland has a lead in ICT
		16	

Consumer	Scoring	Score	
user friendliness / practicality	1 (low) to 5 (high) score	3	Specific to brands, evolving
disruption	1 (high) to 5 (low) score	2	Low
customer acceptance	1 (low) to 5 (high) score	3	like demand response or other smart technologies, those who want to be more proactive will be more accepting that those who do not
savings on bills	1 (low) to 5 (high) score	4	can provide savings if consumers are more aware of energy use when, would integrate better with time of use tariffs
maintenance requirements	1 (high) to 5 (low) score	3	unknown
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	3	unknown
existing consumer protection? (adequacy?)	1 (low) to 5 (high) score	3	unknown
		21	

Opportunities / risks	Scoring	Score	
Critical success factors/watch points	List/Describe		
other relevant considerations/risks/opportunities	List/Describe		
adaptability / future proofing	List / Describe		
		88	

Gaming of energy saving

Offering up household appliances for central network control, in the form of a "game". Win points and prizes for making in-use appliances (energy) available for reduction

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	8	Northern Powergrid currently running a feasibility trial, which has had difficulties recruiting participants
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	4	Given that it's an app, the efficiency should be high.
Reliability	1 (low) to 5 (high) score	3	No data, but given nature of the app, unlikely to be problems with reliability
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	5	Just requires smart plug and smartphone app to participate
complexity of systems/ their integration	1 (complex) to 5 (simple) score	4	Smart plug allows integration with all electronic devices
risk/severity of unintended consequences	1 (high) to 5 (low) score	4	Hard to imagine any unintended consequences; users respond to notifications that encourage them to reduce energy use. Potential for vulnerable customers to be encouraged to reduce energy consumption in a way that may impact on their wellbeing
		28	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	4	Could be considerable; according to those involved in Northern PowerGrid/Open Energi's 'The GenGame', if the same number of people played GenGame as Pokemon GO, it would free up 500MW of capacity, enough to power more than a million homes. The DNO's website states that, "With over 100 homes signing up within the first three days of going live across the electricity distributor's patch and surprising levels of engagement in order to win, with people allowing their games consoles, TVs, and even hot tubs to be turned off whilst in use, the project is on track to be a major success."
whole life environmental impact	1 (high) to 5 (low) score	5	Minimal; the games are usually apps.
		9	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	5	No conflict
compatibility with current regulation	1 (low) to 5 (high) score	5	No conflict
compatibility with current assessment methodologies	1 (low) to 5 (high) score	1	Buildings assessment does not take into account behavioural change
		11	

Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	3	Total project costs for the GenGame feasibility trial is £1.75m. Aim was to get up to 2,000 households
life cycle costs	1 (high) to 5 (low) score	4	No data but likely low
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	4	ACE project as a whole estimated to save 346,000tCO2. Total cost of project is £7m, costing a reasonable £20/tCO2 . (NB Not all of this would be through games; these form a key part of the project but it also involves other interventions)
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	5	If trial is successful there could be very significant economies of scale from a large-scale rollout
		16	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	5	Wide applicability
existing Scottish capacity/skills	1 (low) to 5 (high) score	4	Strong ICT sector
Scottish content	1 (low) to 5 (high) score	3	No known Scottish content to-date but good link in with Scottish gaming sector re IP and design.
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	2	Link to smart plugs which are installed to make appliances available to the grid operator and to allow self-control by customers.
Scottish economic impact potential	1 (low) to 5 (high) score	3	Scotland has a lead in ICT and a thriving gaming sector. Gross value may not be high compared to other sectors with more manufacturing and more uptake.
		17	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	4	Engagement via smartphone app
disruption	1 (high) to 5 (low) score	5	No disruption involved
customer acceptance	1 (low) to 5 (high) score	2	Northern Powergrid trial suggests intensive recruitment efforts needed. Open Energi website suggests 400 households recruited
savings on bills	1 (low) to 5 (high) score	3	Estimated £33/year for participating households according to Northern Powergrid's LCNF submission for ACE, the successor to the GenGame
maintenance requirements	1 (high) to 5 (low) score	4	No data but once an app is established, maintenance should be minimal.
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	3	No obvious benefits in terms of health, wellbeing or comfort
existing consumer protection? (adequacy?)	1 (low) to 5 (high) score		
		21	

Opportunities / risks	Scoring	Score	Comments
Critical success factors/watch points	List/Describe		
other relevant considerations/risks/opportunities	List/Describe		
adaptability / future proofing	List / Describe		
		102	

References:

Norther Powergrid (2015) NIA Project Registration and PEA Document - http://www.smarternetworks.org/NIA_PEA_PDF/NIA_NPG_005_3137.pdf

Northern Powergrid (2016) Network Innovation Allowance Progress Report - http://www.smarternetworks.org/NIA_PEA_PDF/NIA_NPG_005_PR_5245.pdf

http://www.openenergi.com/news-posts/gengame-partnership-demonstrates-power-gamification-drive-domestic-dsr-success/

https://www.thegengame.com/

https://www.theenergycheck.co.uk/single-post/2016/11/25/New-mobile-game-%E2%80%98helping-manage-UK-power-demand%E2%80%99

Low Carbon Network Fund full submission proforma; activating customer engagement, Norther Power Grid https://www.ofgem.gov.uk/ofgem-publications/75317/npg-ace-isp-pdf

Peer-to-Peer Energy Matching Platform

Cloud-based data platform to match business energy demand with local renewable energy resources

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	9	Currently available via Open Utility's Piclo product, in partnership with Good Energy. Available to business consumers only
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	4	
Reliability	1 (low) to 5 (high) score	4	No data, although this is a matching service so shouldn't be subject to any major reliability issues
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	5	Simply requires signing up with a partner electricity retailer
complexity of systems/ their integration	1 (complex) to 5 (simple) score	4	Little data on this but appears to be a straightforward energy matching service
risk/severity of unintended consequences	1 (high) to 5 (low) score	5	No unintended consequences envisaged
		31	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	1	Allows individual business consumers to reduce their carbon footprint but does not reduce emissions from the network overall
whole life environmental impact	1 (high) to 5 (low) score	2	As a trading service this would presumably be low
		3	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	5	No conflict
compatibility with current regulation	1 (low) to 5 (high) score	5	No conflict
compatibility with current assessment methodologies	1 (low) to 5 (high) score		N/A
		10	

Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	5	No direct to consumers other than potentially higher tariff when switching to a partner retailer
life cycle costs	1 (high) to 5 (low) score		N/A
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	1	Allows individual business consumers to reduce their carbon footprint but does not reduce emissions from the network overall
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	1	Having a higher number of generators signed up could enable a wider range of tariffs to be offered but savings likely to be marginal
		7	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	2	applicable only to businesses currently
existing Scottish capacity/skills	1 (low) to 5 (high) score	5	The high levels of renewable generation in Scotland make it particularly relevant to the Scottish context
Scottish content	1 (low) to 5 (high) score	3	Links to strong ICT sector.
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	4	Links formed between generation and demand sectors
Scottish economic impact potential	1 (low) to 5 (high) score	3	Scotland has a lead in ICT. Gross value may not be high compared to other sectors with more manufacturing and more uptake.
		17	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	5	Simply requires signing up with a registered energy retailer and specifying required energy mix
disruption	1 (high) to 5 (low) score	5	No disruption
customer acceptance	1 (low) to 5 (high) score	4	A May 2016 article refers to 37 different participants from across the country buying and selling renewable-generated electricity between themselves. Rosie Frankland, commercial manager at the National Trust, said that the pilot had been a "great experience". "It has provided a transparent, easy to use mechanism for the Trust to offer its renewable energy to consumers wanting to source from a renewable generator.
savings on bills	1 (low) to 5 (high) score	3	The Eden Project said that initial analysis of the project's results had shown that the site could save as much as £20,000 each year through reduced Distribution Use of System (DUoS) charges by prioritising locally-generated electricity. These kind of savings will be highly variable depending on location, but generally energy matching should save on peak demand related charges.
maintenance requirements	1 (high) to 5 (low) score	5	None required
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	3	No impact
existing consumer protection? (adequacy?)	1 (low) to 5 (high) score	5	Energy still provided by retailer so covered by energy market protections
		30	

Opportunities / risks	Scoring	Score	Comments
Critical success factors/watch points	List/Describe		
other relevant considerations/risks/opportunities	List/Describe		
adaptability / future proofing	List / Describe		
		98	

http://www.solarpowerportal.co.uk/news/good_energy_and_open_utility_piclo_trial_brings_renewable_tariffs_to_583

Whole home communication

Home Area Networks for machine to machine communication. The Xsilon solution uses power lines in the home as the conduit.

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9		Unclear. Www.xsilon.com gives the impression that the product has been developed but there is no information on how the product can be acquired
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score		Not relevant
Reliability	1 (low) to 5 (high) score		No data
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	5	Technology fits inside a standard 13-amp plug so can be retrofitted to any appliance
complexity of systems/ their integration	1 (complex) to 5 (simple) score	4	System communicates via existing mains wiring
risk/severity of unintended consequences	1 (high) to 5 (low) score		No data
		9	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score		No data
whole life environmental impact	1 (high) to 5 (low) score		No data
		0	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	3	May undermine the smart meter rollout as it could potentially provide more useful in-home information for householders than a smart meter in-home display
compatibility with current regulation	1 (low) to 5 (high) score	5	No conflict
compatibility with current assessment methodologies	1 (low) to 5 (high) score	1	Not in RdSAP
		9	

Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score		No data
life cycle costs	1 (high) to 5 (low) score		No data
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score		No data
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	5	Likely to be very high if the product is shown to be commercially and technically viable
		5	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	5	In theory, should be applicable in all homes
existing Scottish capacity/skills	1 (low) to 5 (high) score		N/A
Scottish content	1 (low) to 5 (high) score		No data
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	2	Potential for linkages with other in-home communication and control technologies
Scottish economic impact potential	1 (low) to 5 (high) score	1	No obvious wider economic impact potential
		8	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	3	Described as 'plug and play' but no in-use evidence
disruption	1 (high) to 5 (low) score	4	Product description indicates that it would simply require changing plus on devices
customer acceptance	1 (low) to 5 (high) score	1	No evidence as yet
savings on bills	1 (low) to 5 (high) score		No data
maintenance requirements	1 (high) to 5 (low) score		No data
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	2	Product description suggests that the system would allow remote control of appliances but no other apparent comfort/health/wellbeing benefits
existing consumer protection? (adequacy?)	1 (low) to 5 (high) score	3	Would just be covered by standard consumer protections/warranties
		13	

Opportunities / risks	Scoring	Score	Comments
Critical success factors/watch points	List/Describe		
other relevant considerations/risks/opportunities	List/Describe		
adaptability / future proofing	List / Describe		
		44	

Internet of things mesh

allow different people, cities and councils to share data from smart devices and allow them to link to existing information networks as easily as possible

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	8	London, Bristol and Milton Keynes have acted as testbeds for the application of the IoT at City level - HyperCat City. At a more local level, Moixa Gridshare allows households and businesses with smart batteries installed to share their battery energy. The latter is a commercially available product
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score		No data
Reliability	1 (low) to 5 (high) score	3	No published evaluation of HyperCat City but British Standards have issued a PAS specification - PAS2012. Moixa Gridshare products have 5 year warranty.
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	2	No data on this but the publication of the PAS specification should help to enable better integration in future. Moixa Gridshare requires households and businesses to have smart batteries installed first.
complexity of systems/ their integration	1 (complex) to 5 (simple) score	3	At a basic level (individual or groups of businesses/households), relatively simple, particularly once smart meters have been installed but complex at a wider level
risk/severity of unintended consequences	1 (high) to 5 (low) score	2	Obvious risks in terms of cyber crime
		18	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score		
whole life environmental impact	1 (high) to 5 (low) score		
		0	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score		
compatibility with current regulation	1 (low) to 5 (high) score		
compatibility with current assessment methodologies	1 (low) to 5 (high) score		
		0	

Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score		
life cycle costs	1 (high) to 5 (low) score		
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score		
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score		
		0	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score		
existing Scottish capacity/skills	1 (low) to 5 (high) score		
Scottish content	1 (low) to 5 (high) score		
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score		
Scottish economic impact potential	1 (low) to 5 (high) score		
		0	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score		
disruption	1 (high) to 5 (low) score		
customer acceptance	1 (low) to 5 (high) score		
savings on bills	1 (low) to 5 (high) score		
maintenance requirements	1 (high) to 5 (low) score		
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score		
existing consumer protection? (adequacy?)	1 (low) to 5 (high) score		
		0	

Opportunities / risks	Scoring	Score	Comments
Critical success factors/watch points	List/Describe		
other relevant considerations/risks/opportunities	List/Describe		
adaptability / future proofing	List / Describe		
		18	

WiMax

Radio-based telecommunications for relaying data required as part of a smart network

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9		Subject of a broadly successful trial by Western Power Distribution in 2015
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score		No data
Reliability	1 (low) to 5 (high) score	4	In the Western Power Distribution Falcon project, the network is said to have had a 'reasonably reliable level' throughout the project. States that 'the network broadly 100% available throughout'.
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	3	FALCON project demonstrated integration with existing network architecture but requires clear line of sight between installations
complexity of systems/ their integration	1 (complex) to 5 (simple) score		
risk/severity of unintended consequences	1 (high) to 5 (low) score		
		7	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score		
whole life environmental impact	1 (high) to 5 (low) score		
		0	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score		
compatibility with current regulation	1 (low) to 5 (high) score		
compatibility with current assessment methodologies	1 (low) to 5 (high) score		
		0	

Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score		FALCON report suggests that 'WiMAX has proved to be a suitable radio technology for this application yielding a low overall installation and operational cost solution'
life cycle costs	1 (high) to 5 (low) score		
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score		
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score		
		0	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score		
existing Scottish capacity/skills	1 (low) to 5 (high) score		
Scottish content	1 (low) to 5 (high) score		
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score		
Scottish economic impact potential	1 (low) to 5 (high) score		
		0	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score		
disruption	1 (high) to 5 (low) score		
customer acceptance	1 (low) to 5 (high) score		
savings on bills	1 (low) to 5 (high) score		
maintenance requirements	1 (high) to 5 (low) score		
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score		
existing consumer protection? (adequacy?)	1 (low) to 5 (high) score		
		0	

Opportunities / risks	Scoring	Score	Comments
Critical success factors/watch points	List/Describe		
other relevant considerations/risks/opportunities	List/Describe		
adaptability / future proofing	List / Describe		
		7	

Only info available is from WPD Falcon project. This included new telecomms systems but other components too; information not really broken down.

http://www.smarternetworks.org/Files/FALCON_160503095823.pdf

Smart Plugs

Plugs for appliances that facilitate control either or by both of grid operator and customer

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	9	Commercially available in many forms and from multiple vendors
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	4	Smart plug has no efficiency penalty and the device can lead to more energy efficient connected appliance use but depends on user and method of control
Reliability	1 (low) to 5 (high) score	4	High reliability assumed from highly tested and matured products in marketplace
(level of) Compatability with existing systems	1 (low/poor) to 5 (high/good) score	4	Very high compatibility with electrical appliance connections and low power wireless comms to 'control hub points' - wider system compatibility varies
complexity of systems/ their integration	1 (complex) to 5 (simple) score	5	Can buy off the shelf for some devices and use with smart phone apps
risk/severity of unintended consequences	1 (high) to 5 (low) score	4	Fairly low risk associated with the device other than controlling any critical appliances inappropriately
		30	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	3	Unknown: some vendors claim significant energy (and so carbon) savings on decently robust but no independent evidence
whole life environmental impact	1 (high) to 5 (low) score	3	unknown: little published information on through life impacts - most information is on annualised savings
		6	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	5	An important part of the flexibility and demand side agenda
compatibility with current regulation	1 (low) to 5 (high) score	5	All appears to be aligned or straightforward from regulation perspective
compatibility with current assessment methodologies	1 (low) to 5 (high) score	4	Most likely to come under auspices of general Building Energy Management Systems standards for automated and manual supervisory control of energy consumption
		14	

Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	5	Low costs per device and relative to appliance costs and energy costs for end users
life cycle costs	1 (high) to 5 (low) score	4	No ongoing lifecycle costs for devices or services
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	3	Unknown: linked to energy saving and marginal carbon intensity of energy consumption reduction
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	3	Can buy smart hub type kits, but savings are marginal because the cost is reasonably low already
		15	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	5	wide opportunity for applicability at the majority Low Voltage energy consumption locations (residential, public estate and commercial)
existing Scottish capacity/skills	1 (low) to 5 (high) score	2	Some research in universities, not aware of any Scottish companies
Scottish content	1 (low) to 5 (high) score	1	Unknown but assumed low: not clear from evidence if any supply chain components or final assemblies are sourced in Scotland
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	4	Opportunity for cross-sector participation/benefit similar to recent CF/LED lighting programmes
Scottish economic impact potential	1 (low) to 5 (high) score	2	Low opportunity for wholesale/retail activity from any wider roll-out campaign/programme
		14	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	5	plug and play with smartphone devices
disruption	1 (high) to 5 (low) score	5	very low impact on energy amenity at point of use
customer acceptance	1 (low) to 5 (high) score	4	Similarly to other demand response programmes, clear customer benefits and ease of use are essential for wide take up
savings on bills	1 (low) to 5 (high) score	4	Moderate overall savings but potential significant savings for applications where appliances are left in service unnecessarily
maintenance requirements	1 (high) to 5 (low) score	4	Low maintenance expected
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	5	More user control of energy appliances and use in both local and remote applications
existing consumer protection? (adequacy?)	1 (low) to 5 (high) score	5	Basic electrical safety certification in place but few standards cover user features and operation
		32	

Opportunities / risks	Scoring	Score	Comments
Critical success factors/watch points	List/Describe		Wider consumer focused campaigns and application by building energy managers are likely to enhance uptake and successful use
other relevant considerations/risks/opportunities	List/Describe		Further development of the devices and their integration into wider building management systems and beyond could lead to providing services to the system and DNOs e.g. peak reduction, voltage regulation etc.
adaptability / future proofing	List / Describe		Low cost, therefore upgrades or new models easily replaced. Could be superseded by devices with in-built controllability.
		111	

Home Voltage Regulation

Maintains voltage at set point in the home, saving energy and extending life of appliances and light bulbs - average incoming voltage is 245V but appliances generally use 220V, excess lost as heat.

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	9	Products commercially available in marketplace
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	3	Expected gains to consumer and wider system efficiency but more robust evidence required
Reliability	1 (low) to 5 (high) score	3	Unknown on a large scale and while a mature technology it still seems in the early stages of deployment and utilisation
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	5	Plug and play, similar to smart plug devices
complexity of systems/ their integration	1 (complex) to 5 (simple) score	5	Plug and play, similar to smart plug devices
risk/severity of unintended consequences	1 (high) to 5 (low) score	3	More stable and lower consumption voltage is potentially useful but this may lead to some higher losses from higher currents in constant power load types and potential additional losses in the voltage regulator itself
		28	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	4	6 - 18 tonnes of CO2 equivalent savings over 20 years
whole life environmental impact	1 (high) to 5 (low) score	4	Expect this to be minimal as it is a small device
		8	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	5	Energy saving and promotes smart grid technology
compatibility with current regulation	1 (low) to 5 (high) score	5	No reason why it couldn't be installed today
compatibility with current assessment methodologies	1 (low) to 5 (high) score	4	the ND NCM already recognises and makes allowance for voltage regulation (power correction factor) and AMT (automatic monitoring and targeting) – see para 168 at: http://www.gov.scot/Resource/0048/00486061.pdf. Not common in domestic context so not currently part of SAP.
		14	

Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	5	£549 including installation
life cycle costs	1 (high) to 5 (low) score	4	Potential low parasitic loss of additional interposing electrical equipment
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	3	No data, need to convert energy savings to carbon savings
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	3	Higher savings from larger deployments and lower costs expected if relatively simple devices gain mass market scale
		15	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	3	At current costs, most likely to benefit commercial office spaces- larger commercial and industrial facilities may already have such power conditioning equipment for power factor correction or voltage regulation
existing Scottish capacity/skills	1 (low) to 5 (high) score	2	No information on development or deployment in Scotland
Scottish content	1 (low) to 5 (high) score	1	current manufacturer based on Bristol
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	3	Part of building management systems and energy services sector
Scottish economic impact potential	1 (low) to 5 (high) score	2	Expected moderate energy efficiency gains (and some avoided equipment damage) per customer uptake but not expected to be a major economic driver at a wider scale
		11	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	5	No user interaction required
disruption	1 (high) to 5 (low) score	5	Minimal beyond initial installation
customer acceptance	1 (low) to 5 (high) score	3	Early adoption profile at present, but could pick up depending on incentives
savings on bills	1 (low) to 5 (high) score	5	£75-£135 saving on annual energy bill
maintenance requirements	1 (high) to 5 (low) score	4	Minimal
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	3	No impact
existing consumer protection? (adequacy?)	1 (low) to 5 (high) score	4	Similar to other electrical on-site equipment
		29	

Opportunities / risks	Scoring	Score	Comments
Critical success factors/watch points	List/Describe		Campaigns targeted to facilities managers for commercial sector deployments or large cost reduction and residential uptake
other relevant considerations/risks/opportunities	List/Describe		Potential to be included as part of larger building management systems, or connected to a service which would provide voltage support to DNO?
adaptability / future proofing	List / Describe		Can it communicate with wider network through comms? Could interact with grid services in future?
		105	

Home energy management systems

starting at remote controls e.g. thermostats, light and other appliance remote controls, and ranging to whole home controls

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	9	
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	3	Efficiency depends on system configuration or user interaction
Reliability	1 (low) to 5 (high) score	4	Depends on the particular tool, but no significant problems noted
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	3	If using multiple types of control device, there may be interoperability issues combining different brands
complexity of systems/ their integration	1 (complex) to 5 (simple) score	3	If using multiple types of control device, there may be interoperability issues combining different brands
risk/severity of unintended consequences	1 (high) to 5 (low) score	5	Low risk other than possible cyber security vulnerabilities to internet and wireless based technologies
		27	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	4	Energy savings of around 30% quoted in reference sources
whole life environmental impact	1 (high) to 5 (low) score	4	Minimal
		8	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	5	Energy saving and promotes smart grid technology while empowering customers
compatibility with current regulation	1 (low) to 5 (high) score	5	No reason why it could not be installed today
compatibility with current assessment methodologies	1 (low) to 5 (high) score	5	Yes - can improve home energy efficiency
		15	

Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	5	Starts at £150 for individual device, options for subscription solutions (£60 per year)
life cycle costs	1 (high) to 5 (low) score	4	Depends on scale of solution. Ongoing subscription costs are low, minimal maintenance costs
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	4	30% savings on energy use, and relatively low cost so relatively high carbon saving projected
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	5	The more energy there is to manage, the more there is to gain from this solution. It is not expected that costs will reduce significantly with market scale but there will likely be some moderate gains on Internet of things/wireless adapters and competitive pressure on the energy management application software and hardware.
		18	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	4	promotes energy saving and smart grid technologies to wide spectrum of home energy users
existing Scottish capacity/skills	1 (low) to 5 (high) score	2	No record of numbers deployed (are likely already some homes in Scotland) or Scottish supply chain participation in deployments
Scottish content	1 (low) to 5 (high) score	3	Not aware of any Scottish technology developers in this area but generally strong sector identified by Innovas
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	4	Works with smart plugs and combines other types of smart controls to increase efficiency of home system. Good potential for wider energy services, on-site generation and grid/market interaction.
Scottish economic impact potential	1 (low) to 5 (high) score	4	Good potential for altering the energy and financial flows as consumers become more efficient and also procure and provide services related to home energy management
		17	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	5	Varies per vendor system
disruption	1 (high) to 5 (low) score	4	Little disruption other than behaviour and user up-skilling required in some cases
customer acceptance	1 (low) to 5 (high) score	4	Likely high acceptance based on the growth of apps and smart technology
savings on bills	1 (low) to 5 (high) score	4	No figures report but savings in the region of 30% on total energy use
maintenance requirements	1 (high) to 5 (low) score	5	Likely negligible maintenance required as per consumer electronic devices and applications
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	5	likely to enhance overall wellbeing and comfort by more carefully controlling energy use in homes
existing consumer protection? (adequacy?)	1 (low) to 5 (high) score	3	Some potential for uncertainty with sophisticated combination of data, privacy, multiple devices, international vendors
		30	

Opportunities / risks	Scoring	Score	Comments
Critical success factors/watch points	List/Describe		annual review of energy use before and after installation, reduction in energy bills assessed for specific users and also widely reported and tested to build confidence.
other relevant considerations/risks/opportunities	List/Describe		potential to link to renewable resources e.g. pv panels on house. Cyber threats and suspicions over data privacy are likely to be a factor in uptake.
adaptability / future proofing	List / Describe		modular so it can be expanded and changed in future and with opportunity to update software relatively easily.
		115	

https://www.greentechmedia.com/articles/read/hems-the-nuts-and-bolts-of-the-subscription-model

Building Management System

Commercial, industrial

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	9	Mature technology widely available from multiple vendors and widely deployed
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	3	Efficiency depends on user interaction, correct initial configuration and interactions across management system components and energy equipment
Reliability	1 (low) to 5 (high) score	4	Depends on the particular tool, but no significant problems noted (other than misconfiguration so efficiencies not forthcoming as expected)
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	3	Most BMS products are mature and come with integration, interface and interoperability options.
complexity of systems/ their integration	1 (complex) to 5 (simple) score	3	As above
risk/severity of unintended consequences	1 (high) to 5 (low) score	5	Low risk but there are many reported cases of underperforming BMS
		27	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	4	Can reduce operating costs by up to 20% so energy reduction and better management can contribute to carbon emission reduction
whole life environmental impact	1 (high) to 5 (low) score	4	Minimal
		8	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	5	Energy saving and promotes smart grid technology
compatibility with current regulation	1 (low) to 5 (high) score	5	No obvious barriers or reasons why it could not be installed today
compatibility with current assessment methodologies	1 (low) to 5 (high) score	5	It can help improve the efficiencies of devices installed on or around the home
		15	

Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	2	£2-5 PER SQ FOOT
life cycle costs	1 (high) to 5 (low) score	4	It will depend on the scale of the solution, ongoing license/maintenance agreements, and whether the management of the scheme is in-house, or by a third party
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	3	Due to high costs, effectiveness will be greater for larger properties e.g. office buildings
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	5	The more energy there is to manage, the more there is to gain from this solution. Can integrate with Demand Response schemes
		14	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	3	would benefit commercial office spaces, large factory premises with energy intensive operational processes
existing Scottish capacity/skills	1 (low) to 5 (high) score	4	Strong sector identified by Innovas. Example - 'MCE Scotland - engineering firm specialising in HVAC Control and Building Energy Management Systems with offices located throughout Scotland.
Scottish content	1 (low) to 5 (high) score	5	BMS installer companies with offices located in Scotland
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	4	Can be integrated with generation technologies to create self-sufficient sites e.g. minimise supply from grid.
Scottish economic impact potential	1 (low) to 5 (high) score	3	Not knowing the baseline makes the additional economic impact from additional deployment difficult to gauge
		19	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	5	Mature products in marketplace with good usability features
disruption	1 (high) to 5 (low) score	3	Adjustment period required to get balance right on site/factory processes and tune system to maximise gains
customer acceptance	1 (low) to 5 (high) score	4	Already a mature, customer accepted solution deployed at new build and retrofit stages
savings on bills	1 (low) to 5 (high) score	4	Savings in the region of 20% on total energy use reported but more robust evidence required in this significant, mature sector of energy efficiency
maintenance requirements	1 (high) to 5 (low) score	4	Requires regular audit and maintenance to ensure no negative impacts on business operations and that benefits are secured and plant changes are reflected in system configuration
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	5	Reflected in BMS technology/products already
existing consumer protection? (adequacy?)	1 (low) to 5 (high) score	5	Reflected in commercial contractual arrangements for BMS implementation and services
		30	

Opportunities / risks	Scoring	Score	Comments
Critical success factors/watch points	List/Describe		annual review of energy use before and after installation, BMS configuration checks, reduction in energy bills, improved efficiency in processes
other relevant considerations/risks/opportunities	List/Describe		potential to link to renewable resources e.g. pv panels, CHP, GSHP
adaptability / future proofing	List / Describe		modular so it can be expanded and changed in future
		113	

http://blogs.intel.com/iot/2016/06/20/costs-savings-roi-smart-building-implementation/

http://www.mcescotland.com/

Active Network Management

Through Control and Communications infrastructure, management of DER connected within a network area to manage constraints on the network

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	9	Accepted as a technologically mature solution
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	5	Makes efficient use of DER assets and existing network capacity while lowering costs of grid and market integration
Reliability	1 (low) to 5 (high) score	4	Reliability is dependant on the communication, control hardware and DER responsiveness so end-to-end system reliability is able to be enhanced through system tuning
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	5	Is compatible with existing DNO networks and control systems (communicating through a number of comms channels/protocols) and interfacing to a number of customer energy assets
complexity of systems/ their integration	1 (complex) to 5 (simple) score	3	Degree of complexity involved due to security of information transfer and mission critical nature of network and energy asset control
risk/severity of unintended consequences	1 (high) to 5 (low) score	5	Low risk to system
		31	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	5	Increases network losses through higher utilisation but increases the connection of renewables to the network and utilisation of the network assets
whole life environmental impact	1 (high) to 5 (low) score	4	Increases network losses through higher utilisation but increases the connection of renewables to the network and utilisation of the network assets
		9	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	5	Facilitates renewable connections and smart grids
compatibility with current regulation	1 (low) to 5 (high) score	5	Business as usual for DNOs and aligns with major flexibility, 'unlocking capacity' and QMEC regulatory initiatives
compatibility with current assessment methodologies	1 (low) to 5 (high) score	3	Not relevant
		13	

Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	2	£5-10k for a single energy asset solution, growing to £500,000 for an entire scheme controlling multiple generators/DER against multiple constraints in a regional power network area
life cycle costs	1 (high) to 5 (low) score	3	ongoing license costs
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	4	carbon emissions benefit is directly linked to the operation to the renewable energy assets that ANM controls
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	5	Wide area ANM can provide a reduction in cost per MW (but must be led by DNOs)
		14	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	4	applicable to all DER assets integrating to grid system and energy/system services markets
existing Scottish capacity/skills	1 (low) to 5 (high) score	5	ANM vendor Smarter Grid Solutions head office in Glasgow
Scottish content	1 (low) to 5 (high) score	5	Invention from Scotland university sector and commercial ANM provider and technology developer based in Scotland
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	4	As a system wide and all energy asset management solution ANM provides opportunities to work across developers, power network companies, energy suppliers, system operator, consultancies and public sector
Scottish economic impact potential	1 (low) to 5 (high) score	4	See above
		22	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	4	Not really used by an energy consumer, but by a DER Developer and power network company but usability features becoming more prominent
disruption	1 (high) to 5 (low) score	4	Commissioning typically takes place during energy asset connection
customer acceptance	1 (low) to 5 (high) score	5	High when it can facilitate higher export potential, or faster and cheaper connection to the grid
savings on bills	1 (low) to 5 (high) score	3	Flexible connections are cheaper than firm connections requiring grid reinforcements, therefore this reduces network upgrade costs (savings are passed on to the consumer)
maintenance requirements	1 (high) to 5 (low) score	4	updates as and when required, minimal disruption
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	3	No impact - additional power system operation and maintenance procedures already updated to account for new solution
existing consumer protection? (adequacy?)	1 (low) to 5 (high) score	4	Overseen by regulation of power network companies operating ANM schemes with customer participation
		27	

Opportunities / risks	Scoring	Score	Comments
Critical success factors/watch points	List/Describe		Capacity of generation able to connect through managed connections, growth in connections in constrained parts of the distribution network, requirements and markets for managing system flexibility
other relevant considerations/risks/opportunities	List/Describe		Transition to DSO, enhancement of SO roles, new markets for flexibility
adaptability / future proofing	List / Describe		Flexible software based solution that can be upgraded as technology changes and system/user requirements change
		116	

Microgrid Controller

Local controller 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. Can apply to industrial estates or within neighbourhoods e.g. domestic scale

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	9	Commercially deployed solutions growing
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	4	Makes more efficient use of local grid and energy assets and, while energy technology neutral, provides opportunity for greater renewable
Reliability	1 (low) to 5 (high) score	4	Reliability is dependant on the Comms installed
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	5	Is compatible with existing DNO networks, and can communicate with a number of communications protocols
complexity of systems/ their integration	1 (complex) to 5 (simple) score	3	Degree of complexity involved due to data, security, control and operation requirements within microgrid and between microgrid and power system
risk/severity of unintended consequences	1 (high) to 5 (low) score	2	Moderate risks to local dependents on microgrid operation of maloperation or energy resource inadequacy
		27	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	5	Can increase local renewable penetration and reduce transport losses of electricity
whole life environmental impact	1 (high) to 5 (low) score	4	Increases local network losses but increases the connection of renewables to the network - might be efficiency loss with any battery storage
		9	

Policy / Regulation	Scoring	Score	Comments
compatability with Scottish policy	1 (low) to 5 (high) score	5	Can facilitate renewable connections, provide rural or islanded communities with the potential to have greater control over renewable resources in the area
compatability with current regulation	1 (low) to 5 (high) score	3	Depending on the scheme, some areas of DNO regulation which does not permit generation to continue exporting when there are outages. It may have to operate on a private network.
compatibility with current assessment methodologies	1 (low) to 5 (high) score	3	Not relevant
		11	

Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	3	Ranges from $25/kW to $200/kW (http://www.sustainablepowersystems.com/wp-content/uploads/2016/10/UMC-Frequently-Asked-Questions-Rev-1.pdf) depending on manufacturer and scale of grid
life cycle costs	1 (high) to 5 (low) score	4	Minimal for the microgrid controller, but there would be life cycle costs associated with a private network
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	5	carbon emissions benefit is directly linked to the operation to the renewable energy assets that ANM controls
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	5	Increasing the number of elements in the scheme, can spread the costs of central controller but individual units will still be required over device
		17	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	5	particularly relevant for some of the island communities with weak interconnections to mainland grid
existing Scottish capacity/skills	1 (low) to 5 (high) score	4	Lots of work at Scottish Universities, but other than ANM vendor, not aware of Scottish specific companies manufacturing microgrid controllers
Scottish content	1 (low) to 5 (high) score	4	Lots of work at Scottish Universities, but other than ANM vendor, not aware of Scottish specific companies manufacturing microgrid controllers
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	5	Working with developers, DNOs, consultancies, public sector
Scottish economic impact potential	1 (low) to 5 (high) score	5	Could have impact on islanded and rural communities, reduce energy bills and increase the use of local renewable generation
		23	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	4	Not really used by an energy consumer, but by a Developer
disruption	1 (high) to 5 (low) score	4	Commissioning can take place during connection, but sometimes outages required for upgrades
customer acceptance	1 (low) to 5 (high) score	5	High when it can facilitate higher export potential, better security of supply
savings on bills	1 (low) to 5 (high) score	4	can reduce import from national grid and ensure local demand is met by local generation.
maintenance requirements	1 (high) to 5 (low) score	4	updates as and when required, minimal disruption
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	3	No impact - additional power system operation and maintenance procedures already updated to account for new solution
existing consumer protection? (adequacy?)	1 (low) to 5 (high) score	3	would be overseen by network regulator, all solutions would be grid compliant with existing industry standards
		27	

Opportunities / risks	Scoring	Score	Comments
Critical success factors/watch points	List/Describe		ability to facilitate connections in remote and rural areas of the network with weak grid infrastructure
other relevant considerations/risks/opportunities	List/Describe		
adaptability / future proofing	List / Describe		Flexible, can be upgraded as technology changes
		114	

Generation Router Device

a 'box' that communicates with energy management platform and instructs generation response e.g. Broderson RTU or Origami Energy Router

Forms part of the DER Management/ANM system (CI5)

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	9	
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	5	Used to control generation and make more efficient use of existing connection assets, using standard comms protocols
Reliability	1 (low) to 5 (high) score	4	Reliability is dependant on the Comms installed
(level of) Compatability with existing systems	1 (low/poor) to 5 (high/good) score	5	Is compatible with existing DNO networks, and can comminicate with a number of comms protocols
complexity of systems/ their integration	1 (complex) to 5 (simple) score	3	Degree of complexity involved due to security of information transfer etc
risk/severity of unintended consequences	1 (high) to 5 (low) score	1	Hacking in to systems can enable generation or demand to be removed from the system
		27	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	5	Improves flexibility of the network and therefore improves provision of renewable energy on the network
whole life environmental impact	1 (high) to 5 (low) score	4	Improves use of renewables, improves balancing of the network
		9	

Policy / Regulation	Scoring	Score	Comments
compatability with Scottish policy	1 (low) to 5 (high) score	5	supports active management of both demand and generation devices, increase use of renewable generation
compatability with current regulation	1 (low) to 5 (high) score	5	Already in use in Scotland
compatibility with current assessment methodologies	1 (low) to 5 (high) score	3	Not relevant
		13	

Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	3	£4000 - £5000 for Broderson RTU32 (used for ANM systems)
life cycle costs	1 (high) to 5 (low) score	4	minimal for the controller
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	5	carbon emissions benefit is direclty linked to the operation to the renewable energy assets that router controls
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	3	Always need one router per device/site
		15	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	5	Particularly relevant for some of the island communities with weak interconnections to mainland grid
existing Scottish capacity/skills	1 (low) to 5 (high) score	4	No records of numbers deployed, but they are used by Smarter Grid Solutions (based in Glasgow)
Scottish content	1 (low) to 5 (high) score	1	Not aware of any Scottish technology developers in this area
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	5	Working with developers, DNOs, consultancies, public sector
scottish economic impact potential	1 (low) to 5 (high) score	5	
		20	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	4	Not really used by an energy consumer, but by a Developer or aggregator
disruption	1 (high) to 5 (low) score	4	Commissioning can take place during connection, but sometimes outages required for upgrades
customer acceptance	1 (low) to 5 (high) score	5	High when it can facilitate higher export potential,better security of supply, improving revenue through participation in services
savings on bills	1 (low) to 5 (high) score	4	Increase revenue for developers - not really a saving on consumer bills. Perhaps marginally through improved efficiency in balancing
maintenance requirements	1 (high) to 5 (low) score	4	updates as and when required, minimal disruption
health/wellbeing/comfort	1 (high negative imapct) to 5 (high positive impact) score	3	No impact
existing consumer protection? (adequacy?)	1 (low) to 5 (high) score	5	support through the vendor of the equipment
		29	

Opportunities / risks	Scoring	Score	Comments
Critical success factors/watch points	List/Describe		increased participation of demand and generation in energy services, will increase as this is rolled out at distribution level
other relvant considerations/risks/opportunities	List/Describe		Increased flexibility of renewable generation, enhanced control which can be local control or centralised (via DNO/DSO)
adaptability / future proofing	List / Describe		Flexible, can be upgraded as technology changes
		113	

Smart Appliances

Smart appliances are able to respond to signals e.g. price information, direct control signals, and/or local measurements of electricity supply, and where the response leads to a change in when the appliance uses electricity. Using smart appliances to automatically adjust demand at peak times without any customer participation.

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	9	
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	3	Could improves efficiency of devices around the home but very much depends how smart functionality is used
Reliability	1 (low) to 5 (high) score	3	Still in trial stages, reliability to be demonstrated for sustained period
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	4	Typically manufactured with 'smart' capabilities, and are installed the same was as standard appliances; possible to retrofit with a smart plug.
complexity of systems/ their integration	1 (complex) to 5 (simple) score	3	Can buy some devices with it readily integrated, retrofitting the device would be more complex
risk/severity of unintended consequences	1 (high) to 5 (low) score	3	Disconnecting fridges or heating devices can lead to high levels of customer dissatisfaction
		25	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	5	If all refrigerators were 'smart', this would provide significant levels of flexibility to national grid
whole life environmental impact	1 (high) to 5 (low) score	5	Smart appliances have the potential to greatly reduce the carbon impact of some devices e.g. fridge/freezers
		10	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	5	Supports energy efficiency drivers
compatibility with current regulation	1 (low) to 5 (high) score	3	Fully regulated industry so no issues here but smart devices need time of use tariffs and these are hampered by lack of half hourly settlement for domestic consumers.
compatibility with current assessment methodologies	1 (low) to 5 (high) score	5	Yes?
		13	

Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	4	Small cost increase over conventional devices if buying built in smart capability. Around £100 more expensive
life cycle costs	1 (high) to 5 (low) score	5	Minimal
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	5	say 20% more expensive than standard device, with the potential to reduce energy consumption at peak times AND in future, provide services to the grid
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	5	The more devices that are installed nationwide, the greater level of flexibility available to operators
		19	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	5	Would benefit homes, potential to deploy in council housing/sheltered housing scenarios
existing Scottish capacity/skills	1 (low) to 5 (high) score	3	no records of numbers deployed but likely to be in some homes. Not that common yet
Scottish content	1 (low) to 5 (high) score	3	Not aware of Scottish manufacturers
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	5	Can be compatible with new markets for demand response if created under DSO Vision (all DNOs)
Scottish economic impact potential	1 (low) to 5 (high) score	3	Unless sales are via a Scottish company, minimal impact. Could potential be savings on energy bills but not clear
		19	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	3	Can be complex, but users tend to be more interested in learning how to use these things if they have an interest in being more efficient with their devices
disruption	1 (high) to 5 (low) score	4	Some time to learn best way to use device
customer acceptance	1 (low) to 5 (high) score	4	BEIS Consumer Panel 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. Some customers can reject devices with more control, assuming them to be more complex/no interest in smart devices
savings on bills	1 (low) to 5 (high) score	4	Potential to reduce energy use of individual appliances and therefore reduce overall energy costs
maintenance requirements	1 (high) to 5 (low) score	5	Same as standard maintenance requirements for appliances
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	4	Consumer override is typically included - particularly for heating devices
existing consumer protection? (adequacy?)	1 (low) to 5 (high) score	5	regulated appliances, consumer protection provided by heavily regulated industry
		29	

Opportunities / risks	Scoring	Score	Comments
Critical success factors/watch points	List/Describe		Number of appliances deployed, capability of aggregator capacity to support network
other relevant considerations/risks/opportunities	List/Describe		creation of flexibility markets, aggregation of capacity, creation of local services.
adaptability / future proofing	List / Describe		increase in residential DSR participation)
		115	

https://www.theguardian.com/environment/2009/apr/27/carbon-emissions-smart-fridges-environmentally-friendly-appliances

Demand Response

enables reduction/shift of electricity load from buildings through their existing building management systems (BMS) in response to signal from DNO. To facilitate this need aggregation of load shedding and communication between DNO and BMS.

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	8	Technology trials for DSR, but the market is to be developed
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	5	A number of devices already on the market which can provide Demand Response, but there is no wide scale market at the moment
Reliability	1 (low) to 5 (high) score	4	Reliable technology, but customers can override settings and reduce reliability
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	4	New devices to be installed in some cases
complexity of systems/ their integration	1 (complex) to 5 (simple) score	3	Can be complex to adapt user behaviour, but integration of tools is straight forward
risk/severity of unintended consequences	1 (high) to 5 (low) score	4	Low
		28	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	5	0.87Mt for domestic and 0.25Mt for non-domestic
whole life environmental impact	1 (high) to 5 (low) score	5	increased flexibility demand in homes and in large buildings, and able to reduce demand at peak hours
		10	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	5	Aligns with both Scottish, and UK Wide policy
compatibility with current regulation	1 (low) to 5 (high) score	3	Early stages for regulation of Demand Response, TBC
compatibility with current assessment methodologies	1 (low) to 5 (high) score	3	Improved energy efficiency in the home and C&I buildings, although will not impact on building energy efficiency
		11	

Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	4	Capital costs are associated with the technologies required for DR (smart meters, smart appliances)
life cycle costs	1 (high) to 5 (low) score	3	Settlement and billing costs
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	5	Can reduce CO2 through peak shifting, energy reduction, additional system balancing
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	5	The more participants in DR, the greater the benefits are for users and the wider system
		17	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	5	Lots of participants that could use DR
existing Scottish capacity/skills	1 (low) to 5 (high) score	4	Lots of large C&I buildings that could participate
Scottish content	1 (low) to 5 (high) score	1	Not Scotland specific
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	4	Combination of DR and local generation could balance locally i.e. maximise wind export through use of demand response
Scottish economic impact potential	1 (low) to 5 (high) score	5	Potential to reduce building energy costs
		19	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	4	Can be managed via a central controller (as part of BMS), or through individual appliances
disruption	1 (high) to 5 (low) score	3	Requires a change in attitude towards demand use
customer acceptance	1 (low) to 5 (high) score	3	Some users are opposed to demand response, preferring to have their own control over energy consumption. This is not an issue for C&I use
savings on bills	1 (low) to 5 (high) score	4	Can reduce energy use, participation in Time of Use tariffs (where available) could increase savings potential
maintenance requirements	1 (high) to 5 (low) score	4	Low
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	4	Some users argue that there is reduced comfort by not using energy whenever you like e.g. overriding storage heater settings but for the most part this is not the case (may only be relevant for young children or elderly)
existing consumer protection? (adequacy?)	1 (low) to 5 (high) score	3	Unknown?
		25	

Opportunities / risks	Scoring	Score	Comments
Critical success factors/watch points	List/Describe		Numbers of participants, particularly at domestic scale, increase in C&I participation, local energy markets or balancing
other relevant considerations/risks/opportunities	List/Describe		If there is creation of markets for demand response at distribution level, this will increase participation/potential
adaptability / future proofing	List / Describe		
		110	

https://www.surrey.ac.uk/ces/files/pdf/1011_WP_Bradley_et_al_DemandResponse_3.pdf

Smart Invertor' or 'Virtual Oscillator'

A new technique known as virtual oscillator control allows smart solar inverters to sense and adjust to grid disturbances, such as a sudden change in frequency or voltage. As distributed solar grows and big power plants are retired, VOC will help keep the grid stable.

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	7	Still under development
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	5	Greatly improves operation of invertor connected generation
Reliability	1 (low) to 5 (high) score	3	To be determined through trials
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	5	Appears to be compatible with existing systems - that's one of the aims of the development and trials
complexity of systems/ their integration	1 (complex) to 5 (simple) score	3	Could be complex to integrate - to be determined
risk/severity of unintended consequences	1 (high) to 5 (low) score	3	If configured incorrectly it could trip generation or cause issues on the network
		26	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	5	improves the efficiency of the network
whole life environmental impact	1 (high) to 5 (low) score	5	minimal
		10	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	4	Nothing specific about technology in Scottish Policy, but would improve performance of PV plant and therefore increase renewable generation export
compatibility with current regulation	1 (low) to 5 (high) score	2	Unsure - there may be changes required to grid codes to integrate these systems
compatibility with current assessment methodologies	1 (low) to 5 (high) score	3	not applicable
		9	

Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	5	Relatively low cost compared with the cost of the solar panels £100-£900 depending on spec?
life cycle costs	1 (high) to 5 (low) score	5	Low
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	5	Small additional cost to PV panel, to increase export potential
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	1	One inverter per device
		16	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	5	Potential to be developed in Scotland, and deployed in areas with large PV deployment (housing developers?)
existing Scottish capacity/skills	1 (low) to 5 (high) score	1	Not aware of any work being done in Scotland on this
Scottish content	1 (low) to 5 (high) score	1	Research is being led by NREL in the US
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	3	Potential to work with suppliers, developers, and PV manufacturers to install smarter systems
Scottish economic impact potential	1 (low) to 5 (high) score	4	Increase PV export
		14	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	3	not applicable
disruption	1 (high) to 5 (low) score	5	once installed there's no interruption
customer acceptance	1 (low) to 5 (high) score	3	minimal disruption but not well known
savings on bills	1 (low) to 5 (high) score	3	might increase PV export but not enough to notice substantial saving on bills/increase revenue from panels
maintenance requirements	1 (high) to 5 (low) score	4	minimal
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	3	not applicable
existing consumer protection? (adequacy?)	1 (low) to 5 (high) score	3	unknown
		24	

Opportunities / risks	Scoring	Score	Comments
Critical success factors/watch points	List/Describe		Use monitoring data from the device to determine if performance improvements
other relevant considerations/risks/opportunities	List/Describe		
adaptability / future proofing	List / Describe		Ability to incorporate with flexibility markets or grid services in the future
		99	

https://www.nrel.gov/grid/virtual-oscillator-controls.html

DER providing grid services

The PV power plants were able to provide variability smoothing through automatic generation control, frequency regulation for fast response and droop response, and power quality control.

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	7	Market needs to be created, but DER is ready
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	5	Would improve flexibility of the network
Reliability	1 (low) to 5 (high) score	4	Through the use of other technologies (ANM, generation router, controllers) this can respond in real time - but will be reliant on Comms technology
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	5	Technology exists to allow this, but there are no existing markets for this at LV level
complexity of systems/ their integration	1 (complex) to 5 (simple) score	4	participation via an aggregator will simplify things
risk/severity of unintended consequences	1 (high) to 5 (low) score	4	Fail safes can be installed to ensure there are no negative impacts of non-responsive generation
		29	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	5	Greater flexibility, increase use of renewable generation when the resource is available
whole life environmental impact	1 (high) to 5 (low) score	5	Greater flexibility, increase use of renewable generation when the resource is available
		10	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	4	Closely aligned with Scottish policy proposals and plans under energy strategy
compatibility with current regulation	1 (low) to 5 (high) score	3	Market does not exist, and therefore difficult to rank this.
compatibility with current assessment methodologies	1 (low) to 5 (high) score	3	not applicable
		10	

Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	5	Low
life cycle costs	1 (high) to 5 (low) score	3	Administration, subscription costs for aggregator - participants may need to pay for participation in the service, as they do at Transmission)
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	5	improves flexibility of the system, better use of available renewable resources
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	5	The more participants in DER services, the more competitive the market and therefore potential to lower costs
		18	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	5	large volume of DER connected generation in Scotland that could participate in such services
existing Scottish capacity/skills	1 (low) to 5 (high) score	5	Lots of DER installed that could participate IF the market was created
Scottish content	1 (low) to 5 (high) score	1	No trials by Scottish DNOs at the moment for Market services, but maybe in future?
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	1	
Scottish economic impact potential	1 (low) to 5 (high) score	4	DER has the potential to increase revenue through participation in balancing services
		16	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	4	depends if the develop is participating as part of an aggregator or not. Likely to be aggregator if small capacity
disruption	1 (high) to 5 (low) score	3	creation of markets is likely to create disruption in the energy market, lots of discussions with DER would need to take place first to establish rules and regulation
customer acceptance	1 (low) to 5 (high) score	5	customer would only participate if they wanted to - not a requirement
savings on bills	1 (low) to 5 (high) score	5	can increase revenue
maintenance requirements	1 (high) to 5 (low) score	5	low
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	3	not applicable
existing consumer protection? (adequacy?)	1 (low) to 5 (high) score	3	Unknown
		28	

Opportunities / risks	Scoring	Score	Comments
Critical success factors/watch points	List/Describe		Market for DER participation must first be created. Then monitor participation, improved balancing costs, system flexibility, increase revenue potential for DER (which could encourage more development due to lack of subsidies)
other relevant considerations/risks/opportunities	List/Describe		
adaptability / future proofing	List / Describe		markets can be flexible and therefore capability of DER may develop in the future
		111	

Electric batteries, domestic

Electrical energy converted to chemical energy where it is stored, and then discharged as electrical energy to be used at another time. In behind the meter applications, the battery remains in the same place but stores energy generated at one time for use at another time. In a domestic setting, typically used in conjunction with renewable energy (PV).

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	9	Lithium ion most commonly used for light weight and longer life
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	5	Round trip charge to discharge efficiency 98%
Reliability	1 (low) to 5 (high) score	4	Generally good if handled and sited correctly (i.e. not robust to all environmental conditions due to hazardous chemicals)
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	3	Compatible with relatively large PV systems but difficult to keep fully charged if small amount of excess and will not be sufficient to power more than lights, fridge and TV / laptop. In winter mode may not be sufficient to power much.
complexity of systems/ their integration	1 (complex) to 5 (simple) score	2	Higher costs / complexity for installation in a domestic setting. Too heavy for installation on a floor i.e. needs to be ground level?
risk/severity of unintended consequences	1 (high) to 5 (low) score	3	Potential for hazard (e.g. fires) if not properly sited and maintained.
		26	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	3	If combined with renewable energy then saving mostly low carbon energy although sometimes need to charge from the mains to complete charge cycle and maintain battery health.
whole life environmental impact	1 (high) to 5 (low) score	2	Hazardous chemicals are a threat to the environment, and metals need to be mined. Recycling rates can be quite high if there is a market to recover certain elements (e.g. lead).
		5	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	5	Scotland's ambitious renewable energy targets will need storage and / or import / export from neighbouring markets.
compatibility with current regulation	1 (low) to 5 (high) score	4	At domestic level no real conflicts
compatibility with current assessment methodologies	1 (low) to 5 (high) score	3	Consultation on proposed changes takes batteries into account but some stakeholders do not believe these go far enough
		12	

Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	2	$890-1476 /kWh (Lazard) for residential application of lithium ion
life cycle costs	1 (high) to 5 (low) score	2	No data. Lithium not considered toxic or persistent in the environment, but some battery chemistries may have more toxic materials (e.g. cobalt). Limited recycling infrastructure.
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	3	No data per t C saved, but some data to suggest manufacturing of cathode materials and wrought aluminium is carbon intensive.
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	4	High potential for economies of scale, but concerns about scarcity of some cathode elements
		11	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	2	Limited applicability, largely those with renewable energy installations and suitable space and conditions
existing Scottish capacity/skills	1 (low) to 5 (high) score	3	Some support infrastructure for installation, limited UK-manufacturing but none Scotland-specific
Scottish content	1 (low) to 5 (high) score	1	Raw materials largely imported. Historical lead and zinc mining in Scotland.
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	4	Significant links to renewable energy and microgeneration installation, as well as smart grid more generally
Scottish economic impact potential	1 (low) to 5 (high) score	4	Innovas data shows high market value by percentage (Scotland has nearly 12% of UK market value)
		14	

Consumer	Scoring	Score	Comments	
user friendliness / practicality	1 (low) to 5 (high) score	4	Difficult to know but no obvious issues	
disruption	1 (high) to 5 (low) score	2	"Typical domestic systems vary from being the size of a small computer to the size of a washing machine."	BRE
customer acceptance	1 (low) to 5 (high) score	4	Again difficult to know but no particular reason why they wouldn't be accepted, comparable to electric vehicles which are readily accepted.	
savings on bills	1 (low) to 5 (high) score	3	Moderate for domestic use	
maintenance requirements	1 (high) to 5 (low) score	3	Not without maintenance requirements (e.g. to fully charge and winter mode) but more and more semi-automated	
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	3	Neutral on wellbeing and comfort, probably makes little difference unless off-grid	
existing consumer protection? (adequacy?)	1 (low) to 5 (high) score	3	General consumer protection but as emerging technology it is inevitably emerging area	
		22		

Opportunities / risks	Scoring	Score	Comments
Critical success factors/watch points	List/Describe		Lifecycle issues with materials used to manufacture, need better recycling
other relevant considerations/risks/opportunities	List/Describe		
adaptability / future proofing	List / Describe		Good scalability and potential for adaptation to future
		90	

REFERENCES

NYSERDA, December 2014,
BRE, 2016. Batteries and solar power, guidance for domestic and small commercial customers
Lazard, 2016. Lazard's levelized cost of storage. Version 2

Electric batteries - commercial / industrial

Electrical energy converted to chemical energy where it is stored, and then discharged as electrical energy to be used at another time. In behind the meter applications, the battery remains in the same place but stores energy generated at one time for use at another time. In a commercial setting, typically used in conjunction with renewable energy or for peak management / demand response. Assume installed in an industrial setting such as a shipping container or similar.

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	**8 to 9**	8 are near-commerical variants (advanced lead acid, vanadium redox (flow), zinc bromide (flow), sodium nickel chloride), 9 are commercial (lead acid, lithium ion, sodium sulphur, nickel cadmium)
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	3	Round trip charge to discharge efficiency ranges from 60 (nickel cadmium / zinc bromide) to 98 (lithium ion)%
Reliability	1 (low) to 5 (high) score	3	Generally good if handled and sited correctly (i.e. not robust to all environmental conditions due to hazardous chemicals). Some better technically than others for different circumstances - for example some hold charge better than others.
(level of) Compatability with existing systems	1 (low/poor) to 5 (high/good) score	4	Compatible with existing electrical systems, in a technical sense and can have superior ability to support electrical stability. May need some updates to electrical standards.
complexity of systems/ their integration	1 (complex) to 5 (simple) score	3	Installation costs can double total cost, depending on the circumstances, finding right location for battery (which is heavy) can be difficult
risk/severity of unintended consequences	1 (high) to 5 (low) score	3	Potential for hazard (e.g. fires) if not properly sited and maintained.
		16	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	4	Data hard to come by but storage essential for large-scale integration of low carbon technologies. Depends variously on carbon intensity of grid electricity, electrical energy charging the battery, frequency of use.
whole life environmental impact	1 (high) to 5 (low) score	2	Hazardous chemicals are a threat to the environment, and metals need to be mined. Recycling rates can be quite high if there is a market to recover certain elements (e.g. lead).
		6	

Policy / Regulation	Scoring	Score	Comments
compatability with Scottish policy	1 (low) to 5 (high) score	5	Scotland's ambitious renewable energy targets will need storage and / or import / export from neighbouring markets.
compatability with current regulation	1 (low) to 5 (high) score	3	Some challenges in charging regime for storage, although work underway to address these
compatibility with current assessment methodologies	1 (low) to 5 (high) score	3	Consultation on proposed changes takes batteries into account but some stakeholders do not believe these go far enough
		11	

Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	2	Installed energy cost $800-2500 per kWh for "single use" (NYSERDA); levelised cost $515 to 1350 for available use (Lazard)
life cycle costs	1 (high) to 5 (low) score	3	No data. Lithium not considered toxic or persistent in the environment, but some battery chemistries may have more toxic materials (eg cobalt). Limited recycling infrastructure for lithium ion and others. Good recycling structure for lead acid batteries.
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	3	No data per t C saved, but some data to suggest manufacturing of cathode materials and wrought aluminium is carbon intensive.
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	5	Significant, most commentators show costs reducing with scale across all of the battery types
		13	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	3	Extended applicability compared to domestic batteries, but still limited to renewable energy matching and / or microgrid and offgrid applications.
existing Scottish capacity/skills	1 (low) to 5 (high) score	3	Some support infrastructure for installation, limited UK-manufacturing but none Scotland-specific
Scottish content	1 (low) to 5 (high) score	1	Raw materials largely imported. Historical lead and zinc mining in Scotland.
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	5	Significant links to renewable energy and microgeneration installation, as well as smart grid more generally
scottish economic impact potential	1 (low) to 5 (high) score	4	Innovas data shows high market value by percentage (Scotland has nearly 12% of UK market value)
		16	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	3	
disruption	1 (high) to 5 (low) score	2	
customer aceptance	1 (low) to 5 (high) score	4	
savings on bills	1 (low) to 5 (high) score	2	High initial cost and limited use cases at the moment mean moderate bill savings.
maintenance requirements	1 (high) to 5 (low) score	2	Need to maintain optimim charge conditions, winter mode etc
health/wellbeing/comfort	1 (high -ve) to 5 (high +ve) score	4	
existing consumer protection? (adequacy?)	1 (low) to 5 (high) score	3	
		20	

Opportunities / risks	Scoring	Score	Comments
Critical success factors/watch points	List/Describe		Costs need to come down further, and / or multiple use opportunities arise. Technically improved energy density, longer life and lower self-discharge rates. Environmentally, improved recycling infrastructure.
other relvant considerations/risks/opportunities	List/Describe		
adaptability / future proofing	List / Describe		
		82	

REFERENCES

NYSERDA, December 2014,

Heat batteries based on Phase Change Materials (PCMs)

Based on the technology used for re-useable hand warmers, but optimised for storage of excess renewable energy and smoothing of demand

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	8	Available to purchase and some demonstration projects, but not widely used
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	4	Marketed as more efficient than electrical batteries, although needs more data
Reliability	1 (low) to 5 (high) score	4	Experience using PCMs to manage heat of Lithium Ion batteries suggests improved reliability but not enough experience on batteries with PCM as heat store. Intention is for it to be reliable.
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	4	Designed to work with combi boiler, PV, CHP and heat pumps - needs validating with more experience. Not clear how fits with domestic load, charge / discharge requirements of battery.
complexity of systems/ their integration	1 (complex) to 5 (simple) score	3	Seems relatively simple
risk/severity of unintended consequences	1 (high) to 5 (low) score	4	Not toxic materials like batteries so potential seems lower
		27	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	4	Should be good based on estimated bill savings
whole life environmental impact	1 (high) to 5 (low) score		No data
		4	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	5	Storage highly compatible with Scottish policy on low carbon energy
compatibility with current regulation	1 (low) to 5 (high) score	4	At domestic level no real conflicts
compatibility with current assessment methodologies	1 (low) to 5 (high) score	2	Consultation on proposed changes takes batteries into account but some stakeholders do not believe these go far enough, and probably have electrical batteries in mind
		11	

Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	2	Around £1700 for 5kWh system, £340/kWh
life cycle costs	1 (high) to 5 (low) score		?
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	3	Still quite expensive, needs more experience, carbon savings depend on context
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	4	In so far as it is relatively new technology should be scope for economy of scale
		9	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score		Unknown, depends on properties of battery - can it partially charge or must it fully charge and discharge?
existing Scottish capacity/skills	1 (low) to 5 (high) score	3	http://www.sunamp.com/ is only provider we could find, based in East Lothian, working with Edinburgh university.
Scottish content	1 (low) to 5 (high) score	4	Basically unknown for materials but high for IPR
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	4	Potential for a flexible technology used across domestic and commercial sectors. Also has a track record for use in absorbing excess heat from Li ion batteries in EVs
Scottish economic impact potential	1 (low) to 5 (high) score	2	Low in near to medium term simply because its relatively new and small industry
		13	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	4	based on claims
disruption	1 (high) to 5 (low) score	4	Low, small and wall mountable
customer acceptance	1 (low) to 5 (high) score	4	
savings on bills	1 (low) to 5 (high) score	4	Manufacturers claim that Berwickshire housing association shows 45-60% savings on bills in combination with heat pumps - need more experience
maintenance requirements	1 (high) to 5 (low) score	4	Not clear
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	4	
existing consumer protection? (adequacy?)	1 (low) to 5 (high) score	3	Newish technology so will need experience
		27	

Opportunities / risks	Scoring	Score	Comments
Critical success factors/watch points	List/Describe		
other relevant considerations/risks/opportunities	List/Describe		
adaptability / future proofing	List / Describe		
		91	

https://www.sunamp.com

smart conventional heat storage

Conventional heat storage using bricks or water augmented by smart(er) controls

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	9	Established technology with an update for smart controls and improved efficiency
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score		
Reliability	1 (low) to 5 (high) score	2	
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	5	Excellent compatibility given existing technology, and potential to readily integrate into modern demand response
complexity of systems/ their integration	1 (complex) to 5 (simple) score	4	
risk/severity of unintended consequences	1 (high) to 5 (low) score	5	Well known and understood
		25	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	4	study by DNV KEMA, which estimated that retrofitting the storage heaters in ~14m EU homes with 'smart storage' (new generation heaters with digital controls) could lead to efficiency savings of around 20% . Glen Dimplex quote 15% energy savings and 30% financial savings during a pilot project in 140 Irish homes.
whole life environmental impact	1 (high) to 5 (low) score	4	
		8	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	5	
compatibility with current regulation	1 (low) to 5 (high) score	3	Needs more sophisticated time of use tariffs for domestic customers
compatibility with current assessment methodologies	1 (low) to 5 (high) score	4	SAP incorporates 'automatic charge control' for electric storage heaters, which includes a degree of smart functionality.
		12	

Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	3	£800 for a 1kW Quantum heater.
life cycle costs	1 (high) to 5 (low) score	3	
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	3	Claims up to 30% saving on bills
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	3	
		12	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	5	
existing Scottish capacity/skills	1 (low) to 5 (high) score	4	Good for installers and operation, but unknown re manufacture
Scottish content	1 (low) to 5 (high) score	2	
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	3	
Scottish economic impact potential	1 (low) to 5 (high) score	3	
		17	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	3	Not got a good reputation on user friendliness but modern updates have potential to change this.
disruption	1 (high) to 5 (low) score		
customer acceptance	1 (low) to 5 (high) score	3	68% of the GB respondents with storage heating surveyed in 2012 said they were satisfied with it (compared with 91% of respondents with gas central heating), while 25% were dissatisfied. An earlier survey of British public opinion on energy issues found that storage heating was the least popular option for shifting electricity load (water heating was the most popular) and that only 35% of respondents thought there would probably be a growth in the use of electric storage heaters. Interestingly, younger respondents were more likely to be interested in adopting storage heating than the older ones. Scottish respondents – that is, those from the coldest regions of GB – were the least enthusiastic. - significant potential to improve image of storage heating with smarter alternatives.
savings on bills	1 (low) to 5 (high) score	4	Project in Ireland shown that Quantum has the potential to deliver a 30% economic saving to individual homeowners (€37,000 saving across 140 units per year or €264 saving per home)
maintenance requirements	1 (high) to 5 (low) score		
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	3	
existing consumer protection? (adequacy?)	1 (low) to 5 (high) score		
		13	

Opportunities / risks	Scoring	Score	Comments
Critical success factors/watch points	List/Describe		Need better developed time of use tariffs (and half hourly settlement for domestic customers) to really tap demand response potential
other relevant considerations/risks/opportunities	List/Describe		
adaptability / future proofing	List / Describe		
		87	

REFERENCES

Consumer Focus. From devotees to the disengaged. A summary of research into energy consumers' experiences of Time of Use tariffs and Consumer Focus's recommendations. (2012)

IpsosMORI Energy Issues 2009. Survey of British public opinion. (2010) https://www.ofgem.gov.uk/sites/default/files/docs/2010/06/mori-energyissuesreport- final.pdf

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.

http://www.glendimplex.com/news/view/glen_dimplex_group_launches_revolutionary_quantum_heating_system

Ice batteries

Makes ice during the charge cycle, powered by excess renewable energy or off peak grid electricity, delivers cooling for air conditioning units as the discharge

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	9	Commercially available and in use in the US
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	3	Less use but more efficient in colder climates
Reliability	1 (low) to 5 (high) score	4	Good reliability in trial
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	4	Replaces the compressor unit of HVAC systems, some teething problems with existing thermostat in trial
complexity of systems/ their integration	1 (complex) to 5 (simple) score	3	Needs some modification for UK application (currently sold from the US); longer charge times due to lower domestic voltage in UK than US
risk/severity of unintended consequences	1 (high) to 5 (low) score	4	
		27	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	3	charges (freezes) in off-peak times and replaces energy intensive compressor unit of AC to provide cooling. In lower ambient temperatures of UK does not meet its full potential for energy saving. Main benefit in the trial was peak lopping, which saves carbon indirectly through reduced need for peaking plant.
whole life environmental impact	1 (high) to 5 (low) score	3	Refrigerant needs to be properly managed and disposed of
		6	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	4	
compatibility with current regulation	1 (low) to 5 (high) score	3	No particular barriers but storage generally not well incentivised
compatibility with current assessment methodologies	1 (low) to 5 (high) score	2	Consultation on proposed changes takes batteries into account but some stakeholders do not believe these go far enough, and probably have electrical batteries in mind
		9	

Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	3	$1500-2500/kW; 'Of total cost installation 65%, ice bear unit 28%, shipping 7%. Current price high due to low pound, but on high end of per kW for generation.
life cycle costs	1 (high) to 5 (low) score	3	Add 1.5-2% of capital cost for maintenance, plus cost of disposal
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	2	No data. But in the Thames Valley trial the project could find no suitable participants to self fund installation from 194 buildings due to lack of customer benefits and no market incentivisation. The DNO ended up funding 3 units themselves and installing them at volunteer locations.
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	4	Assumed significant potential due to low market penetration at present.
		12	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	2	Not strong demand for air conditioning based on cooling in Scotland
existing Scottish capacity/skills	1 (low) to 5 (high) score	1	Product marketed mainly in US
Scottish content	1 (low) to 5 (high) score	1	
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	3	Part of an air conditioning and even BMS
Scottish economic impact potential	1 (low) to 5 (high) score	1	Based on low applicability
		8	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	3	Not much data but no adverse reports in the trial
disruption	1 (high) to 5 (low) score	2	Some disruption from civil and mechanical works to place and connect the unit. Commissioning of 7kW units took 1-2 days. Installation 11 days.
customer acceptance	1 (low) to 5 (high) score	3	Scepticism on whether it would be worthwhile
savings on bills	1 (low) to 5 (high) score	2	Limited savings unless a particularly high and constant need for cooling
maintenance requirements	1 (high) to 5 (low) score	3	
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	3	
existing consumer protection? (adequacy?)	1 (low) to 5 (high) score	4	
		20	

Opportunities / risks	Scoring	Score	Comments
Critical success factors/watch points	List/Describe		Along with thermal and electrical storage needs appropriate incentives
other relevant considerations/risks/opportunities	List/Describe		Low applicability to Scotland due to low ambient temperatures
adaptability / future proofing	List / Describe		
		82	

REFERENCES

https://www.ice-energy.com/technology/

http://www.smarternetworks.org/Files/Thames_Valley_Vision_150916140427.pdf

http://www.thamesvalleyvision.co.uk/wp-content/uploads/2017/05/NTVV-Learning-Outcome-Report-LV-Network-Storage-Cold-Thermal-Storage.pdf