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CATAPULT Energy Systems

Future Power System Architecture Project 2

Work Package 1B Final Report - Future Stakeholder Needs

A report commissioned by Innovate UK and delivered through a collaboration between the Institution of Engineering and Technology and the Energy Systems Catapult.

FUTURE POWER SYSTEM ARCHITECTURE

MEETING BRITAIN'S FUTURE POWER SYSTEM CHALLENGES

The Institution of Engineering and Technology

Catapult Energy Systems

Future Power System Architecture Project 2

Final Report

Work Package 1B:
Future Stakeholder Needs

Future Power System Architecture – A report commissioned by Innovate UK

The Future Power System Architecture (FPSA) project 2 was commissioned by Innovate UK and delivered through a collaboration between the Institution of Engineering and Technology (IET) and the Energy Systems Catapult.

The collaboration built upon the shared commitment to responding effectively to the challenges presented by the energy trilemma: decarbonisation, security of supply and affordability. The Energy Systems Catapult and the IET drew upon their respective strengths and engaged with a broad community of stakeholders and other experts to deliver the project.

The collaboration brought extensive expertise and experience to the project, combining technical, commercial and customer perspectives, and included the significant contribution of senior thought leaders from the IET membership. The unique combination of complementary skills enabled innovation in approach, deep analysis and strong evidence building. The collaboration worked closely on project governance, delivery and commercial management and applied best practice in all aspects of its work. The position of the IET and the Energy Systems Catapult in the energy sector assured independence of the outcomes.

About the Institution of Engineering and Technology

The Institution of Engineering and Technology is one of the world's largest engineering institutions with over 167,000 members in 127 countries. It is also the most multidisciplinary – to reflect the increasingly diverse nature of engineering in the 21st century.

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The Energy Systems Catapult is the UK's technology and innovation centre set up to support companies and Government for the development of new products and services to address the new commercial opportunities created by the transformation of UK and global energy systems (covering electricity, heat and combustible gases).

The Catapult's mission is to bring the worlds of industry, academia and Government together to encourage and support the development of new technology-based products and services in the energy sector. It is a non-profit, non-partisan company limited by guarantee.

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Executive Summary

Key messages:

- The future set of power system stakeholders is likely to be far more diverse than the current set of stakeholders. Customers will be more empowered, and stakeholders will range, for example, from transport-as-a-service companies to cities and communities to smart home companies.
- These stakeholders will have a *much wider set of requirements*[1] than current stakeholders. They are likely to range from optimising distributed energy assets through to bundling energy (and capacity) provision and products into services.
- The *thirty-five* functions identified in FPSA1, whose definitions have been reviewed and refined during the FPSA2 study, can suitably meet the future requirements of the future stakeholders identified in the research and analysis of Work Package 1B.

This report examines the future power system requirements of future stakeholders. Our focus has been on visioning the change in behaviours and activities of stakeholders in 2030 that could impact the power system, rather than working incrementally forwards from today.

For this time period we have explored, through primary and secondary research:

- Who will be the stakeholders in the power system?
- What will be their needs?

Our focus has been on examining key themes and drawing out answers to the above questions and the impact on the power system – not on making quantitative predictions about the future.

For two of these – **mobility** and **heating and cooling** – we have explored from a ‘requirements of stakeholders’ perspective. We have started with understanding the needs and aspirations of customers and how societal/behavioural trends may impact these over time, following this through to look at interactions between service provision, technology development and the impacts of this on the power system. For the third theme – **distributed and connected energy** – we have started with technology, and explored interactions between customer requirements, service provision and the impact on the power system.

1.1 Seven key themes for the future power system

Our analysis, based on literature reviews, existing Delta-ee[2] research, and interviews with key stakeholders around these themes, has identified the following key findings:

1. The boundaries of the power system will increasingly spill over onto the customer side of the meter – incorporating electric heating and cooling, electric vehicles, batteries, and distributed generation. Flexibility will be applied to all of these technologies. The power system will likely comprise of millions of distributed assets.
2. The deployment rates of the above technology are uncertain, as they are subject to a wide variety of factors (including policy, technology development and regulation). The overall direction of travel is, however, clear.
3. Part of the market for energy related services will move from product provision towards service provision (bundles of products, services and in some cases energy/capacity). Mobility-as-a-service (e.g. combining transportation services from public and private providers through a unified platform), heat-as-a-service (e.g. providing agreed levels of comfort), and energy service business models (e.g. providing energy services from distributed assets) are examples of these.
4. Business models that incorporate optimising, influencing and controlling the timing of demand, storage and generation will be an important part of the future. This optimisation will take place at different levels of the power system (from buildings to regions), across various classes of assets (from electric vehicle charging at multiple sites to

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[1] Needs and requirements; “needs” has been used in FPSA2 to refer to specific attributes of the *thirty-five* FPSA2 functions. To avoid confusion with stakeholders’ needs and requirements, we use the word “requirements” exclusively to refer to stakeholders needs and requirements.

[2] Delta Energy and Environment is the consultancy company delivering the WP1B research project.

optimising a wide variety of assets in a commercial building). The markets around security of supply, reliability, capacity and balancing services may change significantly from today.
5. Connectivity, big data and analytics, artificial intelligence, machine learning, and software will be important enablers of optimisation and service-based business models.
6. The ecosystem of service providers with stakes in the power system will be broad and diverse. They will include companies from outside the energy sector (such as vehicle manufacturers), companies that are product focused today but service orientated in the future (such as heating equipment manufacturers), and start-ups and new entrants, some of whom do not exist today.
7. Customers and communities (physical or virtual) will exert increasing amounts of market power in the future, providing services to, as well as buying services from, the wider energy system. Autarky or greater independence from the grid will become important for certain customers and communities, as may the requirements for renewable sources of energy.

1.2 The future requirements of future stakeholders

The specific requirements of stakeholders vary across the three themes that have been explored in this research – **mobility, heating and cooling**, and **distributed and connected energy**. Many different requirements have been identified, but seven commonly recurring requirements are as follows:

1. The ability to exploit commercial opportunities for flexible demand, storage and generation (including linkages between different energy vectors).
2. Optimising distributed energy assets at a customer, community or regional level – with optimisation driven by different factors such as financial reward, independence, or emissions.
3. Access to data relating to energy consumption, generation, capacity and associated price signals.
4. New commercial arrangements for buying and billing energy/capacity, such as (1) bundling this into wider service offerings (for example bringing together transport and energy), and (2) buying energy/capacity from particular sources (for example renewables).
5. New commercial arrangements for exchanging services between customers (and communities), or between customers (and communities) and other power system players.
6. Increasing requirements around capacity services (and potentially less around energy), with storage perhaps leading to lower requirements for continuity of supply.
7. Inter-operability access to energy system price signals for the automation of technology and services for seamless integration into customers' lives.

The *thirty-five* functions of the future power system considered in FPSA2 (whose definitions have been reviewed and refined) can meet the above common requirements from across the three themes, and can also meet the specific requirements of future stakeholders as detailed in this report.

1.3 Examples of future stakeholders

Our research demonstrates that the range of future power system stakeholders is likely to be far wider than today's set of stakeholders. Of today's stakeholders, customers will have a much wider set of requirements. In some cases, customers themselves will be much more active participants in the power system. In other cases, service providers will act on customers' behalf.

In the ~2030 time horizon that we have considered, examples of future stakeholders include:

1. Mobility-as-a-service companies. These will range from automotive manufacturers that move more towards service provision, to companies such as Uber.
2. Fleet operators.
3. Electric vehicle charging infrastructure companies.
4. Cities and municipalities.
5. Climate service providers bundling together product, commodity and controls to provide agreed levels of comfort.
6. Local energy companies (e.g. traditional network operators, new microgrid companies, community-led companies) knitting together distributed energy assets and distribution infrastructure to provide energy services.
7. Providers of optimisation services (using flexibility to optimise distributed energy assets and demand side response).
8. Smart home/home service companies.

1.4 Future evolution of the three horizontals are interlinked

The three horizontals considered in this study are interdependent/overlap in a number ways, with the connected and distributed energy horizontal being an important enabler of, but also dependent in some ways on, the mobility and the heating and cooling horizontals.

In the future, a fully connected, optimised power system with lots of distributed generation (i.e. the connected and distributed horizontal), in part, depends on, and will be enabled by, the significant deployment of electric vehicles (i.e. the mobility horizontal), the charging of which can be controlled/optimised, and that can be used to store energy for use later (via V2G, resulting in EVs becoming 'micro-distributed generators'). Also, the electrification of heating will drive the deployment of electric heat pumps (i.e. the heating and cooling horizontal), most of which will be connected or come with smart controls enabling their operation to be influenced (for example by price signals) which will help facilitate the connected and distributed energy future.

The connected and distributed horizontal considered within this study is not just limited to bigger generation assets, but includes small distributed generation assets (such as fuel cells, micro CHP, solar PV, batteries, electric vehicles plugged in at home/work), allowing stakeholders of various sizes to supply energy back to the grid, to a neighbour, to a building/commercial premises, if needed. It also includes controllable loads (such as smart appliances, controllable electric heating/cooling), the operation of which can be influenced.

A highly connected and distributed energy future will be an important enabler of the mobility and the heating and cooling futures. For example, it is likely that generators of all sizes, and controllable loads/appliances will be connected to, and 'talking' to, each other, and that price signals (or some form of financial mechanism to incentive controlling/influencing the timing of operation of new loads) will be needed in order to realise the full potential of the heat as a service and mobility as a service themes identified in this study.

2. Introduction

2.1 Purpose of this report

Work Package 1B (WP1B), part of the Future Power System Architecture Phase 2 (FPSA2) project, was tasked with enhancing understanding of the potential future requirements of future power system stakeholders. This report presents the findings of WP1B, and hence attempts to identify potential future power system stakeholders and their requirements. The future stakeholders and the requirements identified were used to inform the wider FPSA2 project.

2.2 Background

The purpose of FPSA2 is to deepen the analysis of requirements considered in FPSA1, understand barriers to implementation, and to consider innovative frameworks for delivering new functionality. FPSA2 builds on the first FPSA project, which was commissioned by the former Department of Energy and Climate Change (DECC), whose portfolio is now part of the Department for Business, Energy and Industrial Strategy (BEIS). The findings called on the power industry and government to focus urgently on delivering new capabilities to transform GB's power system architecture by 2030, making it fit to respond to the challenges presented by the energy trilemma: decarbonisation, security of supply and affordability.

The team that worked in collaboration to deliver FPSA1 – the Energy Systems Catapult and the Institution of Engineering and Technology (IET) – is now working on FPSA2. Innovate UK is providing funding via the Catapult.

The objectives for FPSA2 are to deliver:

- A comprehensive exploration of the current and future requirements of both existing and emerging stakeholders.
- A review of the *thirty-five* FPSA1 functions to identify possible gaps or new insights into required functionality.

- An assessment of the feasibility of delivering the functions under the current power sector structure.
- Identification of possible areas of Research, Development and Demonstration (RD&D) and Innovation.
- A methodology for assessing the probability and consequence of late or non-delivery of the functions.
- A methodology for determining the relative impact of the identified barriers to functions under the current structure, and hence the priorities for establishing *Enabling Frameworks* to address those barriers.
- The identification of a number of *Enabling Frameworks* for development under FPSA3 to[3] deliver the functions.
- Full documentation of both the methodology and outputs to provide the necessary audit trail and overall process assurance.
- A clear explanation of the complex messages delivered to relevant audiences throughout FPSA2.

The tasks for FPSA2 are split into a number of Work Packages to enable project activity to be co-ordinated and managed effectively. A Work Package champion leads each Work Package, supported by external suppliers and contractors to deliver the work. The main tasks associated with each Work Package are summarised in the table opposite.

Work Package 1B (together with Work Package 1A) make up the core 'stakeholder' research element of FPSA2. In particular, the focus of Work Package 1B is to understand the future power system requirements of **future stakeholders** of the power system, based primarily on secondary research and analysis.

Figure 1-1: Tasks within each FPSA2 Work Package

WP1A: Engage with Stakeholders
Establish a survey technique to identify the barriers being encountered, especially for communities and grid-edge technologies.
WP1B: Future Stakeholder Needs
Research future socio-political drivers on customer and stakeholder behaviour.
WP2: Review the Functional Analysis, Identify no-regrets actions, assess RD&D required to accelerate deployment
Check validity and completeness of functions and options for delivery. Progress no-regrets actions where feasible through today's sector processes, including touch points with other vectors. Identify RD&D and Innovation opportunities to accelerate delivery.
WP3: Impact Analysis
Identify the barriers to developing and implementing the functions within current sector processes and assess the impact of non or late delivery.
WP4: *Enabling Framework* Identification
Assess architectural options to remove institutional (regulatory, market, technical, cultural, etc.) barriers to delivering functions. Identify *Enabling Frameworks* and potential trials for development under FPSA3.
WP5: Synthesis Integration and Reporting
Ensure key findings are integrated between Work Packages and deliver final reports.
WP6: Dissemination
Ensure complexities of FPSA are appropriately shared to audiences. Explore improved communication techniques.

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[3] FPSA3 is currently proposed to build further on the *Enabling Frameworks* activity completed in WP4 of FPSA2 and validate this work by developing a Framework (and associated tools and techniques) for a specific use case.

3. Objectives and Approach to the Work Package

3.1 Objectives of Work Package 1B

As part of the FPSA Phase 2 objective of closing the gap in the understanding of the potential future requirements of future power system stakeholders from FPSA Phase 1, WP1B aims to review and explore existing international research and insights in order to:

- Understand the **future requirements and aspirations of future power system stakeholders** (e.g. domestic customers, SMEs, communities/cities, etc.).
- Identify additional/new potential future stakeholders and explore their future requirements and aspirations that could have implications for the power system.
- Identify the impact that cultural/societal/behavioural changes may have on the power system and how different stakeholders might buy into the changes in the power system.

The understanding developed on the future requirements of future power system stakeholders will feed into other Work Packages (specifically WP2 and WP4), and may influence/support their activities on analysing the functionality of the future UK power system (WP2) and potential mechanisms for enabling change in this system (WP4).

The purpose of WP1B is not to consider incremental change, but rather envision possible step changes beyond that related to current innovation and business models – that could have a significant impact on the functionality of the future power system.

3.2 Approach and methodology for Work Package 1B

In order to build a robust, evidence-based view on the future requirements of the power system from future stakeholders, the following four-step process was applied:

- Step 1: Develop a model to provide structure to the synthesis of evidence for future stakeholder requirements.
- Step 2: Gather evidence via secondary research of existing literature, insights from the project team, and conducting interviews with key research bodies and institutes.
- Step 3: Synthesise this evidence and map on to the model to draw out key findings/themes in order to identify future stakeholders and their power system requirements. This will be done during workshops involving the project team.

- Step 4: Identify any gaps in the research and fill these gaps with supplementary research. At this stage, insights gathered during the process may be used to modify and improve the model.

Development of the model

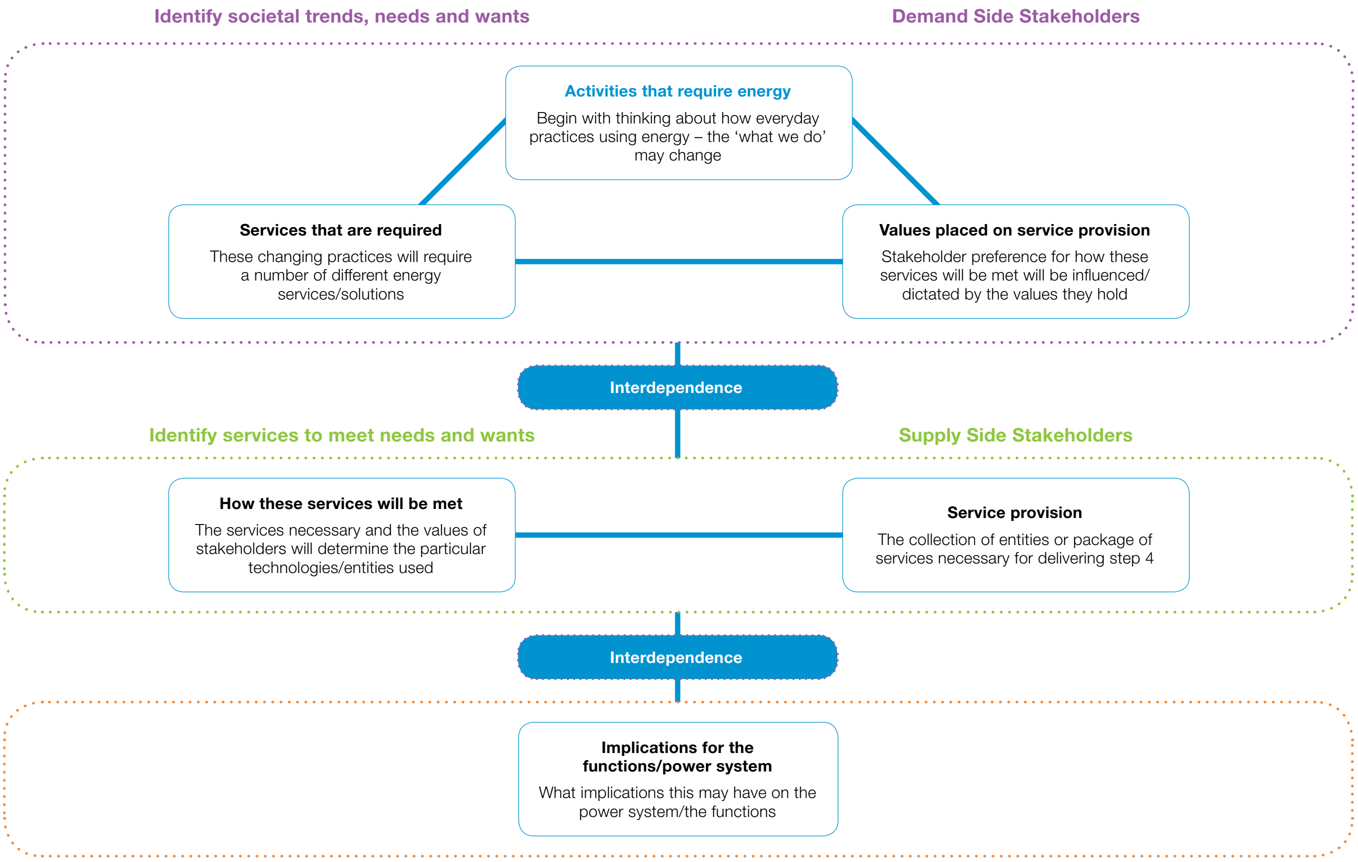
To reflect the aims of the project – emphasising the future stakeholder requirements of the future power system – the starting point of the model is to focus on the **practices of stakeholders that require energy** i.e. the behaviours/activities of stakeholders that drive energy use. By grounding our research in understanding the social trends that drive these practices, and how these social trends might evolve out towards 2030, we can build a picture as to how these practices requiring energy may develop. This is represented by the three interlinked boxes at the top of Figure 2 below.

These changing behaviours/practices will require certain energy services to be delivered, and these energy services will also need to change as behaviours and practices change. The kind of energy service required for each specific activity is captured in the two interlinked boxes in the middle of Figure 2 below.

How these energy services are delivered – i.e. the types of physical infrastructures that are utilised to deliver these energy services and the types of propositions/business models that are successful in delivering these energy services is mediated to a large extent by the values stakeholders hold. The values that stakeholders place on different services may change in the future as societal/behavioural trends develop, which could drive a change in the way certain energy services are delivered. Gathering evidence on how stakeholder values may change, and the impact this could have on the infrastructure/propositions/business models needed to deliver these services will be an important part of our analysis. By dissecting the processes of change in this way, the model can be used to map the evidence gathered in a clearly structured manner.

The model utilised in this study is illustrated in Figure 2 below.

Figure 2: Basis of model



Activities that require energy
Begin with thinking about how everyday practices using energy – the 'what we do' may change

Services that are required
These changing practices will require a number of different energy services/solutions

Values placed on service provision
Stakeholder preference for how these services will be met will be influenced/dictated by the values they hold

How these services will be met
The services necessary and the values of stakeholders will determine the particular technologies/entities used

Service provision
The collection of entities or package of services necessary for delivering step 4

Implications for the functions/power system
What implications this may have on the power system/the functions

An example of how we map learnings/insights from existing studies on to each stage of the model can be seen in Figure 3 below. This is illustrative only, to demonstrate how and where we mapped learnings, and not designed to be exhaustive.

In most cases, the societal trends, behaviours and activities illustrated on the left of Figure 3 will drive the kinds of energy services required, which are met by a combination of physical system infrastructures, the choice of which is mediated by values (such as cost, convenience, trust and reliability). The outcome of this is a collection of services and product offerings, offered to the customer to meet their evolving practices.

However, it is recognised that not all change is driven primarily by changing stakeholder practices, but can also be driven by the types of services on offer, technical innovations and new business models, which in turn can create new energy-using practices, which can then in turn drive new services etc. We illustrate this feedback element within the graphic at the top of Figure 3 below.

The themes (horizontals) considered

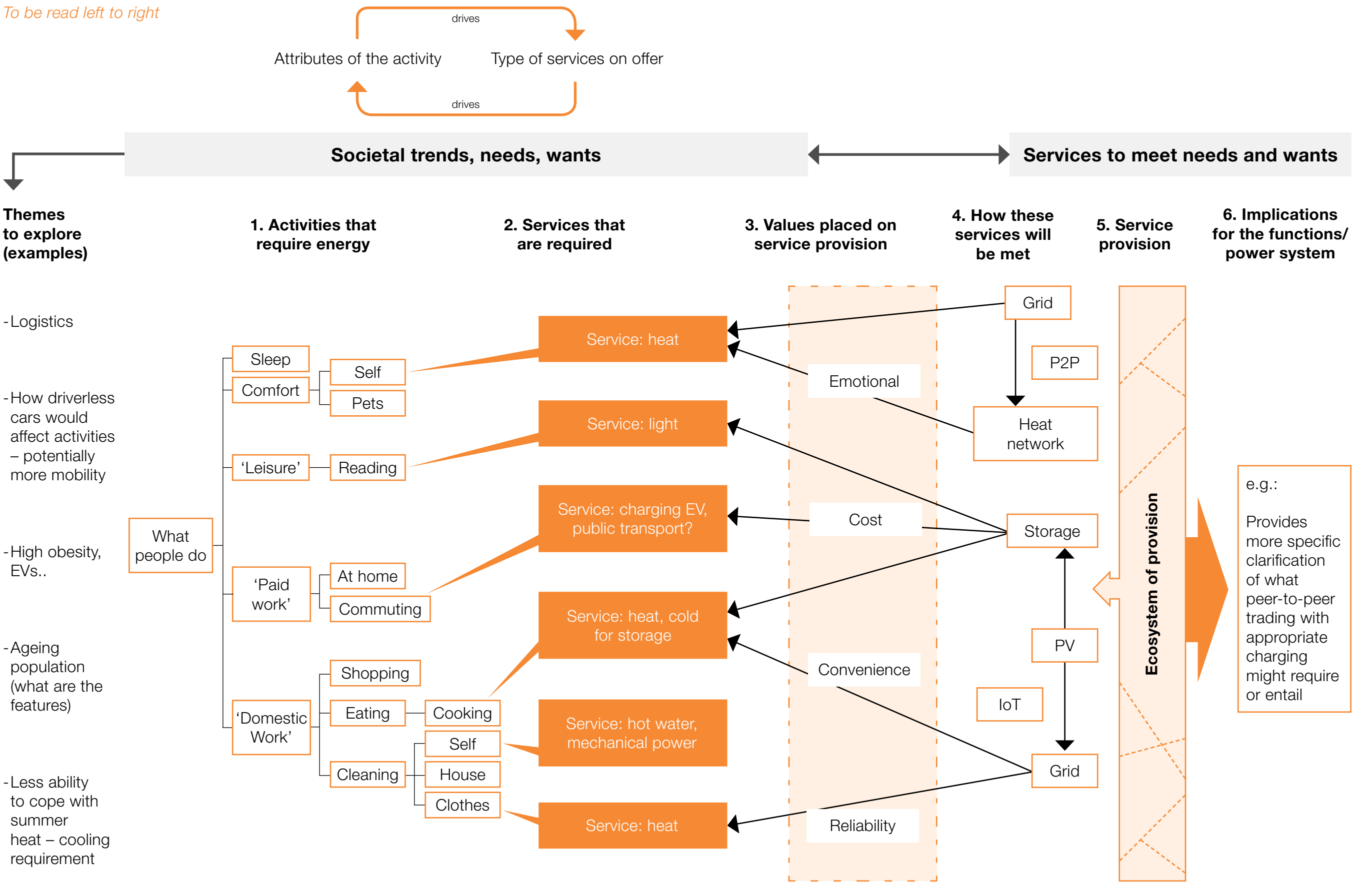
In order to focus the research, three themes or horizontals were selected. The choice of these horizontals was influenced by consultation with interviewees, the project team and the Steering Group, and focused on those horizontals that could result in the most significant change for the system. Following the research across each of the horizontals separately, we considered the impact on the power system of a combination of the three horizontals (all of which are likely to happen, but at varying levels of penetration).

The three horizontals chosen were:

1. **Mobility** – due to the potential for large scale change and mass electrification of vehicles. Likely to be closer to 2030 before a significant volume of EVs are on the road.
2. **Heating and cooling** – due to the expectation of electrification of these energy services. This is slowly beginning to happen today, with potential for millions of heat pumps in the UK by 2030.

Figure 3: Example of using the model to map evidence

To be read left to right



3. **Connected and distributed energy** – due to the anticipated wide-scale deployment of distributed generation, the increased connectivity and 'smartness' of appliances, and the optimisation of generation and demand expected to occur at various levels in the power system. We are likely to see more rapid deployment of this during the 2020 – 2025 period (which could potentially be accelerated by the smart meter roll out).

For the third horizontal, the focus was on connected and distributed energy. This horizontal is more technology/business model led, with new technology and customer propositions driving a change in stakeholder behaviour and activities.

This horizontal is described as:

- A future where distributed energy assets are widespread and appliances are largely connected to the internet via the cloud (as well as potentially via smart meters).
- Data analytics is widely deployed and highly utilised, enabling for example appliances (or aggregators) to forecast their energy demand and flexibility.
- A 'web of energy' future where peer-to-peer trading and provision of flexibility (energy, capacity and power) across the electricity system is common.
- There has been a prosumer revolution where stakeholders – such as individuals, buildings, or communities - increasingly generate, store and manage energy on site, near site or virtually. In many cases, stakeholders will be generating more than their own requirements at certain times, supplying the excess energy back to the network/ trading it with other stakeholders in the local area.

In this future, we see the deployment of a range of new technologies and business models/services as illustrated in Table 1 below.

Table 1: Key technologies/enablers and business models that will be captured in the connected and distributed energy horizontal

Technologies/enablers	Business models/services
• Distributed generation (e.g. CHP, micro CHP, fuel cells, PV, engines, etc.). • Home/building energy management systems (HEMs/BEMS). • Storage. • Electric vehicles including vehicle to grid. • DSR/ToU tariffs. • Connectivity (appliances, smart homes, smart buildings). • Analytics and distributed intelligence.	• Peer-to-peer (P2P) trading. • Community based energy systems/microgrids. • Auto-switching. • Aggregation. • Independence. • Energy-as-a-service. • Optimisation at various levels in the power system (at building, local, DSO levels for example).

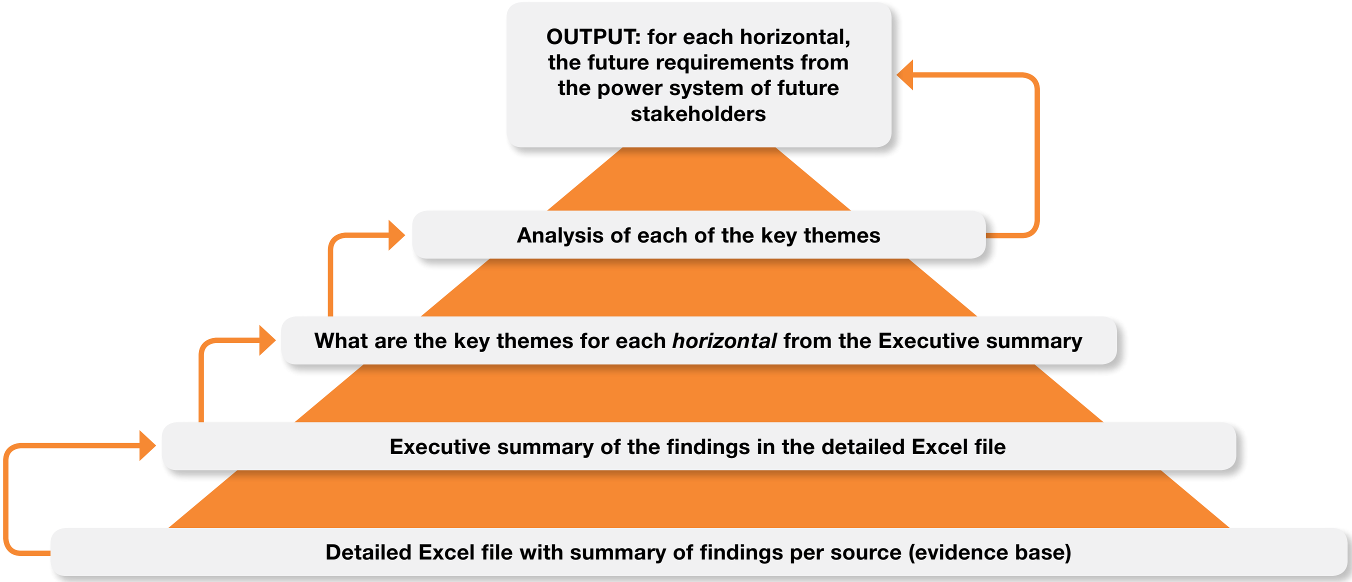
Gathering evidence

For each of the horizontals considered, a wide range of studies that analysed behavioural and societal changes/trends around each horizontal, or that assessed the future evolution of each horizontal were considered. This was supplemented with interviews with researchers in the transport/mobility, heating and cooling, and connected/distributed energy fields, who also provided key research papers or recommendations for reading on specific topics.

The evidence from each source was mapped on to the model (outlined in Figures 2 and 3) by recording elements from each source that corresponded with each stage of the model under that stage's heading. From this evidence, the project team were able to spot trends running through both the individual stages and also throughout multiple stages of the model. From this, key trends for each horizontal were identified.

Once the key trends for each horizontal had been identified, the key stakeholders relevant to the trend were considered and their future power system requirements summarised. By considering who the stakeholders for each trend are, and their requirements in the future, we could draw conclusions on their potential requirements from the power system in the future and link this to the drivers and functions identified during FPSA1. This process is illustrated in Figure 4 below.

Figure 4: Process of reaching future requirements of future stakeholders from the evidence base for each horizontal



4. Key Findings on the Mobility Horizontal

4.1 The future requirements and future stakeholders arising from mobility

The future requirements of future stakeholders resulting from the evolution of mobility to 2030, that will impact the power system, can be grouped into the following key topics:

- High levels of flexibility and choice for recharging vehicles.
- New commercial arrangements are required for buying/packaging energy.
- Much greater data handling, processing, optimisation and connectivity.
- New types of energy suppliers or energy partnerships.

The key stakeholders driving these requirements, made up of existing and new stakeholders, are:

Traditional stakeholders	New types of stakeholders
	Public and private transport mode and network operators.
End users (domestic, commercial).	Smart cities and communities/local authorities.
Fleet operators/businesses.	Service providers (e.g. MaaS, car as a service, parking, couriers).
Energy companies.	Car manufacturers (including driverless cars).
Charging infrastructure manufacturers.	Battery manufacturers.
Service station operators.	Companies billing/charging for the use of infrastructure.
	Data service providers/AI developers.

Below, we flesh out the more specific requirements of the stakeholders above for each topic.

Topic 1: High levels of flexibility and choice for recharging vehicles

The future requirements of stakeholders (including end users, fleet operators, transport mode and network operators, smart cities and car manufacturers) related to this topic are:

1. Multiple forms of re-charging:
   a) In a variety of locations (depots, work, public, 'on-the-go'/overhead lines in cities or along public transport routes, motorway service stations, dedicated bays).
   b) Flexible (rapid, fast, slow, trickle, 'on-the-go', battery swap) – convenient for the customer, gives the customer freedom of choice.
   c) At various times – some coinciding with peak demand times.
2. High density (clusters) of charging infrastructure in urban areas (for car clubs/fleets).
3. High levels of reliability and availability for electrified public transport to avoid system congestion or failure of service. As a minimum, a certain level of redundancy and/or operation of a limited service under power outage needs to be planned for.
4. Recharging may map onto transport peaks (geography and time).

Topic 2: New commercial arrangements are required for buying/packaging energy

The future requirements of stakeholders (including end users, energy companies, service providers and companies billing for the use of charging infrastructure) related to this topic are:

1. New commercial arrangements for transport service providers such as paying for capacity (at certain times) rather than energy.
2. Billing and ID systems to enable easy payment for recharging vehicles and to enable seamless transition between various electrified transport modes.
3. The ability to buy packages of energy for fleet/car club operators and service providers.
4. The ability for energy suppliers to sell/package energy:
   a. Renewable or low carbon or local bundles of energy.
   b. Bundling energy by the kWh/by distance/for the year.
   c. Enabling vehicle to grid.

Topic 3: Much greater data handling, processing, optimisation and connectivity

The future requirements of stakeholders (including end users, service providers, charging point manufacturers, energy companies and companies billing for the use of charging infrastructure) related to this topic are:

1. Huge amounts of data and data processing is required, resulting in additional demand for power, which needs very high levels of reliability.
2. Centralised data management systems and data processing is needed to allow rapid optimisation/automation/charging of vehicles.
3. Highly reliable power supply to enable near continuous communications and data processing.
4. Optimisation of transport networks, energy generation and supply, vehicle recharging which will require mechanisms for managing lots of vehicles charging during peak times/in constrained areas of the network.
5. High levels of communication, data analytics, digital platforms – tying together online shopping data, vehicle availability data, GPS/transport routes, energy pricing, network/generation constraints.

Topic 4: New types of energy suppliers or energy partnerships

The future requirements of stakeholders (including car manufacturers and smart cities) related to this topic are:

1. Car manufacturers and energy companies may need to work closely together to develop service based offerings including transport and energy.
2. Car manufacturers likely to becoming energy suppliers/home energy service providers.
3. Cities need to be able to plan where charging points are based on areas of charging need.

4.2 Six key trends for how mobility will develop to 2030

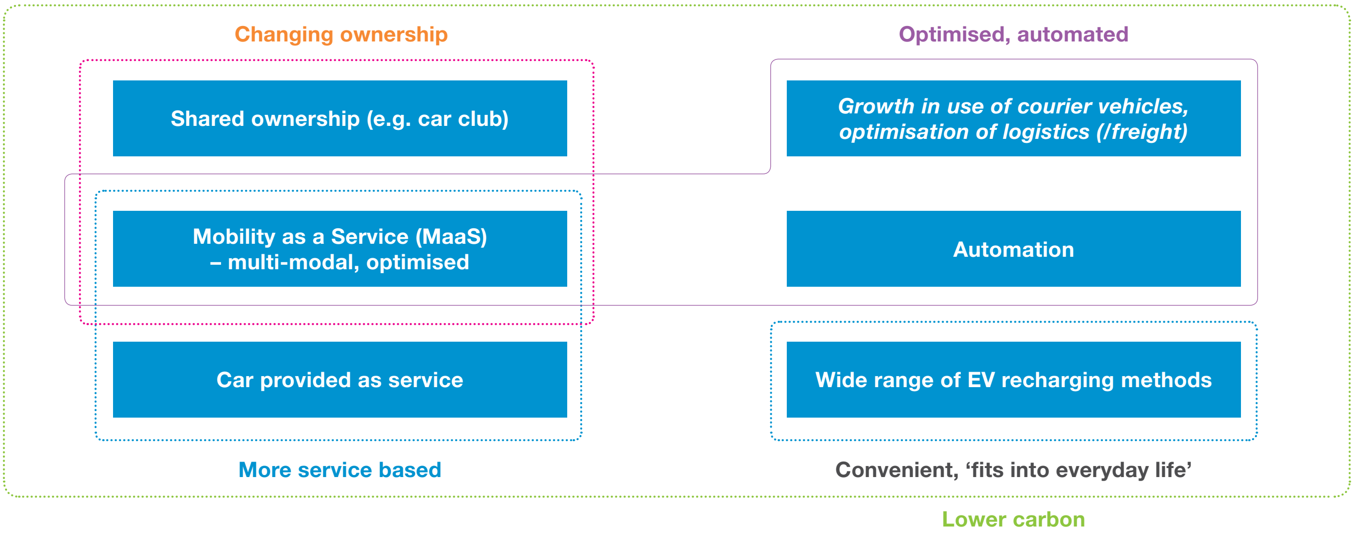
Having reviewed a wide range of existing studies and reports looking at future scenarios for transport, electrification of transport, behavioural/societal trends in transport and technology trials, six key trends for the future of transport – that could have implications for the power system – have been identified.

These trends (illustrated in Figure 5 below) are:

1. **Shared ownership** – a shift away from stakeholders owning individual vehicles towards more shared ownership models (e.g. car clubs) which could reduce the upfront cost hurdle of purchasing vehicles and accelerate the deployment of electric vehicles.
2. **Mobility as a service (MaaS)** – a much more service-based transport future where stakeholders pay for a highly convenient, efficient and optimised transport solution, rather than owning vehicles. This will involve much greater use of public transport and much more intermodal transport – a large proportion of which will likely be electrified.
3. **Car provided as a service** – a shift in the offerings by car manufacturers away from simply selling vehicles (a low margin business) towards more service orientated and customer centric options (e.g. a vehicle being sold along with a year's worth of low cost and flexible 'green' fuel). The vehicle is still owned by the stakeholder, but the vehicle sale is packaged with additional service offerings. Electric vehicles coupled with 'green miles' offerings will likely be a key offering from manufacturers in the future.
4. **Automation** – more driverless vehicles, greater automation of travel services/integration and optimisation of travel, including electric vehicles.
5. **Wide range of EV recharging options** – driven by the aspiration for low carbon/lower polluting travel. The range of stakeholders utilising electric transport, and the high level of convenience/flexibility that needs to be maintained (varied locations, speed, and method by which the range of transport modes are recharged) will require high volumes and varied methods of recharging.
6. **Growth in courier services and optimisation of logistics** – as stakeholders do more online shopping, demand for delivery services and delivery vehicles (many of which will increasingly be electric) will grow. This could result in stakeholders travelling less (e.g. doing less short trips to supermarkets), but they will still keep their own vehicle for other transport needs. This will likely result in more vehicles overall as courier vehicles are needed to transport the goods instead. Optimisation of logistics could see these delivery vehicles being used for multiple services (maximising use of the available transport capacity) and in some cases, potentially for transporting individual customers.

Figure 5: The key trends in mobility that could have an impact on the power system in the future

Mobility:



These specific trends are **based on evidence** gathered (extracts of which are summarised in Tables 2 and 3 below) that suggests stakeholders of transport want to see:

- Changes in ownership models of vehicles.
- More service based travel.
- Greater optimisation/automation.
- Less polluting and lower carbon options.
- The above changes occurring whilst fitting into ‘everyday life’.

4.3 Summary of the evidence behind one of the key trends for mobility

For one of the trends above, ‘Wide range of EV recharging methods’, we summarise some of the detailed evidence gathered from a range of sources that justifies this trend in Table 2 below.

Table 2: Linking evidence gathered on how mobility will evolve to one of the key trends

Key sources	Headline
‘Powering Electric Vehicles on England’s Roads’	Part of a programme of work aimed at demonstrating the viability of inductive charging on certain roads. Engaged a number of stakeholders to identify their views on EV and inductive ‘on-the-go’ charging - found that introducing inductive charging would increase the likelihood of having an EV as a main car.
Green Peace Energy Revolution Scenarios	Sees different charging strategies best suited to different applications, based on current trends/research/demonstration projects. In its scenarios, it views conductive quick charging (overhead for trams/buses as well as for trains and some HDV) being prevalent in day-to-day use for a range of public transport modes in urban centres (as advantageous over battery/FC vehicles in many respects), inductive charging (in road) particularly at turning points, and robotic battery swapping stations at strategic points.
‘Traveller Needs’, Transport System Catapult	Via interviews with 10k+ stakeholders, including experts and companies, identifies key requirements and value opportunities in mobility out to 2030. Finds that the key values for travellers are flexibility and convenience - flexibility in options for travel/charging is needed, travel and charging must be convenient – ‘on-the-go’, fast, slow charging, charging at home must all therefore be available.
‘Intelligent Infrastructures Scenarios’, Government Foresight project	Research looked into the psychology of travel and found that ease of use is a key factor in mobility mode uptake. New modes should fit in with everyday life. People tend to stick with habits, and so new modes (such as EVs) must not require dramatic changes to these habits. Also important is continuing to deliver choice.
‘Unplugged’, European Green Vehicles Initiative	Trailing prototypes of inductive charging – finds method has many attractive aspects such as increasing comfort, automates charging, and can be easy to use. Reports that such aspects increase customer acceptance and adoption of EVs. Can be deployed at various locations – at home, at work, taxi ranks, traffic lights etc., but in the short-term, expects the technology to be applied to specific cases such as taxi fleets – where there are slow moving vehicles for certain periods (i.e. in under taxi line).
Research article (Robinson et al.) – Analysis of EV driver recharging demand profiles	Study analysed the results from a large UK field trial of EVs, where the charging times of vehicles were unconstrained and vehicles could be charged at home or when parked away from home. Their results indicated EV users want significant at-home charging during peak times.
Kate Armitage, Route Monkey	Believes payment methods will not restrict users – will provide flexibility and ‘tap and go’ functionality. Downplayed hype for inductive charging – it’s very slowly progressing, but has the potential for some applications such as in parking spaces.
Harriet Bulkeley, Durham University	Research points to strong emphasis on routines in combination with available technologies shaping use of technology (such as EVs). Sees result of this as EVs often charged as soon as users get back from work, during peak hours. Identifies reliability/availability as a key requirement for EV owners. Charging options need to be available to meet this requirement.
Paul Zanelli, TRL	Sees that by 2030, battery technology will improve to the point that most charging will be done at home, overnight, and therefore unlikely that other methods (on-the-go/inductive charging) will come to dominate. Growing fleets of electrified service assets (e.g. buses) will possibly utilise different charging models (top-up charging at points along routes). Believes overhead conductive lines are more advantageous from a cost and efficiency perspective (plus being a tried and tested technology) for larger, shared vehicles.

Key ‘trends’
Mobility as a service
Shared ownership
Car as a service
Wide range of EV charging methods
Automation
Growth in ‘courier’ vehicles, optimisation of logistics

The evidence gathered from across the full range of sources considered in this project has been captured in an Excel 'infobase', which has been used to develop Table 3 below, which summarises some of the wider themes from across the full range of studies reviewed and conversations carried out on mobility.

Table 3: Summary of the key themes and direction of change in mobility from across the full range of sources considered

Societal Trends	Behaviour Practice Change	Services Required	Values	How these services will be met	Service provision/ business models
More metropolitan living. Growing demand and greater accessibility ('transport for all') vs virtualisation. Decarbonisation, low carbon/low pollution cities and urban areas (shift to electrification and H2). Transport system will become more connected and intelligent. Greater automation and optimisation. Ownership model will change (shared vehicles, offerings will change). 'Mobility as a service' – more public transport, multi-modal, optimised. New charging modes emerge and become widespread. Growth in online shopping/delivery.	Habits slow to change – 'good enough' journey is fine for most. 'Optimised' travel is attractive. 'Ease of access' (many modes, low cost, efficient) is key for transport mode choice. Majority of people open to sharing mobility data, a smaller but growing share open to sharing possessions. Openness to making more journeys virtually offset by desire to explore. Growing interest in autonomous vehicles (safety, optimised, convenience). Demand for connected, smart vehicles increasing.	New forms of car ownership/use offerings. Multi-modal networks. More low cost options. More low carbon/ low pollution options. Autonomous vehicles. EV charging. Data gathering and management, optimised travel.	Flexibility and convenience – fitting seamlessly into their lives. Comfort is valued highly. Cost, ease of use. Low noise/ pollution, ecological aspects. Some people will still attach notions of freedom and personal meaning to the way they travel.	Convenient, reliable and numerous charging methods (inductive 'on-the-go' charging, rapid). Localised smart grids that are highly connected in areas of high EV usage. Data processing and management centres. Intelligent and connected transport systems (many modes) – open sharing of data. New vehicles/ mobility modes, e.g. autonomous taxis, dynamically routed buses, self-drive cars. Managed EV charging to prevent curtailment of renewables/reduce stresses on the distribution network.	Build customer buy-in via integrated services across energy and transport e.g. car plus miles packages, 'car as a service', 'heat and miles' package. Dynamic pricing that responds to new charging methods/new peaks. Access to renewable generation/bundled energy packages (e.g. one year of 'renewable' miles). Tariffs or membership fees to use 'vehicles as a service'/car club vs full cost of ownership. New ownership models, new automotive offerings. Ticketing, booking and scheduling all integrated across transport modes. Personalised rapid transit systems, customer ID devices send signals to 'swarming' shared transport (multi-modal)/ dynamically scheduled transport. Models that enable multi-purposing (e.g. delivery service with public transport) of mobility assets. V2G offered as way of reducing cost (via using electricity from EV during times of high electricity prices). Public and private sectors working together – shift ownership to private shared-mobility providers.

The full list of research sources and contacts consulted for understanding how mobility will develop to 2030 is summarised below in Tables 4 and 5.

Table 4: List of secondary sources used and the research focus for the mobility horizontal

Source	Focus
UK Government	Foresight Project – Intelligent Infrastructure Scenarios.
UKERC	Scenarios for the development of smart grids (transport focus).
TSC	Traveller Needs Study and Technology Strategy – Future needs and Mobility as a Service (MAS).
Greenpeace	[R]evolution Scenarios (Transport Section).
European Green Vehicles Initiative	Trialled different modes of EV charging.
Highways England	Feasibility study for inductive charging in UK.
Mini E study	Assessing the acceptance of EVs in everyday use.
NREL	Analysis of grid impact of ‘on-the-go’ charging.
Innovation Portal	Analysis of competing and co-existing business models for EVs.
My Electric Avenue	Looked at ways of managing local networks during peak EV charge periods.
Nissan and ENEL	Trial of V2G in UK.
Academic papers	A review of the impact and prospects of EV tech, including V2G.
Academic papers	Looking at the potential of peer-to-peer trading between EVs.
BNEF/McKinsey	Examines different potential service mobility futures.
IEA	Potential acceptance of MAS – BMs and customer attitudes.
Frost & Sullivan	Development of MAS BMs.
Academic paper	Utilisation of EVs to allow for further renewables generation.
UCL/Dept for Transport	https://www.ucl.ac.uk/bartlett/energy/sites/bartlett/files/maas.pdf
Travel Spirit	www.travelspirit.io
EUTravel	http://www.eutravelproject.eu https://europa.eu/european-union/topics/transport_en
Sunset	http://sunset-project.eu

Table 5: Primary research/interviews conducted for the mobility horizontal

Interviewee	Organisation
Jillian Anable	University of Leeds – Institute for Transport Studies
Kate Armitage	EDF Energy (EVs)/Route Monkey
Adam Cooper	UCL
Harriet Bulkeley	Durham
David Shipworth	UCL
Paul Zanelli	TRL
Liam Lidstone	ETI

4.4 Detailing the future stakeholders and their future requirements for each key trend

By analysing each of the trends in Figure 5 separately (considering the future stakeholders that will drive the trend), we can summarise the future stakeholder requirements of the power system. In Tables 6 to 11 below, the future stakeholders associated with the six trends identified for mobility and their future power system requirements are summarised.

Table 6: Future stakeholders and their future requirements resulting from 'Mobility as a service'

Who are the future stakeholders?	What are their future requirements?
Individual travellers using the service. (Public and private) Transport mode operators. MAS network/digital interface operators. Smart cities and communities.	1. Use of large quantities of data, with the capacity to store and process such data streams. 2. Where transport is electrified, power will need to have high levels of reliability and availability to avoid system congestion or failure of service. As a minimum, a certain level of redundancy and/or operation of a limited service (and emergency operation e.g. emergency lighting) under power outage needs to be planned for. 3. More 'on-the-go' (inductive) charging in cities/roads along which public transport travels. 4. Recharging may map onto transport peaks (geography and time). 5. New commercial arrangements for transport service providers – paying for capacity (at certain times)/power/energy. 6. Billing and ID systems to enable seamless and smooth transition between transport modes for end users.

Table 7: Future stakeholders and their future requirements resulting from a growth in 'Shared ownership'

Who are the future stakeholders?	What are their future requirements?
Fleet operators/businesses – fleets of 'shared' vehicles rather than individual company cars. Car manufacturers. Cities/communities – green, low emission transport, reduced congestion. Consumers – wanting access to vehicles, shared ownership. Energy companies (access to green energy, billing, bundles of energy for 'green' miles/'green' car clubs).	1. High density (clusters) of charging infrastructure in urban areas (for car clubs/fleets). 2. Multiple forms of recharging: a) In a variety of locations (work (fleets), public, at dedicated bays). b) More fast charge (due to high utilisation rates of cars) and charging 'on-the-go' (inductive). 3. Link to renewable energy, 'bundles' of 'green' energy. 4. Buy packages of energy for fleet/car club operators. Charging for energy use (different distribution networks may be used). 5. Car manufacturers and energy companies working closely together.

Table 8: Future stakeholders and their future requirements resulting from more ‘Car as a service’ offerings developing in the future

Who are the future stakeholders?	What are their future requirements?
Car manufacturers. Car service providers. Individuals buying car services. Energy suppliers. Companies charging for the use of infrastructure.	1. Multiple forms of recharging: a) In a variety of locations (home, work, public, ‘on-the-go’). b) Flexible (fast, slow, trickle) – convenient for the customer, gives the customer freedom of choice. 2. The ability to sell/package energy: a) Access to low carbon/local energy. b) Bundled by the kWh/by the mile/for the year. 3. Manage charging cost through flexible demand and V2G. 4. Various locations for charging. 5. Car manufacturers and energy companies working together. 6. Car manufacturers becoming energy suppliers/home energy service providers (e.g. Mercedes is investing in battery manufacturing and selling branded home energy storage systems; Nissan getting into battery manufacturing; BMW partly owns Solarwatt (battery company) which is supplying batteries to E.ON).

Table 9: Future stakeholders and their future requirements resulting from a ‘Wide range of EV charging methods’ developing in the future

Who are the future stakeholders?	What are their future requirements?
Consumers using EVs. Charging infrastructure manufacturers. EV/battery manufacturers. City/Local authority (planning departments). Transport mode operators. Transport network operators. Retail/commercial company parking areas. Service stations.	1. Multiple forms of recharging: a) In a variety of locations (home, work, public, ‘on-the-go’/overhead lines). b) Flexible (fast, slow, trickle) – convenient for the customer, gives the customer freedom of choice. 2. Reliable/available when needed (implication - mechanism for managing lots of vehicles charging during peak times/in constrained areas of the network). 3. Seamless billing/payment mechanism that allows easy charging. 4. City/LA to be able to plan where charging points are based on areas of charging requirements. 5. Faster charging at home. 6. Vehicle to grid.

Table 10: Future stakeholders and their future requirements resulting from 'Automation' developing in the future

Who are the future stakeholders?	**What are their future requirements?**
Car manufacturers of driverless cars. AI developers. Data service providers. Safety regulator. Consumers – owning or using the vehicles.	1. Safe, secure system of transport. 2. Centralised data control/management system/high level of data processing to allow rapid optimisation/automation/charging. 3. Highly reliable internet/power supply, to enable near continuous communications and data processing. 4. Optimisation of transport networks/vehicle recharging. 5. More sophisticated/larger system of navigational tools/satellites. 6. Main need – digital platforms/GPS/automated systems - power needs to be uninterruptable as otherwise system falls apart.

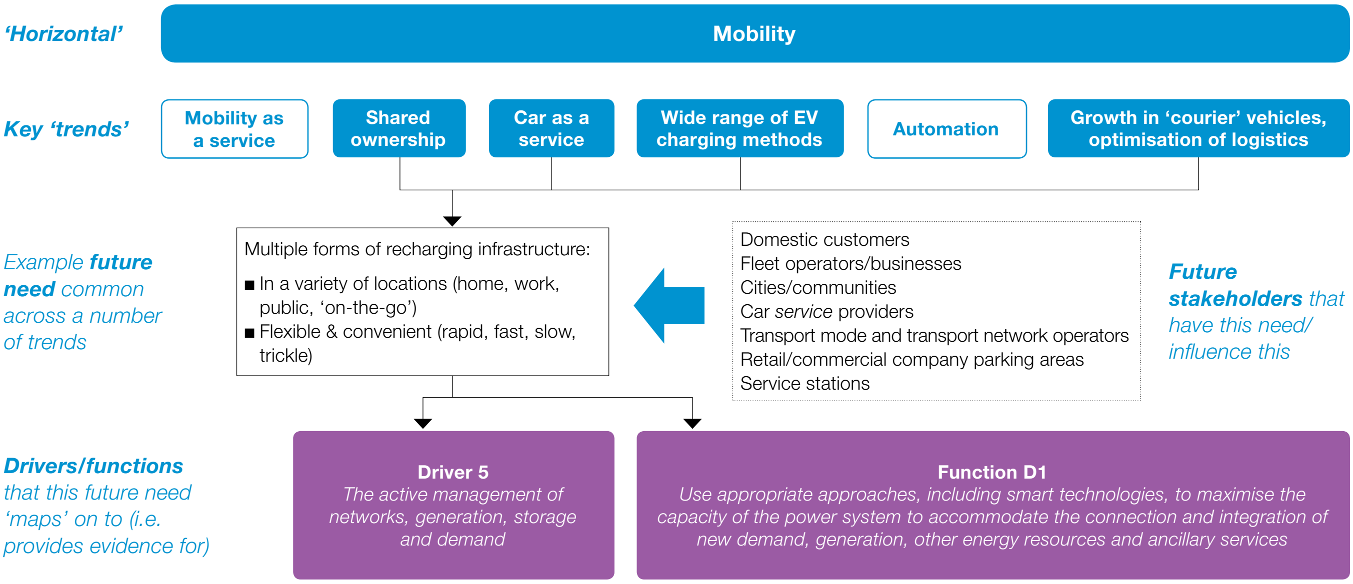
Table 11: Future stakeholders and the future requirements resulting from a 'Growth in 'courier' vehicles, optimisation of logistics (/freight)'

Who are the future stakeholders?	**What are their future requirements?**
Logistics/courier services/online shopping companies. Fleet operators/businesses. Car manufacturers. Consumers. Energy companies.	1. High levels of communication and data analytics – tying together online shopping data, vehicle availability data, GPS/transport routes. 2. Multiple forms of recharging: a) In a variety of locations (depots, work, public, 'on-the-go'/overhead lines, motorway service stations). b) Flexible – rapid charging, slow charging.

4.5 Linking future requirements to the drivers and functions of the future power system

Across these key trends for transport/mobility there are similar and overlapping future requirements from across the various future stakeholders. In Figure 6 below, we illustrate how one of the future requirements that is common to a number of the trends links to the drivers and functions required by the future power system as being reviewed and refined in FPSA2 by WP2. The linking of the future requirements of stakeholders identified in WP1B to the drivers and functions of the power system has been agreed upon via dialogue and meetings between WP1B and WP2 (with review and input from other WPs).

Figure 6: Linking the trends identified in mobility to the drivers and functions for the future power system identified in FPSA1



Multiple forms of recharging infrastructure:

- In a variety of locations (home, work, public, 'on-the-go')
- Flexible & convenient (rapid, fast, slow, trickle)

Domestic customers
Fleet operators/businesses
Cities/communities
Car *service* providers
Transport mode and transport network operators
Retail/commercial company parking areas
Service stations

Driver 5
The active management of networks, generation, storage and demand

Function D1
Use appropriate approaches, including smart technologies, to maximise the capacity of the power system to accommodate the connection and integration of new demand, generation, other energy resources and ancillary services

In Table 12, we illustrate a selected number of the future requirements identified via the research on the mobility horizontal, and via discussion with WP2, have linked these to the drivers and functions being reviewed and refined by WP2 in FPSA2. All the requirements found by WP1B on the mobility horizontal provide further evidence for the *thirty-five* functions in FPSA2.

4.6 Conclusion on mobility and its implications for the power system

The research and analysis carried out on the future evolution of mobility in WP1B has generated a significant evidence base for the future requirements of future stakeholders, summarised above. Each of the requirements identified can be linked to the drivers and functions in FPSA2, providing further evidence for the drivers and functions that have been reviewed by WP2 during FPSA2, and for which WP4 is developing *Enabling Frameworks* for future implementation.

Table 12: Linking a number of the requirements identified to a range of drivers and functions

Future need	Drivers	Function(s)
Multiple forms of recharging in a variety of locations.	5	D1
Highly reliable internet/power supply, to enable near continuous communications and data processing.	5	D1
Seamless billing/payment mechanism that allows easy charging.	3, 4	B5, H6
The ability to sell/package energy: Access to low carbon/local energy; Bundled by the kWh/by the mile/for the year.	3, 4	H5, H6, C7
High density (clusters) of charging infrastructure in urban areas (for car clubs/ fleets).	5	D1
Ability (of cities/LAs) to plan where charging points are based on areas of charging need.	3, 4, 5	C1, D1, B2, B3, H3

Below, we summarise the key headlines for how mobility may develop to 2030 based on the evidence gathered, and the potential implications this could have for the power system.

- By 2030, electrification of transport modes will become commonplace, entailing significant new load on the system. At what point electric vehicles are prevalent and to what extent they penetrate the mobility market by 2030 is less certain.
- Private vehicle ownership will still dominate by 2030, but we will see lots more service based offerings (e.g. MaaS, car as a service) and shared vehicle models which could accelerate the deployment of electric vehicles and influence the recharging methods needed.
- Different stakeholders will require flexibility in the choice of transport options and recharging methods, meaning the location, timing, and sizing of new loads on the network (in potentially constrained parts of the network) will be difficult to predict. Most charging will occur at home during peak times, but we will see fast/rapid charging, inductive 'on-the-go' charging (particularly in city centres/along transport routes), overhead conductive charging and possibly battery swapping all emerging as options suiting different vehicle types and contexts.
- Automation, connectivity, optimisation (of transport and charging) and the introduction of new models of mobility presents big challenges for the power system as it may have little or no control over the timing of new demand which could require significant new capacity. V2G and influencing the timing of charging via financial incentives etc. may be required in order to manage this new load.
- New players in the energy space include car manufacturers and mobility service providers, leading the transition to shared, service based offerings.

5. Key findings on the heating and cooling horizontal

5.1 The future requirements and future stakeholders arising from heating and cooling

The future requirements of future stakeholders resulting from the evolution of heating and cooling to 2030 that will impact the power system can be grouped into the following key topics:

- Increased control, optimisation and automation of heating and cooling systems to maintain (or exceed) current comfort and convenience levels.
- Increased flexibility to access other value streams and utilise thermal storage.
- New types of commercial arrangements, value chain integration, and heat or service based offerings.
- Increased utilisation of low carbon heat and cold, at lower cost.

The key stakeholders driving these requirements, made up of existing and new stakeholders, are:

Traditional stakeholders	New types of stakeholders
End users (domestic, commercial, industrial).	Smart cities and communities/local authorities, especially where ‘heat islands’ are likely to occur.
Energy companies (across all vectors).	Service providers (HaaS/ESCo).
Heating appliance manufacturers.	Controls/BEMS companies.
District heating (and cooling) companies.	Thermal storage developers/manufacturers.
Heating/cooling appliance installers.	Thermal storage operators offering demand response services.
Maintenance companies.	Companies providing the conversion and transport of energy vectors.
	Service providers offering optimisation of heating/cooling and monitoring services.

Below, we flesh out the more specific requirements of the stakeholders above for each topic.

Topic 1: Increased control, optimisation and automation of heating and cooling systems to maintain (or exceed) current comfort and convenience levels

The future requirements from stakeholders (including end users, appliance manufacturers, service providers and controls companies) related to this topic are:

1. Have access to heat instantly and to 'boost' heat output when necessary.
2. To access data and control heating systems in response to this data input.
3. Optimise energy used for heating/cooling by different stakeholders to minimise the impact on the system.
4. Allow high levels of connectivity and control of heating/cooling appliances and across multiple systems.
5. More controllable loads to enable transition towards 24/7 renewable generation.
6. Maintain comfort levels even on the coldest days of the year and as temperatures (particularly in urban centres) increase.

Topic 2: Increased flexibility to access other value streams and utilise thermal storage

The future requirements from stakeholders (including service providers, thermal storage manufacturers and operators, energy companies) related to this topic are:

1. Access to ToU, off-peak tariffs, financial incentives, value mechanisms for both the customer and the supplier/service provider.
2. Flexibly charge thermal storage to make full use of incentives.
3. Have the physical infrastructure available to facilitate the smooth conversion between different energy vectors.
4. The ability to store and transport large quantities of intermittent energy supplied in the form of heat or cold.
5. Time heat/cold generation to coincide with availability of renewable generation, and if this generation is not available, use thermally stored energy generated from renewable sources.

Topic 3: New types of commercial arrangements, value chain integration, and heat as a service based offering

The future requirements from stakeholders (including end users, appliance manufacturers, installers, maintenance companies, service providers and energy companies) related to this topic are:

1. Allow the buying of energy in different ways, e.g. buying grid capacity.
2. The ability to buy alternatives to units of energy, from suppliers offering multiple services.
3. Commercial arrangements in place to incentivise control/management of numerous heating systems.
4. Engagement and communication between many heating/cooling commercial actors, sometimes cross vector.
5. The ability to increasingly deploy waste heat/cold recycling methods and capture the value from this.

Topic 4: Increased utilisation of low carbon heat/cold, at lower cost

The future requirements from stakeholders (including end users, appliance manufacturers, smart cities/ local authorities, service providers and energy companies) related to this topic are:

1. Cluster heat pumps, potentially in areas with high deployment of EVs.
2. Potentially higher capacity grid connections to the electricity network to enable a shift from gas boilers to electric heat pumps.
3. Access to bundles of renewable energy, perhaps linked directly to local generation.

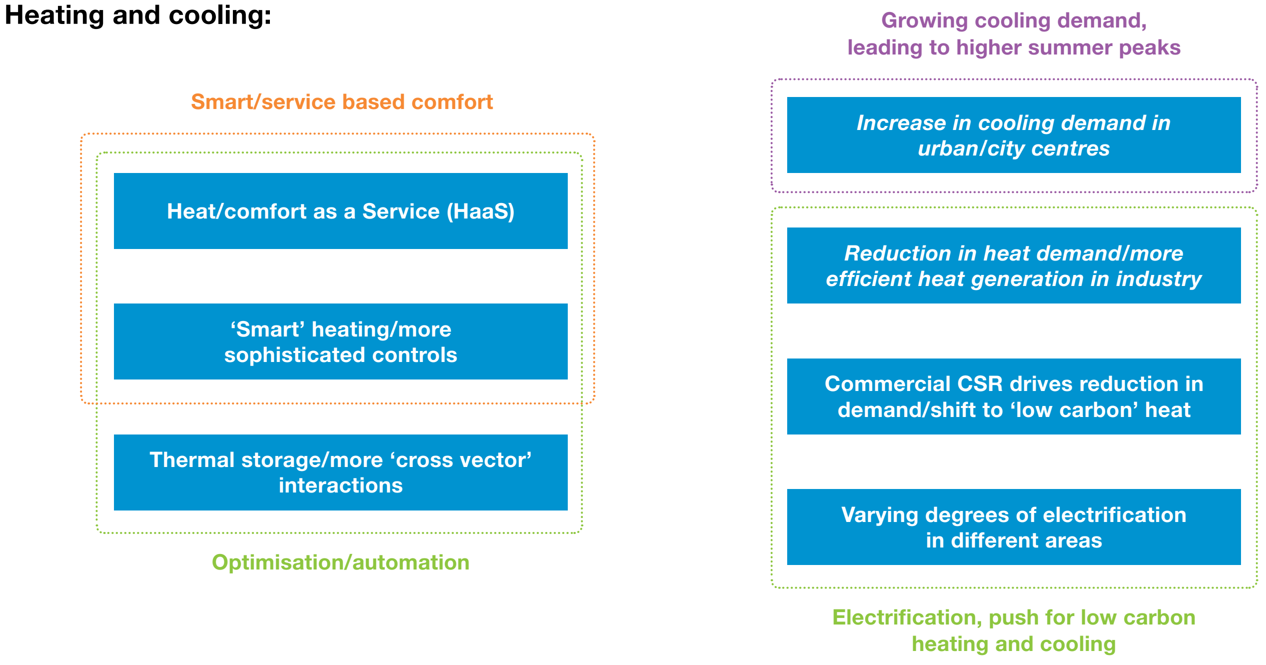
5.2 Seven key trends for how heating and cooling will develop to 2030

Having reviewed a range of existing research and studies looking at the 'future of heating/cooling', and having a number of conversations to add to this, we have identified seven key trends for how heating and cooling may develop in the future.

These trends (shown in Figure 7 below) are:

1. **Heat/comfort as a service (HaaS)** – this involves the provision of heat/cooling (or a certain level of comfort) to stakeholders rather than selling heating appliances and gas/electricity. Stakeholders pay for ‘units of comfort’ rather than units of commodity and this will usually involve a contract ensuring a level of comfort is provided at a lower (or fixed) cost than before. More common with commercial stakeholders today, likely to expand to cover domestic customers.
2. **Smart heating/more sophisticated controls** – to enable greater control of heating/cooling in buildings and increased comfort. Cost reduction is a minor driver for some stakeholders who place a greater value on comfort and control.
3. **Thermal storage/more cross vector interactions** – greater deployment of thermal storage technologies to store excess renewable electricity/low cost electricity as heat/cooling, enabling more load shifting to support the transmission and distribution networks.
4. **Increase in cooling demand, particularly in urban/city centres** – as average summer temperatures grow and ‘heat island’ effects in dense urban/city centre areas increase, driving the requirement for more cooling. Reversible heat pumps could also improve access to cooling, which could increase cooling use as a consequence.
5. **Reduction in heat demand/more efficient heat generation in industry** – driven by the desire to reduce ongoing operational costs via deploying more efficient electric heating appliances and better control/use of the heat being generated.
6. **Commercial corporate social responsibility (CSR) driving a reduction in demand/shift towards lower carbon heat** – as commercial companies increasingly look to be seen to be ‘doing their bit’ for the environment, sometimes driven by ‘league tables’ on CSR/energy performance. Reducing ongoing operational costs is also a key driver.
7. **Varying degrees of electrification of heat** – wide scale deployment of heat pumps (likely in off-gas, rural and suburban areas) with heat pumps supplying district heating networks in more densely populated areas/city centres.

Figure 7: The key trends in heating and cooling that could have an impact on the power system in the future



These specific trends are **based on evidence** gathered (extracts of which are summarised in Tables 13 and 14 below) that suggests stakeholders of heating and cooling want to see:

- More smart and service-based heating and cooling.
- Greater optimisation/controllability/convenience.
- More lower carbon and renewable heating/cooling options.
- Improved comfort/cooling in urban areas.

5.3 Summary of the evidence behind one of the key trends for heating and cooling

For one of the trends above, 'Smart' heating/more sophisticated controls', we summarise some of the detailed evidence gathered from a range of sources that justifies this trend in Table 13 below.

Table 13: Linking evidence gathered on how heating/cooling will evolve to one of the key trends

Key sources	Headline
Big push from industry	Energy companies and smart home companies are deploying a wide range of offerings enabling customers to have more control over their heating and awareness of energy bills. Examples include: Nest, Hive (British Gas), Connect (Scottish Power), Netatmo (EDF Energy), Tado (SSE).
Matthew Lipson and John Batterbee (ESC/ETI)	Research points to customers wanting more control over their heating system – with the ability to optimally use heat to suit their preferences. End-users can't do this with existing controls. Smart controls provide the best way of configuring multiple assets to achieve the optimal experience for the customer and cost for the supplier.
David Shipworth - UCL	Research indicates that user requirements of new heating systems is shaped by their experience of previous systems. Users will therefore expect their systems to have qualities such as the ability to provide instantaneous heat. This means that heat pumps alone may not be sufficient (more hybrid/better controlled systems will be needed). New HEM systems play about with internal temperatures to optimise heat use – may influence customer expected levels of comfort.
ETI – SSH Consumer Challenges for Low Carbon Heat	People involved in the trials for this study valued the additional functionality offered by smart heating controls. The use of low carbon heat solutions such as HPs required advanced controls to make it easier for consumers to get the experiences they want in their homes, and to meet requirements that are important to users – e.g. fit into everyday life and give instantaneous heat.
ETI – SSH Reference Library Documents	Connects together understanding of consumer requirements with the development of new technologies/ business models. Early evidence from study trials highlight the need to improve control within customers' homes. More sophisticated controls enable customers to take advantage of off-peak heat/cool and storage, and help people optimise/plan their heating.
Delta-ee Heat Pump Innovative Business Models Report	New business model offerings such as HaaS (considered a key element in overcoming some of the obstacles to HP uptake) require smart controls to enable the collection of customer data and to make use of off-peak tariffs thereby making these kinds of service models attractive for the supplier. Provides evidence for supplier push of these controls as part of heating service (as well as consumer 'pull').
Delta-ee Connected Homes Service	~400,000 smart heating controls/smart thermostats sold in the UK during 2010 – 2015. ~300,000 of which were in 2015. More than 1.5 million new sales anticipated by 2018. Again, evidence for supplier push/optimism for smart heating control uptake.

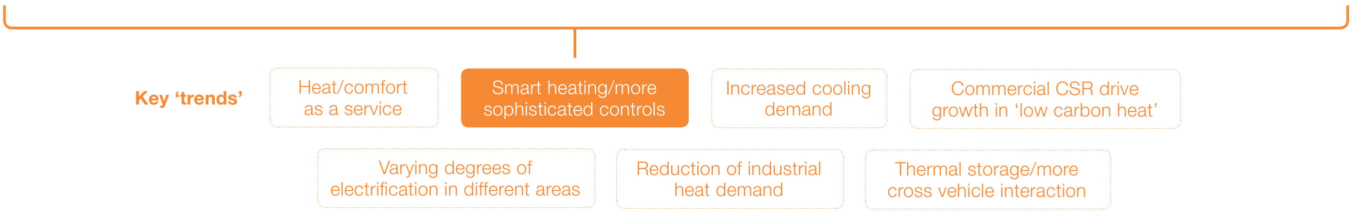


Table 14: Summary of the key themes and direction of change in heating/cooling from across the full range of sources considered

Societal Trends	Behaviour Practice Change	Services Required	Values	How these services will be met	Service provision/ business models
Household space heating demand decreases due to increased efficiency/ better insulation, but more appliances using more electricity overall. Electrification of heat – scenarios range from <25 – 80+%. Cooling demand increases – UK summers getting hotter, access to cooling improved from heat pump deployment. Heat islands (resulting from urbanisation/dense buildings in city centres, lots of AC pushing heat outside, heating up outside – feedback loop). Climate impacts are regional – generally mean temp rises more/sooner in south of England, followed by rest of UK (North Scotland warms last).	Poor customer understanding of options – operate on 'gut feel', lack the right info. to make behaviour change/decisions. Difficult to shift behaviour as wants and requirements shaped by experience of previous systems – instantaneous high temp. heat. Evidence for rebound effect to certain extent, but demand for higher internal temperatures also levelling off. Reduction in demand for process heat in industry (more off-shore activities). Commercial company activities become more influenced by CSR/ league tables. More activities become home-based e.g. increase in working from home, less retail/ more digital purchases.	Heating and cooling. Storing energy as cold/heat (rather than electricity), utilising intermittent, off-peak renewable electricity. Improved/ automated control that is optimised to comfort requirements.	Comfort – but the level to which this is important is unclear. Unless stakeholders are uncomfortable, interest in heat is low. Domestic consumer cares little about delivery options - just the experience heat affords. Control – want instantaneous heat/cold, and to feel that they are in control. Convenience – ease of use, easy installation. Cost. Some stakeholders value 'green' heat/cold. CSR.	Smart controls – more advanced control of supply of heat/cold. Choice of low carbon heating system driven by how best integrated into different housing site types – e.g. HPs for suburban/flats/well-insulated dwellings; DH (with CHP/HPs) for high density cities. Utilising different energy vectors to suit infrastructure/ requirements. Novel/proven thermal storage technologies giving more flexibility. More of a 'systems' approach to heating and cooling buildings involving multiple technologies. Recycling of waste heat. Commercial/industrial cooling – use 'waste cold' generated in re-gasification process of LNG vs electrical cooling. Innovative cooling systems in e.g datacentres. Reversible heat pumps (heating/ cooling). Increased demand and regulation for lower carbon heat sources. Increased electrification of heat, but maybe not to previously anticipated levels.	Access to lower tariffs (cheaper heat) for a range of stakeholders, producing cold/heat in off-peak times. Supply of units of heat (rather than units of gas/ electricity). Heat cold as a service (supplying comfort). A more integrated heat/ cooling equipment supply chain to drive down installed costs of newer technologies. Integration between heat/ cooling and energy value chains to enable lower cost 'heat/cold as a service' provision.

The full list of research sources and contacts consulted for understanding how heating and cooling will develop to 2030 is summarised in Tables 15 and 16.

Table 15: List of secondary sources used and the research focus for the heating/cooling horizontal

Source	Focus
ETI/ESC	Smart Systems and Heat findings (including consumer behaviour study).
UK Government	The Future of Heating: Meeting the Challenge/Strategic Framework.
Birmingham Energy Institute	Doing Cold Smarter – system level analysis of the developing ‘cold economy’.
Element energy	Future of decarbonising heat in buildings.
Academic research papers	On topics such as: Integrated heat and electricity systems/Smart heating/testing integrated domestic heating strategies for future UK housing/Variations in winter indoor temp/Driving factors for occupant-controlled space heating/Implications of heat electrification on UK supply-demand balance/Uncertainties in decarbonising UK heat/Understanding occupant heating practices in UK dwellings.
Imperial/ICEPT Discussion papers	UK 2030 low carbon scenarios (focus on heat section). Managing Heat System Decarbonisation.
UKERC	The future role of thermal energy storage in the UK energy system.
WIRES Energy Environ 2016	Industrial energy use and carbon emissions reduction: a UK perspective.
Delta-ee	Heating innovative business model research to be published under the Heat Pump Research Service and Business Model Research Service.
National Grid	UK Future Energy Scenarios.
WWF	Outlook for space/water heating in buildings.
Carbon Trust	Refrigeration roadmap.
Carbon Connect report	Analysis of multiple future pathways for low carbon heat in residential buildings.
UK Government	Overview of projected climate forecasts.

Table 16: Primary research/interviews conducted for the heating/cooling horizontal

Interviewee	Organisation
David Shipworth	UCL
John Batterbee	ETI/Energy Systems Catapult
Matthew Lipson	ETI/Energy Systems Catapult
Keith MacLean	UKERC
Lukas Bergmann, Steven Ashurst	Internal experts on heat at Delta-ee

5.4 Detailing the future stakeholders and their future requirements for each key trend

By analysing each of the trends in Figure 7 separately (considering the future stakeholders that will drive the trend), we can summarise the future stakeholder requirements of the power system. In Tables 17 to 23 below, the future stakeholders associated with the seven trends identified for heating/cooling and their future power system requirements are summarised.

Table 17: Future stakeholders and their future requirements resulting from ‘Heat/comfort as a Service’

Who are the future stakeholders?	What are their future requirements?
Residential customers Commercial/industrial customers Heating appliance manufacturers Energy companies HaaS companies/ESCo District heating companies Finance companies Heating equipment installers and maintenance/service providers Controls/optimisation/monitoring companies	1. To have the same/increased levels of comfort, at the lowest possible cost (either at lower cost, or the same as current cost). 2. The ability to ‘boost’ the heat output when necessary/access to lots of power when demand for heat is high. 3. Renewable or lower carbon heat – bundles of ‘green’ heat, perhaps linked directly to renewables/localised generation. 4. Greater integration of the heat value chain to enable cost reductions and delivery of low cost comfort to stakeholders. Boilers companies and energy companies working together? 5. To integrate smart devices/controls into the system to take full advantage of the flexibility of heating system operation – e.g. shift load to low energy price periods, gain value from DSR services, requires constant monitoring of heat demand profiles, etc. 6. Access to ToU tariffs, off-peak tariffs, management of thermal storage – full flexibility. 7. For suppliers, access to this data, the ability to control HP/DH heating system network in response to this data. 8. For ESCo/service companies providing comfort to a wide range of stakeholders in certain locations (e.g. urban areas), new commercial arrangements allowing them to buy energy/grid capacity in different ways.

Table 18: Future stakeholders and their future requirements resulting from ‘Smart heat/controls’

Who are the future stakeholders?	What are their future requirements?
Residential customers Commercial/industrial customers Network companies Heating equipment installers and maintenance/service providers Controls/BEMS companies ESCOs	1. Better visibility of heating/cooling use and of expected energy bills – improved connectivity, more data/IHD, metering will likely be required. Perhaps buying degrees centigrade of comfort rather than units of energy. 2. Automated/improved operation of heating and cooling systems. 3. Optimising self-sufficiency through trying to optimise energy used for heating with local (or onsite) supply of renewable energy. 4. Lower energy bills (via smart control, or access to ToU/off-peak tariffs dependent on customer preference). 5. More control of heat, increased comfort and convenience – easy to control, remote turn off/on. 6. The ability to access a ‘portfolio’ of appliances (or controls systems) and influence operation/control via digital platforms connected to the grid to shift demand (and possible reduce overall demand). 7. Commercial arrangements to incentivise the control/management of numerous heating systems.

Table 19: Future stakeholders and their future requirements resulting from a growth in ‘thermal storage/more cross vector interactions’

Who are the future stakeholders?	What are their future requirements?
Thermal storage developers/manufacturers Thermal storage operators (potentially new stakeholders)/demand response type companies Energy companies (across energy vectors) Heating/cooling service providers District heating (and cooling) companies Network operators (utilising the technology for balancing their network) Companies providing the conversion and transport of energy vectors Industrial customers	1. Wide scale deployment of thermal storage systems at various locations on the network (likely at the higher capacity levels), potentially located near to high heating/cooling demand areas. 2. The ability to flexibly charge the thermal stores, time of use tariffs. 3. Financial incentives/value mechanisms that can be accessed by service providers for shifting cooling/heating demand, for example in a hybrid system between a gas boiler and electric heat pump. 4. High levels of connectivity and controllable heating/cooling appliances at commercial and residential sites that can be integrated/operated as part of a ‘smart heat/cooling’ network. 5. Engagement and communication between energy companies (including cross vector), network operators, aggregators, smart heating appliance manufacturers, heat suppliers – to ensure this all works seamlessly (and have the regulatory environment to support this). 6. Having the right physical infrastructure available in order to facilitate smooth conversion between energy vectors (such as LNG -> liquid air). 7. Ability to transport and store large quantities of intermittent energy supplied by renewables in the form of heat or cold.

Table 20: Future stakeholders and their future requirements resulting from a growth in ‘cooling demand’

Who are the future stakeholders?	What are their future requirements?
Smart city/urban area (planners) – where ‘heat islands’ are likely to occur Commercial stakeholders Residential customers Cooling technology developers	1. Increased cooling demand in built up/urban areas, where demand is already high (due to lighting, cooling IT), and where summer peaks are already an issue. 2. Increased comfort as average summer temperatures increase, and access to cooling (via reversible heat pumps) improves (could drive growth in electricity demand in remote/rural areas, with more continuous load during the day). 3. Capturing the ‘waste cold’ at re-liquification of NG sites - more utilisation of cooling technologies that do not produce heat as a by-product, such as exploiting forms of waste cold. 4. Deploying waste heat recycling to produce cooling, for example via absorption chiller.

Table 21: Future stakeholders and their future requirements resulting from ‘Commercial CSR driving a reduction in demand/shift towards lower carbon heat’

Who are the future stakeholders?	What are their future requirements?
Commercial stakeholders Electric heating/heat pump manufacturers Energy companies District Heating operators Thermal storage operators (potentially new stakeholders)/demand response type companies	1. Lower carbon heating technologies, at lower cost. 2. Potentially higher capacity grid connections to the electricity network to enable a shift from gas boilers for heating to electric heat pumps, fed by renewable electricity. 3. Access to bundles of renewable energy, linked to local or renewable energy generation. 4. More controllable loads to enable a transition towards 24/7 renewable operation – i.e. time the operation of heat/cooling generation to the times when renewable (or excess renewable) generation is available. 5. When this generation is not available, to use thermally stored energy generated from renewable sources to meet cooling/heating demand.

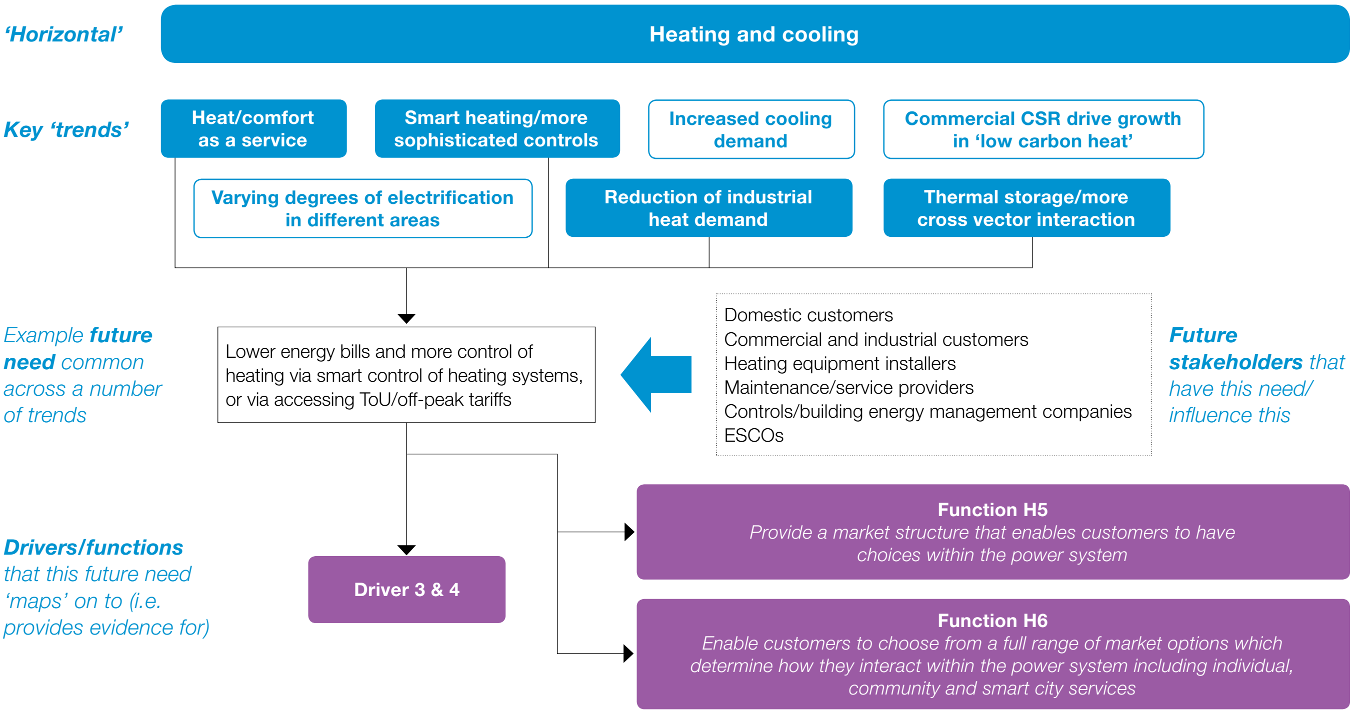
Table 22: Future stakeholders and their future requirements resulting from a ‘reduction in heat demand/more efficient heat generation in industry’

Who are the future stakeholders?	What are their future requirements?
Industrial stakeholders Electric heating/heat pump manufacturers Energy companies DH operators Thermal storage operators (potentially new stakeholders)/demand response type companies	1. Lower carbon heating technologies, at lower cost. 2. Potentially higher capacity grid connections to the electricity network to enable a shift from gas boilers for heating to electric heat pumps, fed by renewable electricity. 3. Ability to deploy or invest in large scale renewable farms (PV, wind) to offset carbon emissions. 4. Use of electric heating to meet high temperature process heating requirements using novel technologies such as high temperature heat pumps.

Table 23: Future stakeholders and their future requirements resulting from ‘varying degrees of electrification of heat’

Who are the future stakeholders?	What are their future requirements?
Commercial stakeholders Industrial stakeholders Residential customers Electric heating/heat pump manufacturers Energy network companies Community/town/city planners (to develop coherent strategies for electric heating deployment) District heating companies Government Installers/maintenance of heat pumps	1. Flexibility in (or regulated choice of) heating system choices in various locations. a. Energy distribution vector for full electric heating/partial electric heating with gas to meet peaks/gas heating/heat networks. b. Above choices may be regulated, for example by dense urban areas, suburban areas, rural, commercial sites. 2. Ability for electric heating to provide enough heat on the coldest days of the year – system needs to be designed for a 1 in 20 winter peak. This could result in significant amounts of additional generation plant and capacity in the transmission and distribution networks that is only utilised on the coldest day of the year (significant amount of investment and redundancy in the system). 3. Clustering of heat pumps, potentially in areas with high deployment of EVs. 4. Co-ordination between network operators, district heating companies, city/town planners, housing developers to minimise the disruption to stakeholders and to ‘plan’ for a particular energy vector to meet heating requirements in a particular geographic area. 5. More control/connectivity to manage electric heating for different types of stakeholders and to minimise impact on the upstream electricity system.

Figure 8: Linking the trends identified in heating/cooling to the drivers and functions for the future power system identified in FPSA1



5.5 Linking future requirements to the drivers and functions of the future power system

Across these key trends for heating and cooling, there are similar and overlapping future requirements from across the various future stakeholders. In Figure 8 above, we illustrate how one of the future requirements that is common to a number of the trends links to the drivers and functions required by the future power system as being reviewed and refined in FPSA2 by WP2. The linking of the future requirements of stakeholders identified in WP1B to the drivers and functions of the power system has been agreed upon via dialogue and meetings between WP1B and WP2 (with review and input from other WPs).

In Table 24, we illustrate a selected number of the future requirements identified via the research on the heating and cooling horizontal, and via discussion with WP2, have linked these to the drivers and functions being reviewed and refined by WP2 in FPSA2. All the requirements found by WP1B on the heating and cooling horizontal provide further evidence for the *thirty-five* functions in FPSA2.

Table 24: Linking a number of the requirements identified to a range of drivers and functions

Future requirement	Drivers	Functions
Lower energy bills (via smart control, or access to ToU/off-peak tariffs dependent on customer preference).	3, 4	H5, H6
Clustering of heat pumps, potentially in areas with high deployment of EVs.	5	D1
Potentially higher capacity grid connections to the electricity network to enable a shift from gas boilers for heating to electric heat pumps, fed by renewable electricity.	5	D1
Access to bundles of renewable energy, linked to local or renewable energy generation.	3, 4	H5, H6
Better visibility of heating/cooling use and of expected energy bills – improved connectivity, more data/IHD, metering will likely be required.	3, 4	E8, H5, H6
Commercial arrangements to incentivise the control/management of numerous heating systems.	3, 4	H1, H2
Optimising self-sufficiency through trying to optimise energy used for heating with local (or onsite) supply of renewable energy.	3, 4	H4, H5, H6

5.6 Conclusion on heating and cooling and its implications for the power system

The research and analysis carried out on the future evolution of heating and cooling in WP1B has generated a significant evidence base for the future requirements of future stakeholders, summarised above. Each of the requirements identified can be linked to the drivers and functions in FPSA2, providing further evidence for the drivers and functions that have been reviewed by WP2 during FPSA2, and for which WP4 is developing *Enabling Frameworks* for future implementation.

Below, we summarise the key headlines for how heating and cooling may develop to 2030 based on the evidence gathered, and the potential implications this could have for the power system.

- By 2030, we expect to see significant deployment of electric heat pumps and hybrid heat pumps in residential, commercial and industrial applications, and a growth in cooling demand, all of which will drive significant new load on the power system.
- Wide scale deployment of smart heating controls and connected heating appliances in the 2020s will enable greater control over, and optimisation of, the operation of heating systems by end users and service providers. This could result in a change in the load profile of electric heating systems and at an aggregated level could have significant impacts on distribution networks, in particular in constrained areas where clusters of heat pumps are deployed. Increased visibility of heat use (enabled by smart heating controls and connectivity) could increase the engagement and interest of end users in energy, and in turn could accelerate the shift to a lower carbon and more optimised heating system future.
- More service based offerings (e.g. heat as a service, rental options) that are tailored to different end users could remove the upfront cost hurdle and accelerate the deployment of heat pumps. This could drive a faster uptake of heat pumps in the short term, but it will likely be post-2025 before high enough volumes of heat pumps are in place to cause major challenges for the power system (except for in local areas where the network is constrained).
- Deployment of thermal storage technologies and growing cross-vector interactions is likely to occur, but the extent to which this will happen by 2030 is very unclear. This will require much closer interactions and co-operation between power system stakeholders, thermal energy storage providers and other energy vector (natural gas, hydrogen, district heating) stakeholders.

6. Key Findings on the Connected and Distributed Energy Horizontal

6.1 The future requirements and future stakeholders arising from connected and distributed energy

The future requirements of future stakeholders resulting from more distributed energy and much more connectivity/digitalisation of energy to 2030 that will impact the power system can be grouped into the following key topics:

- Financial mechanisms and platforms to incentivise and enable participation in providing services to the power system, and to incentivise co-ordination of these services.
- Greater control over, and automation of, assets to drive lower costs, increased value and greater grid independence.
- Access to more data and greater transparency of information within the power system.
- Technical developments to enable greater distributed energy deployment and controllability of assets.
- New approaches from power system stakeholders to enable distributed generation and more service based, customer centric offerings.

The key stakeholders driving these requirements, made up of existing and new stakeholders, are:

Traditional stakeholders	New types of stakeholders
End users	Aggregators/DSR service providers.
Distributed generation and storage manufacturers	Appliance manufacturers.
Existing service providers/operators of distributed generation (e.g. ESCos)	Controls/BEMS manufacturers.
Network operators	Smart home companies.
Aggregators/DSR service providers/energy management platform builders (that optimise how a range of DG works together)	Software and App developers.
Traditional energy suppliers	IoT/interoperability protocol designers.
Energy distribution/infrastructure companies (all vectors)	Building managers.
Installers/maintenance companies	Communities/smart cities.
New service providers from within the energy sector and outside (e.g. telcos, companies that don't yet exist)	New energy suppliers.
	Microgrid providers/developers.
	Optimisation platform developers/aggregators.
	Customer facing service providers that will be a mix of new companies (e.g Tesla, Sonnen) and existing companies e.g. HomeServe.

Below, we flesh out the more specific requirements of the stakeholders above for each topic.

Topic 1: Financial mechanisms and platforms to incentivise and enable participation in providing services to the power system, and to incentivise co-ordination of these services

The future requirements from stakeholders (including end users, service providers, existing and new energy suppliers, and optimisation platform developers) related to this topic are:

1. Price signals/financial mechanisms need to be in place to incentivise stakeholders giving up control of loads/generation assets, and to incentivise the control of loads/generation assets, for supporting grid balancing.
2. A change from today's capacity and energy charging structure as end users buy much less energy but require the same or increased capacity connection to the network.
3. The ability to access off peak/ToU tariffs that incentivise flexing timing of operation of appliances to reduce energy bills.
4. Financial incentives and reimbursement mechanisms in place to incentivise the aggregation of many loads for participation in providing services to the system.
5. Ability to buy and sell energy in localised areas, to and from a range of stakeholders (e.g. neighbours, community, commercial building, network, etc.).
6. Ability to participate in physically optimising the energy system in a local area and having the financial mechanisms to make this attractive.

Topic 2: Greater control over, and automation of, assets to drive lower costs, increased value and greater grid independence

The future requirements of stakeholders (including end users, cities/communities, controls/BEMS companies, DG manufacturers, installers, appliance manufacturers, service providers and microgrid providers) related to this topic are:

1. End users want better control over and more optimal utilisation of (or increased value from) their generation and storage assets and loads.
2. Ability to access lower cost energy (reduced operational costs) and lower carbon energy.
3. Closer matching of timing of demand to timing of on (or near) site generation and storage to maximise or increasing self-consumption, potentially leading to less utilisation of the transmission/distribution network.
4. Automation and optimisation of appliances and generation and storage assets so that it is easy to participate in load shifting/DSR, and lower energy bills can be realised.

Topic 3: Access to more data and greater transparency of information within the power system

The future requirements of stakeholders (including end users, service providers, aggregators, DSR providers, software/app developers and customer facing service providers) related to this topic are:

1. Service providers want access to controllable generation plants and flexible loads to support network balancing/provide network balancing services to the system.
2. Greater visibility and transparency for end users over their energy consumption, energy prices/price signals, and value in optimising loads within buildings or the value in participating in service provision to the power system.
3. More data exchange, communications in local areas, visibility of supply/demand/energy prices in local areas (microgrid level).
4. Service providers want access to a broad range of data on customers such as billing data, energy consumption, temperature data, data from mobile phones (locational data), habits, interests, etc.

Topic 4: Technical developments to enable greater distributed generation deployment and controllability of assets

The future requirements of stakeholders (including appliance manufacturers, DG manufacturers, controls manufacturers, IoT/interoperability protocol designers, smart home companies and network companies) related to this topic are:

1. Connectivity needs to be built into distributed generation and storage to enable control/optimisation of assets.
2. Ease of connection of distributed generation and storage to the distribution network.
3. ‘Smartness’/technical ability built into DG/appliances to enable automatic participation in DSR activities on various levels (appliance level (functionality built into machines), household level, building level, etc.)
4. Standardised IoT/interoperability protocols across appliances, distributed generation assets and the power system.

Topic 5: New approaches from power system stakeholders to enable distributed generation and more service based, customer centric offerings

The future requirements of stakeholders (including end users, existing and new energy suppliers, and existing and new service providers) related to this topic are:

1. Varying levels of grid reliability is needed by end users as more onsite/local generation and storage reduces dependence on electricity from the grid. The future focus could be on providing a required quantity of kWh in a defined time, as opposed to having no interruptions of supply.
2. The ability for national and local network operators to utilise storage/local distributed generation (including taking control) to support network operation e.g. for black start.
3. ‘This all has to work’, within levels and between levels e.g. one microgrid trading with another microgrid, or one household trading with the DNO.
4. The ability for service providers to personalise energy offers/packages tailored to different customers and the availability of personalised service offerings for end users – bundling of various services/offerings into one package.

6.2 Four key trends for how connected and distributed energy will develop to 2030

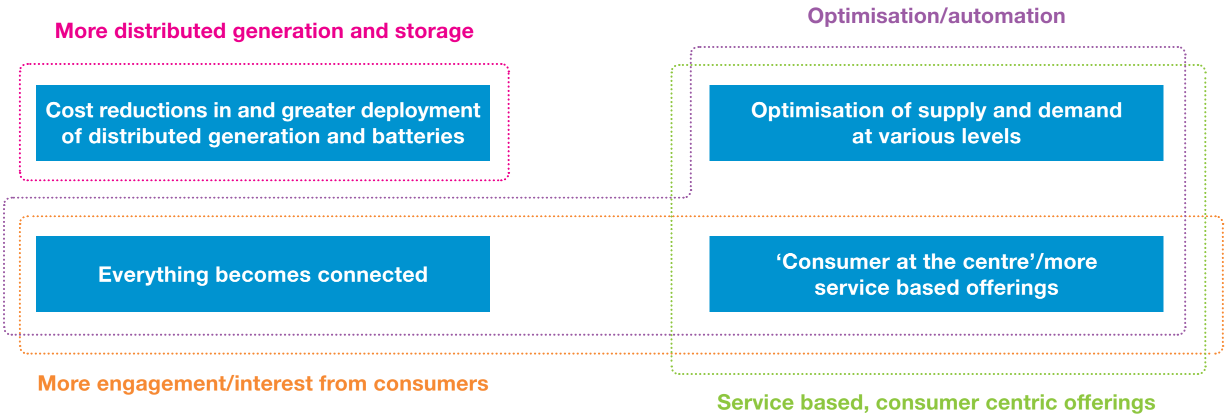
For the third horizontal, the focus was on connected and distributed energy. This horizontal is more technology/business model led, with new technology and customer propositions driving a change in stakeholder behaviour and activities. From reviewing a range of existing research and studies looking at how connectivity and distributed energy will evolve, we have identified several key trends for how connected and distributed energy may develop in the future.

These trends (shown in Figure 9) are:

1. **Cost reductions in and greater deployment of distributed generation and storage** – increased deployment of distributed generation and storage assets will occur as installed costs continue to fall. Significant cost reductions observed in solar PV in the last decade with further cost reductions to come; fuel cell costs steadily falling (this could be accelerated if automotive industry adopts fuel cells); battery costs are expected to fall significantly in the next five years (falling from ~$1,000 / kWh in 2015 to $700 – 800/kWh in 2020); more deployment of CHP, gas engines and diesel gen sets (driven by capacity market) in the short term.
2. **Everything becomes connected** – distributed generation and storage assets will be ‘connected’ to the ‘cloud’ enabling e.g. remote control/monitoring, demand response capability. Appliances/controls in homes and buildings increasingly become ‘connected’ to the ‘cloud’ (as ‘smart-ready’ offerings from appliance manufacturers becomes business as usual) and connected to each other i.e. ‘internet of things’ (IoT).

Figure 9: The key trends in connected and distributed energy that could have an impact on the power system in the future

Connected and distributed energy:



3. **Optimisation of supply and demand at various levels** – greater control and optimisation of appliances/loads to utilise generation (at local levels) where available. This optimisation/matching load to supply will occur at various levels – household level (e.g. maximising self-consumption of PV, which will grow with deployment of batteries, EVs, controlling appliances), building level (e.g. Apple HQ becoming independent of grid), town/village level (maximising use of local/community energy), city level, distribution network level (DNO to DSO transition), national system level, international level.
4. **'Consumer at the centre'/more service based offerings** – many more customer focused propositions and offerings; peer-to-peer trading enabled by internet business models (e.g. Uber); disruption to business models and existing value chains.

These specific trends are based on evidence gathered that suggests technology development/new business models will drive change, and on evidence that suggests stakeholders to connected and distributed energy want:

- Automation/optimisation.
- Service based propositions.
- Tailored offerings.
- Control/visibility of appliances, reward for participating in DSR.

6.3 Summary of the evidence behind one of the key trends for connected and distributed energy

For one of the trends, ‘Optimisation of supply and demand at various levels’, we summarise some of the detailed evidence gathered from a range of sources that justifies this trend in Table 25 below.

Table 25: Linking evidence gathered on how connected and distributed energy will evolve to one of the key trends

Source	Headline
UKERC Scenarios for the development of smart grids in the UK	Active management for EV and HP by DNOs at local level. ‘Smart grids’ will be ‘hotspots’, rather than widespread by 2030. Most households to have IHDs, with growing participation in aggregation services, dynamic/critical peak pricing tariffs. Suggests that the tendency for EVs to cluster means owners required to take part in DSM.
‘Greening the Future’ and other articles, McKinsey	Big growth in advanced analytics, smart grids and energy management systems – for all industries and buildings wanting more control, reduced operational costs and access to DSR values. ‘Internet of things’ will lead to new product and management options, with mobile applications extending into smart homes and connected buildings. Digital management of distributed energy resources, from individual sites to entire systems, has already begun and will grow.
Flexiciency – EU project (Horizon 2020 funded)	Project running from February 2015 to January 2019 that aims to demonstrate and accelerate the deployment of technology and services that provide a range of services to the power system. In five countries where smart metering is already in place. Framework will empower customers with higher quality and quantity of information on their energy consumption (and generation in case of prosumers) – driving efficient energy behaviours and usage via advanced energy monitoring and control.
SEDC: Demand Response at the DSO level	Volume of renewable energy sources connected to the grid is expected to multiply in the future. Electric vehicles, public charging stations, and exponential technology evolution will drive change – allowing customers to interact with the market and grid conditions. Demand side flexibility is key.
Boston Consulting Group: Optimising grids to meet new demands on power	Consumers’ expectations are rising, with consumers demanding greater control over their power consumption and holding utilities to higher service standards. Growth in DG and the increasing reach of digital technologies will allow for better monitoring and management of power generation and consumption.
Drive for self-sufficiency & Corporate Social Responsibility	Apple HQ: already self-sufficient in energy. Google: Electricity demand is 100% renewable in 2017 in Europe, with an ambition to be renewable on a 24/7 basis. Drive for greater self-consumption of PV in Germany, with several companies offering self-consumption optimisation solutions for PV in the UK.
Delta-ee Flexibility & Business Model Research Services	Trend in the movement away from ad-hoc manual behaviour in response to grid instability towards a more connected, automated, proactive ecosystem where individuals are responding more to price based market signals.
Aggregator activities in the UK and further afield	**Voltalis**: France. Aggregates at residential level. Install for free (a box – machine learning, algorithms, optimises appliances/heating – no impact on comfort). Customer gets energy insights, energy efficiency saving. Voltalis aggregates all this to other service to transmission system. 100,000 sites, 1 million appliances to date. **Restore:** BE based, active in the UK. Targets C&I loads for ancillary services. SaaS for C&I customers to optimise onsite consumption and generation portfolio against wholesale market prices. SaaS can also be sold to suppliers to flex their customers’ generation and consumption to reduce potential imbalance costs. **Dezera** (Germany) - C&I customers want to generate revenue (by providing ancillary services), reduce operating costs and have more control over assets. **UK based companies:** Flexitricity, Kiwi Power, Enernoc, Origami Energy. Target C&I customers to provide grid balancing services (ancillary services) – ‘optimising at the transmission system level’. C&I customers want to generate revenue (by providing ancillary services – rev share with Dezera for example) and to reduce operating costs (so these stakeholders want this service), also more control over assets.

Key ‘trends’

Everything becomes connected

Consumer at the centre/more service based offerings

Optimisation of supply and demand at various levels

Cost reduction in and greater deployment of DG

The list of research sources and interviews carried out for the connected and distributed energy horizontal are summarised in Tables 26 and 27 below.

Table 26: Primary research/interviews conducted for the connected and distributed energy horizontal

Source	Focus
Jeremy Yapp	BEAMA
Luis Miguel Alcedo	OPower
Nazmiye Ozkan	Cranfield University - Focuses on how smart grids and smart home market in the UK may develop
Harriet Bulkeley	Durham University
Matti Kahola & Arthur Jouannic	Managers of Delta-ee's Connected Home and Customer Data Analytics Research Services
Dr Philippa Hardy & John Murray	Delta-ee's knowledge leads on Flexibility and Microgrids
Jenny Carson	Manager of Delta-ee's Business Model Research Service
Dave Gorman	IBM Blockchain Lab Enablement Team
Greig Paul	University of Strathclyde, Power Networks Demonstration Centre (Blockchain focus)

Table 27: List of secondary sources used and the research focus for the connected and distributed energy horizontal

Source	Focus
Vienna *EventHorizon* Blockchain Conference	The outlook for Blockchain's application to certain use cases in the energy industry, and emerging companies and business models using Blockchain in the energy field.
TED talk, Alex Laskey, Opower	How behavioural science can lower customer energy bills by targeting certain messages at different types of customers.
Cornwall Local Energy Market	An EU and Centrica funded three-year project focused on developing solutions to enable more effective balancing of local generation and demand in Cornwall to maximise the use of renewable and local generation in the South West of England. Includes flexible demand, generation and storage technologies. Started in 2016.
Cranbrook Community Energy project	A community energy centre developed by E.ON in Cranbrook that will supply heat and hot water to both the community of Cranbrook and a business park. Gas boilers will be gradually replaced by gas-fired combined heat and power (CHP) and biomass fuelled CHP. Renewable generation technologies will likely be deployed to support low carbon targets in the future.
UKERC Scenarios for the development of smart grids in the UK report	Active management for EV and HP by DNOs at local level. Smart grids will be hotspots, rather than widespread by 2030. Most households have IHDs, growing participation in aggregation services. DSM devices stimulated. Reversible HPs.
Greening the Future, McKinsey	Big growth in advanced analytics, smart grids and energy management systems – for all industries and buildings wanting more control, reduced operational costs and access to DSR values. Internet of things will lead to new product and management options, with mobile applications extending into smart homes and connected buildings. Digital management of distributed energy resources, from individual sites to entire systems has already begun and will grow.
Delta-ee Business Model Research Service	Trend in the movement away from ad-hoc manual behaviour in response to grid instability towards a more connected, automated, proactive ecosystem where individuals are responding more to price based market signals.
Delta-ee's Demand Response & Flexibility Multi Client Research	Many companies are already providing DSR services in the UK and Europe to power systems by utilising and controlling C&I loads and generation assets. Several companies are now targeting, or starting to target residential customers in the UK, with some offering energy savings in return for control over individual appliances. Automation of individual appliances in response to price signals/direct signals from the power system will likely become common by 2020.
Delta-ee's Connect Homes and Customer Data Analytics Research Services	Significant activity and deployment of smart home devices and smart heating controls, driven largely by manufacturers and developers. Growing demand from end users and increasing engagement in energy/home automation as a result of this.

6.4 Detailing the future stakeholders and their future requirements for each key trend

By analysing each of the trends in Figure 9 separately (considering the future stakeholders that will drive the trend), we can summarise the future stakeholder requirements of the power system. In Tables 28 to 31 below, the future stakeholders associated with the trends identified for connected and distributed energy, and their future power system needs are summarised.

Table 28: Future stakeholders and their future requirements resulting from 'greater deployment of DG and storage'

Who are the future stakeholders?	What are their future requirements?
End users Distributed generation and storage manufacturers Operators of DG (ESCOs) Customer facing service providers (e.g. Tesla, Moxia, Sonnen) mix of new companies and existing providers e.g. HomeServe Aggregators/DSR service providers (energy management platform builders that optimise how a range of DG works together) Network operators Traditional energy suppliers New energy suppliers Installers/maintenance companies	1. Access to lower cost energy (reduced operational costs). 2. Access to lower carbon energy. 3. End users want better control over and more optimal utilisation of (or increased value from) their generation assets and loads. 4. Service providers want access to controllable generation plants and flexible loads to support network balancing/provide network balancing services to the system. 5. Connectivity to, and the controllability of, DG assets to be enabled. 6. Price signals/financial mechanisms in place to incentivise giving up control of loads/generation assets for supporting grid balancing. 7. Ease of connection of DG/batteries to the network. 8. Maximise self-consumption. 9. Change in capacity and energy charging structure. People buy much less energy but require the same or more capacity. 10. Grid reliability/availability requirements may not be so high at certain times, but certain of delivery of required/contracted kWh. 11. National and local network operators to utilise storage/DG to support network operation e.g. for black start.

Table 29: Future stakeholders and their future requirements resulting from 'everything becomes connected'

Who are the future stakeholders?	What are their future requirements?
End users/customers Distributed generation manufacturers Operators of DG (ESCos) Aggregators/DSR service providers Network operators Appliance manufacturers Controls manufacturers Smart home companies Software and App developers IoT/interoperability protocol designers	1. Lower energy bills via having access to off peak/ToU tariffs that incentivise flexing timing of operation of appliances. 2. 'Smartness'/technical ability to automatically participate in DSR activities on various levels (appliance level (functionality built into machines), household level, building level, etc.). 3. Financial incentives and reimbursement mechanisms in place to incentivise the aggregation of many loads for participation in providing services to the system/to enable the automatic participation in DSR. 4. High level of cyber security. 5. Standardised IoT/interoperability protocols across appliances, DG, power system. 6. Much more visibility and transparency over energy consumption, energy prices, price signals, and value in optimising loads within buildings. 7. Automated. Ease of participation/ease of use/hassle free.

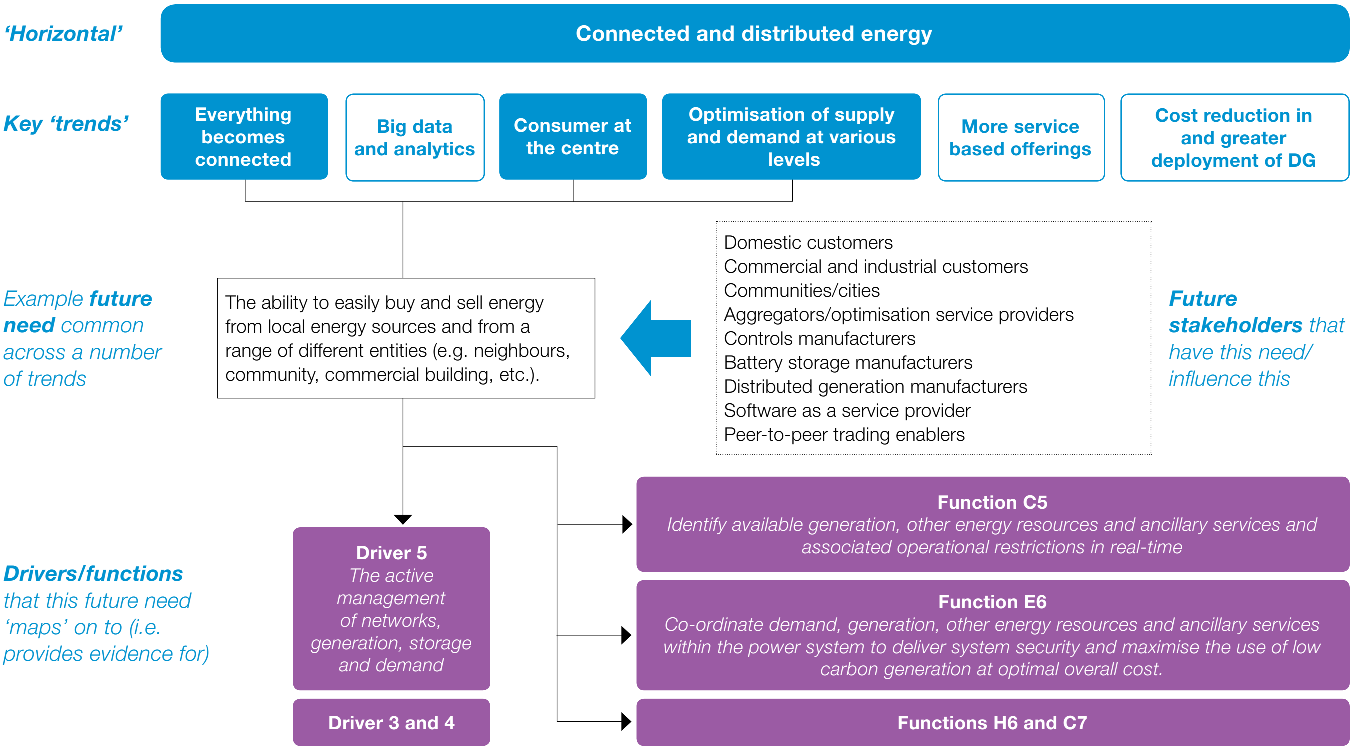
Table 30: Future stakeholders and the future requirements resulting from 'optimisation of supply and demand' at various levels

Who are the future stakeholders?	What are their future requirements?
End users BEMS/controls manufacturers Building managers Communities/smart cities Energy distribution/infrastructure companies (all vectors) Microgrids – providers/developers Optimisation platform developers/aggregators	1. More control/visibility over consumption and generation on site. 2. Optimised utilisation of their generation assets to lower energy bills/reduce exposure to volatile energy prices. 3. Closer matching of timing of demand, to timing of, on (or near) site generation – increasing self-consumption. 4. Access to lower carbon and lower cost energy. 5. Greater self-sufficiency in energy – potentially leading to less utilisation of the transmission/distribution network. 6. Ability to buy and sell energy in localised areas to and from a range of stakeholders. 7. Ability to participate in physically optimising the energy system in a local area and having attractive financial mechanism for this. 8. More data exchange, communications in local areas, visibility of supply/demand/energy prices in local areas (microgrid level). 9. This must work within levels and between levels e.g. one microgrid trading with another, or one household trading with a DNO.

Table 31: Future stakeholders and their future requirements resulting from 'customer at the centre/service based offerings'

Who are the future stakeholders?	What are their future requirements?
End users Service providers – existing energy companies/ESCOs New service providers from within the energy sector and outside (e.g. telcos, companies that don't yet exist)	1. Greater visibility over energy consumption (in homes) and energy needs (e.g. for transport), energy prices, the value in participating in service provision to the power system. 2. Ability to buy/sell energy locally, from/to a range of stakeholders (neighbour, community, commercial building, network, etc.). 3. Service providers want access to a broad range of data on customers such as billing data, energy consumption, temperature data, data from mobile phones (locational data), habits, etc. 4. Ability to personalise energy offers tailored to different customers. 5. Personalised service offerings – bundling of various services/offerings into one package. 6. Access to lower carbon energy/lower cost energy bundles/packets of energy. Bundling of renewable/lower cost energy into service based packages for customers.

Figure 10: Linking the trends identified in connected and distributed energy to the drivers and functions for the future power system identified in FPSA1



6.5 Linking future requirements to the drivers and functions of the future power system

Across these key trends for connected and distributed energy there are similar and overlapping future requirements from across the various future stakeholders. In Figure 10 above, we illustrate how one of the future 'needs' that is common to a number of the trends, links to the drivers and functions required by the future power system as being reviewed and refined in FPSA2 by WP2. The linking of the future requirements of stakeholders identified in WP1B to the drivers and functions of the power system has been agreed upon via dialogue and meetings between WP1B and WP2 (with review and input from other WPs).

In Table 32, we illustrate a selected number of the future requirements identified via the research on the connected and distributed energy horizontal, and via discussion with WP2, have linked these to the drivers and functions being reviewed and refined by WP2 in FPSA2. All the requirements found by WP1B on the heating and cooling horizontal provide further evidence for the *thirty-five* functions in FPSA2.

Table 32: Linking a number of the requirements identified to a range of drivers and functions

Future requirement	Drivers	Functions
Ability to buy/sell energy locally, from/ to a range of stakeholders (neighbour, community, commercial building, network, etc.).	3, 4 ,5	C5, E6, H6
Greater visibility over energy consumption (in homes) and energy needs (e.g. for transport), energy prices, the value in participating in service provision to the power system.	3, 4	D1, B2, E8
Closer matching of timing of demand to timing of on (or near) site generation – increasing self-consumption.	1, 3, 5	F3, D1, E3
Lower energy bills via having access to off peak/ToU tariffs that incentivise flexing timing of operation of appliances.	3, 4	H5, H6
Ease of connection of DG/batteries to the network.	5	D1

6.6 Conclusion on connected and distributed energy and its implications for the power system

The research and analysis carried out on the future evolution of connected and distributed energy in WP1B has generated a significant evidence base for the future requirements of future stakeholders, summarised earlier. Each of the requirements identified can be linked to the drivers and functions in FPSA2, providing further evidence for the drivers and functions that have been reviewed by WP2 during FPSA2, and for which WP4 is developing *Enabling Frameworks* for future implementation.

Below, we summarise the key headlines for how connected and distributed energy may develop to 2030 based on the evidence gathered, and the potential implications this could have for the power system.

- Today, we are already seeing numerous companies offering, and pushing, smart devices/controls (for homes and buildings), optimisation services and automation services. This number will continue to grow rapidly to 2020 and beyond – enabling a lot more control and influence of loads and generators in the near future. This will quickly result in many more players having an influence over the timing of loads on the power system and could significantly alter the load profiles to which the power system currently plans investments and capacity investments.
- ‘Smart ready’ appliances are becoming the norm from most appliance manufacturers – the internet of things will grow rapidly in the next few years, which could lead to greater automation and optimisation of appliances.
- Numerous aggregator companies are currently active in the industrial and commercial sector, influencing the timing of loads and operation of generation assets are beginning to target the residential sector with propositions that will enable them to control individual appliances and optimise at the household level. This could result in distribution and transmission networks needing to be able to support volatile loads and generation assets at various points and levels on the system.
- There is a clear trend emerging in end users maximising self-consumption/wanting less dependence on the grid at the residential and commercial scale. This could drive less utilisation of the distribution and transmission networks.
- The wealth of data now available on end users (energy usage patterns, behaviours, preferences, etc.) is enabling more personalisation and targeting of offerings, which will likely include energy bundled with other services in the future. This will likely enable a range of new stakeholders and traditionally non-energy related companies to enter the energy space.
- Peer-to-peer trading is slowly being unlocked, enabling more localised trading of energy between various types of stakeholders and at various levels. If this gains traction and grows significantly, it could potentially by-pass the requirement for energy suppliers/traders.

7. Key Conclusions

WP1B was tasked with reviewing existing international research and having selected conversations with the relevant industry/research experts, to:

- Build a robust, evidence-based view on the **future requirements and aspirations of future power system stakeholders** (e.g. domestic customers, SMEs, communities/cities, etc.) – strengthening evidence for the drivers and the *thirty-five* functions being reviewed and refined in FSPA2.
- Identify additional potential future stakeholders and any additional future requirements/aspirations that could have implications for the power system and result in new functions (beyond the *thirty-five* in FPSA2) being needed.
- Identify the impact that cultural/societal/behavioural changes may have on the power system and how different stakeholders might buy into the changes in the power system.

In order to do this, we focused our research and evidence gathering around three key horizontals (mobility, heating and cooling, connected and distributed energy) where societal and behavioural trends, and technological developments, will drive a significant change by 2030 that could have a significant impact on the power system.

The headlines from WP1B's research on the three horizontals considered are:

- The future set of power system stakeholders is likely to be far more diverse than the current set of stakeholders. Customers will be more empowered, and stakeholders will range from transport-as-a-service companies to cities and communities to smart home companies.
- These stakeholders will have a much wider set of requirements than current stakeholders. They are likely to range from optimising distributed energy assets through to bundling energy (and capacity) provision and products into services.
- The *thirty-five* functions in FPSA1, whose definitions have been reviewed and refined during the FPSA2 study by WP2, can suitably meet the future requirements of the future stakeholders identified in the research and analysis of WP1B.

While the three horizontals considered do not cover all the changes in society that could impact the power system by 2030, they do cover the areas that will likely have the biggest impact on the power system, and therefore give a good representation of the major changes we will see. The stakeholder requirements associated with the themes/trends arising from these horizontals are captured by the *thirty-five* functions considered within FPSA2.

Developments in other areas outside the three horizontals considered in this study will occur, and these may well have an impact on the power system – but these impacts will likely be lower than that of the three horizontals considered in this study. Finally, as a note of caution, the future requirements identified in this study have been inferred from (or logically arrived at) using a broad range of existing research, studies and opinions, rather than direct research with stakeholders. In reality, specific incentives or motivators may be necessary in order to encourage stakeholders to fully engage with the power system, and to minimise any obstacles to their participation.

8. Glossary of Terms

Term/Acronym	Definition
BEMS	Building energy management system.
CHP	Combined heat and power.
DH	District heating.
Distributed energy asset	An electricity generating technology or electricity storage system that is installed at, or near to, a stakeholder site. Typically connected at the distribution network level. For example: roof top solar PV, micro CHP, battery storage.
DSO	Distribution system operator.
DSR	Demand side response.
ESCO	Energy services company.
HEM	Home energy management system.
Horizontal	A key 'theme' or type of stakeholder activity that will likely change in the future and have a significant impact on electricity demand or on the power system e.g. one stakeholder activity (or 'horizontal') considered is mobility due to the anticipated electrification of transport having a potentially huge impact on the power system.
HP	Heat pump.
ToU	Time of use (referring to varying electricity tariffs depending on the time of day).
Trend	A key way in which the 'horizontals' will change in the future, or an expected shift away from current practices today. For each 'horizontal', a number of 'trends' will be identified.
V2G	Vehicle to grid.

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Energy Systems

Future Power System Architecture Project 2

Final Report

Work Package 1B:

Future Stakeholder Needs

The full set of FPSA2 documentation including the Main Synthesis Report, Policy Briefing paper, individual Work Package Reports and project data files are available online via the Institution of Engineering and Technology and the Energy Systems Catapult.

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