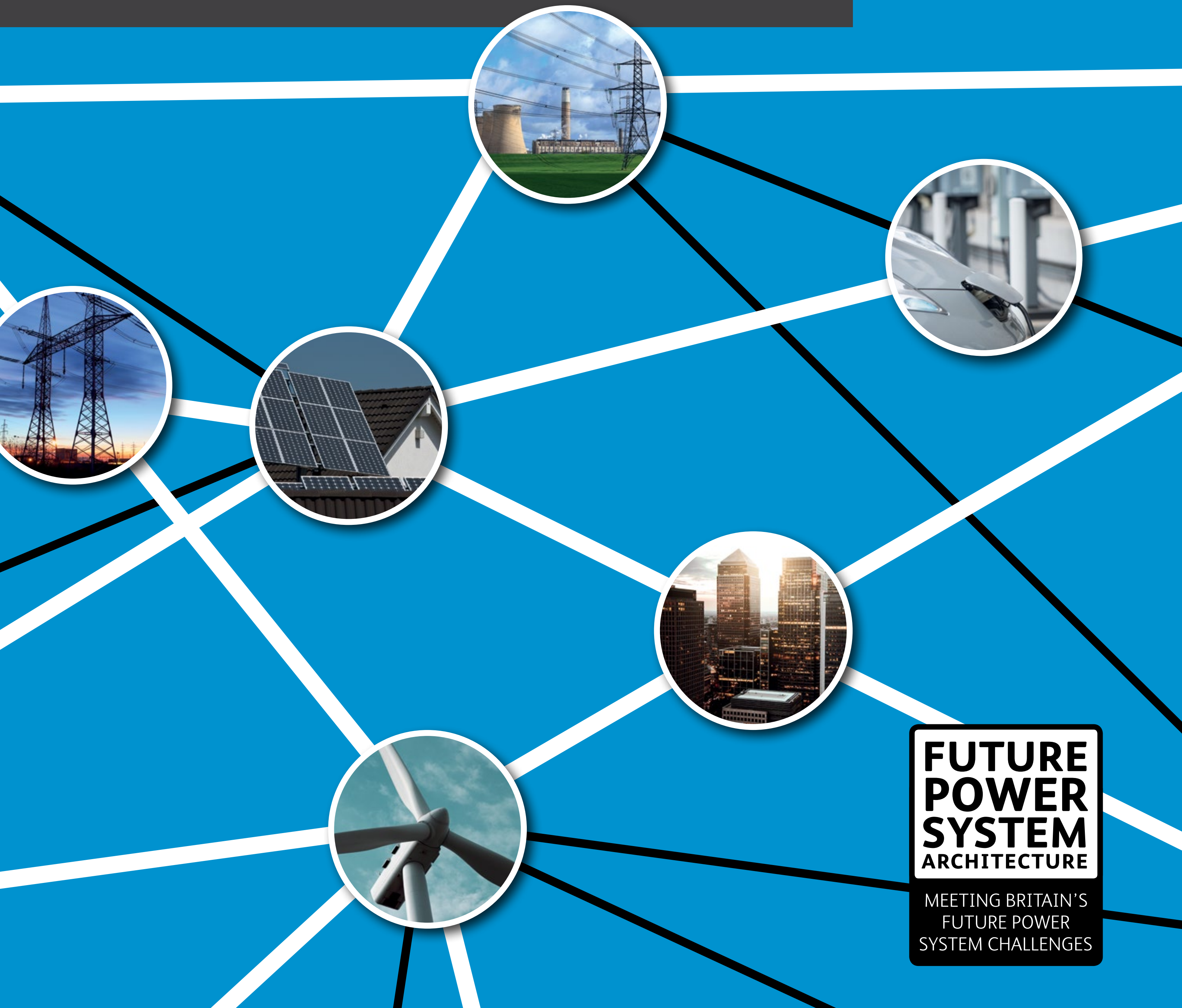
The Institution of Engineering and Technology

CATAPULT Energy Systems

Future Power System Architecture Project 2

Synthesis Report

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



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Energy Systems Catapult

Future Power System Architecture Project 2

Synthesis Report

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.

The IET is working to engineer a better world by inspiring, informing and influencing its members, engineers and technicians, and all those who are touched by, or touch, the work of engineers. The Institution of Engineering and Technology is registered as a Charity in England and Wales (No. 211014) and Scotland (No. SCO38698).

About the Energy Systems Catapult

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

The power system in Britain is undergoing radical transformation. The Future Power System Architecture (FPSA) programme is taking a holistic and whole-system approach to the evolution of its architecture - considering technical, governance, commercial and societal factors. FPSA is a multi-stakeholder collaboration led by the Institution of Engineering and Technology (IET) and Energy Systems Catapult, sponsored by Innovate UK.

The FPSA journey is illustrated in Figure 1 below. This shows the key stages of the work, from problem identification through to supporting the sector in responding effectively. Developing a new approach to enabling transition is core to the programme focus going forward.

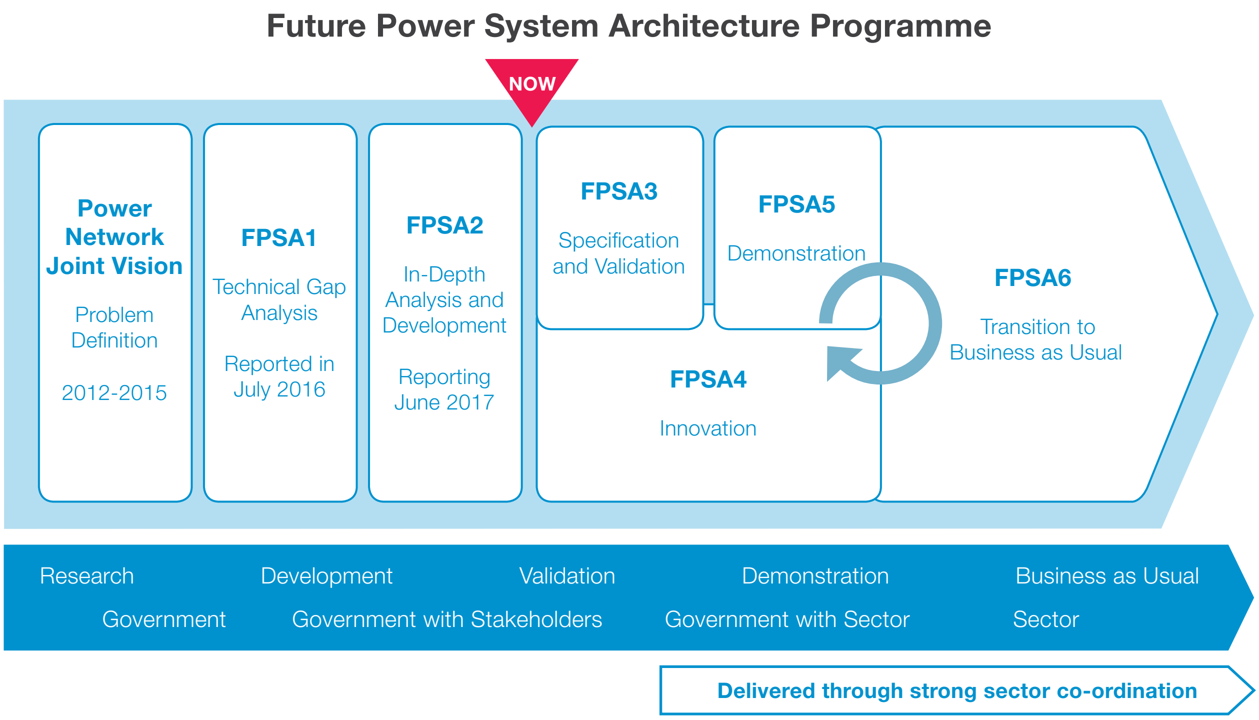
The work of the FPSA programme to date has highlighted the importance of acting now to ensure that Britain's power system can adapt to address the complex and uncertain demands that will be placed on it in the period to 2030 and beyond. These demands were identified and documented in the Power Network Joint Vision work that preceded FPSA.

The programme seeks to continue this work by further building its understanding of the changing functional needs, potential future structures, innovation gaps and approaches for managing change as the power system undergoes transformation.

The speed of change in the energy sector is such that if we wait for certainty before we act, it is likely that development of the system will not be quick enough to respond to changing stakeholder requirements, and system functionality will become inadequate for the needs of society. Despite the uncertainties, it is possible to draw conclusions about likely future requirements of the power system, and this can be used to identify a direction of travel for innovation and development. This then becomes part of an iterative pathway that, combined with tracking trends that drive new functionality, will provide flexibility and agility while maintaining safety, sustainability, cost-effectiveness, and security of supply.

The first Future Power System Architecture project, FPSA1, reported in July 2016 and found that new or significantly

Figure 1: The FPSA Journey



different functionality will be needed in the future power system in order to meet changing needs of customers and society. This document summarises the findings of the second phase of the programme, FPSA2, which further explores the required future functionality, identifying barriers for implementation, and proposing an approach that would enable the implementation of new functions. FPSA2 has produced six in-depth reports, available through the IET and Catapult websites: **www.theiet.org.uk/fpsa** and **https://es.catapult.org.uk/fpsa**

There are five primary drivers of the transformation:

- **Sustainability** – statutory decarbonisation targets and air quality measures that are helping drive a change in the technologies throughout the power system, including distributed low carbon generation, storage, and electrification of heat and transport.
- **Cost-effectiveness** – cost-efficiency and innovation objectives of the Industrial Strategy driving smart grids and demand-side participation in the power system.
- **Security of supply** – stability and the need for security of supply, including cyber security.
- **Evolving changes in customer requirements and sentiment** – including greater autonomy, engagement with new energy service providers and new technology.
- **New market-based business models** – including new customer groupings, community energy enterprises, and tariffs that reward customers for system services.

The changing environment is described in sections 1 and 2.

It is not realistic to define a detailed 'future state', with a rigid set of requirements and activities at which to aim. However, it is possible to draw conclusions about the likely future requirements of the power system, and the FPSA analysis has identified and validated a requirement for ***thirty-five*** new or enhanced functions required to meet power system objectives for 2030. These have been categorised into eight groups, A-H below, and set out in detail in section 3.

A. Design a competitive framework to address the energy trilemma, of balancing the need for sustainability, cost-effectiveness, and security of supply.

B. Manage the interface with connected energy systems.

C. Form and share best view of the state of the system in each time scale.

D. Use smart grid and other technologies to accommodate new demand, generation and energy resources.

E. Enable and execute necessary operator interventions.

F. Monitor trends and scan for the emerging risks/ opportunities on the power system, and implement appropriate responses.

G. Provide capabilities for use in emergencies.

H. Develop the market and the power system to support customer aspirations and new functionality.

There are significant barriers to the implementation of new functions in today's power system landscape, and it is unlikely that the functions can be delivered in an effective or timely manner. All *thirty-five* functions were found to have significant barriers to their implementation, including:

Technical barriers – including limitations to the technical functionality of the system, the technical challenges of implementation, the degree of upgrading required to the physical infrastructure (including power system assets and IT and communications capability), and the requirements for new technical standards or codes.

Governance barriers – encompassing policy and legislation, the regulatory framework, and sector code governance processes which are unsuited to dealing with rapid and continuous changes to technical or commercial codes (or introduction of new codes) with a whole-system focus.

Commercial barriers – including limitations and anomalies in the commercial framework and market structure that act as a barrier to new functionality. For example, the uncertainty over the status, ownership and operation of energy storage which if unresolved could limit its contribution to support a number of functions. Functions that require information sharing between parties will require attention to the treatment of commercially sensitive data.

Societal barriers – accommodating customer requirements and being able to integrate new parties such as energy communities and smart cities into the power system. The existing one-way transactional relationship between the power system and consumers creates a set of expectations that make it difficult for individual customers to envisage change, which can be a barrier for new services to becoming established. Distrust of energy sector parties, risk aversion, or simply lack of awareness, might also be a barrier to the take-up of new service offerings and consumers allowing automated control of their electrical appliances as a means of providing system balancing and ancillary services. The inertia generated by current social norms around customer engagement with the energy system, as outlined above, create an important challenge for all involved in developing new functions within the future system.

The impact analysis undertaken in FPSA2 has revealed that today's power sector change governance mechanisms have neither the scope nor the agility to ensure the timely delivery of the new functions. This has potentially significant consequences for system security, sustainability and cost-effectiveness, ultimately risking delivery of GB energy policy. Taken together, the barriers and consequences analysis indicates that a new approach, moving beyond today's power system arrangements, is a matter of priority.

This change of approach will need to establish a whole-system view, broader stakeholder participation and significantly greater agility (the means to respond in a timely manner to the uncertain or changing future requirements). This new approach is referred to in this report as ***Enabling Frameworks*** and their key features are outlined below and set out in greater depth in section 5. '*Enabling Frameworks*' (*EFs*) has been coined as new terminology, reflecting that the approach is new to the power sector.

Individual *EFs* would be set up to implement and maintain a particular area of functionality, an example might be electric vehicle (EV) charging. An *EF* would, for example, refine function specifications, establish plans for delivery and testing, develop standards and tools, and address data and information procedures. It will be a key feature of the *EFs* that new functionality requirements can be brought forward easily by any party. Within FPSA2, the *thirty-five* identified functions should be considered as the first list of required functionality that can be discerned from today's known needs.

A strong and inclusive **Stakeholder Network** would play a significant role in developing the approach and in decisions about new and enhanced functionality. It will be vital for each *EF* to interact with others, and with cross-cutting topics such as policy and safety, which will be managed by ***Common Enabling Frameworks***.

An ***Enablement Organisation*** would facilitate the development of *Enabling Frameworks*, provide governance, resolve disputes, ensure co-ordination across the system and other energy vectors such as gas or heat, and interact with other bodies as appropriate, including government, trade associations, and standards organisations. The *Enablement Organisation* is not necessarily a single body and could comprise of a number of different disciplines and organisations, and further assessment is required to define aspects such as structure and governance.

In summary, the conclusions of FPSA2 are:

1. Transformational change in the power system is in progress and will accelerate over the period to 2030. It is driven by the triple challenges of sustainability objectives, cost-effectiveness and security and stability of supply. New customer demands and novel business models are adding to the pace of change.

2. The power system is becoming more complex and localised, with many new developments on the customer side of the meter, new service-based business models, and new real and virtual customer communities. The developments, which are increasingly 'whole-system' in their impact, create both opportunities and risks.

3. The conclusion of FPSA1 that *thirty-five* new or enhanced functions are required in the GB power system architecture has been tested and is robust. Development and implementation of a systematic programme to deliver these functions efficiently and in a timely way is a significant challenge of considerable complexity and some urgency.

4. A range of topics for research, development or innovation has been identified from the analysis of these functions, and these would be useful to pursue in the short term.

5. There are numerous barriers to delivering new functionality, including substantive governance, technical, regulatory and commercial issues. The consequences of non-delivery or late delivery will be to compromise decarbonisation objectives, frustrate customer expectations, increase costs and/or adversely affect reliability and security of supply.

6. *EFs* could provide a new approach. Developing the concept and implementing them in a systematic way

could create a flexible, agile and inclusive approach to the development of the GB power system architecture and its functionality. The key features are agility in programme development, a high degree of inclusive stakeholder participation, timely decision-making and an iterative learning approach that embraces uncertainty, innovation and whole-system integration concepts.

7. These conclusions are consistent with earlier reports (FPSA1 and Power Network Joint Vision, PNJV) but now provide greater clarity, validation and approach to the way forward. The PNJV reports noted the role observed in other sectors for a 'System Architect'. We have not used that term in this report as it might suggest a single role or body, whereas the learning developed in FPSA2 presents the need for a more subtle and potentially multi-party series of activities under the overall accountability of an *Enablement Organisation*.

It is intended that the proposed next stages of the FPSA programme will comprise three parts that will run in parallel and be closely coupled with each other:

- **FPSA Programme** – strengthen the current project approach with a well-defined and structured programme management capability that will sit across all FPSA activities and assure convergence, coherence and alignment in approach.
- **FPSA3** – build further on the *EFs* activity completed in FPSA2 and validate this work by developing a framework (and associated tools and techniques) for one or more use cases (a possible use case could be the functions needed to enable EV deployment).
- **FPSA4** – build and execute a portfolio of projects to address innovation requirements and opportunities identified in FPSA2 which are aligned with implementation of the *thirty-five* functions.

The purpose of the FPSA programme is to meet evolving customer expectations and ambitious national environmental objectives, and to maintain cost-effectiveness, stability and security of supply. It will collaborate with a wide range of stakeholders to demonstrate and establish an approach to supporting and enabling required change in the power system. Further engagement with work on other energy vectors (for example, natural gas, heat, or hydrogen) is also envisaged. FPSA3 and FPSA4 will deliver proof points, learning and preparation outputs that will enable demonstration of the approach and its associated structures at appropriate scale, and innovations in a further stage of the work. If successful, this will make clear a path for transition to "Business as Usual" for an approach that responds to the stated requirement for coherent, co-ordinated transformative change.

> "A pathway for coherent, co-ordinated transformative change"

1. Setting the Scene

1.1 Project Background – Future Power System Architecture (FPSA)

The vision of the FPSA programme is to work collaboratively with a broad set of stakeholders to support transformation of the GB power system in a way and at a pace that serves the needs of individuals, communities, industry and society. The programme will pursue its vision by building and applying its understanding of functional needs, potential future architectures and market structures, innovation opportunities. This would include revised approaches for managing change in a co-ordinated, inclusive, agile and responsive way with a whole-system focus.

> "These challenges will require a transformation of Britain's electricity system"

With changing customer priorities, development of new technology, diverse energy policy drivers, and emerging new business models, the parallel challenges of sustainability, energy security, and ensuring cost-effectiveness will require a major transformation of the electricity system in many countries, including Britain, over the next 15 to 20 years.

The Future Power System Architecture (FPSA) programme aims to analyse and address the impact that these transformative forces will have on the requirements of the whole GB power system and its underlying design (its 'system architecture') and operation. It seeks to create a dynamic environment in which the architecture of the GB power system can be shaped in response to policy, market and customer requirements, taking a holistic and whole-system perspective.

Key to this is the definition of 'whole power system', which within FPSA is widely defined to include the physical, commercial, policy, data, regulatory, consumer and other aspects of the complete electricity system and their interactions. This includes all aspects of generation, networks, and notably end-use, and the system's interaction with other energy systems including power systems internationally.

The first Future Power System Architecture project, FPSA1, which was commissioned by the Department of Energy and Climate Change (now the Department of Business, Energy and Industrial Strategy) and reported in July 2016, was focused only on technical aspects, and did not include market, commercial, or societal issues. The findings were that there is new or significantly different functionality that the future power system will need to have in order to meet changing needs of customers and society, within the context of the trilemma of constraints: cost-effectiveness, security, and sustainability. It identified *thirty-five* new or enhanced functional requirements for 2030 and called on the power industry and government to focus urgently on further defining and delivering these new capabilities.

> "FPSA1 indentified *thirty-five* new or enhanced functions that need to be addressed with some urgency"

As part of FPSA1, an international study was carried out[1] in order to gather international solutions and learning. The key remaining question from FPSA1 was around the implementation of new functionality – could these functions be implemented within the structure of today's power system? And if not, how could they be best implemented?

The Future Power System Architecture 2 project, FPSA2, which was sponsored by Innovate UK, has built on this work to deepen the analysis of requirements, understand barriers to implementation, and to consider innovative frameworks for delivering required new functionality. FPSA2 proposes an agile approach enabling inclusive and diverse stakeholder collaboration and a framework for ensuring timely delivery of functionality at a whole power system level, and details a number of key innovation, research and development areas that can be developed in order to support the pathway to enabling the functionality needed by the future power system. FPSA2 comprised the following core Work Packages (WP):

- WP1A – Stakeholder Engagement.
- WP1B – Analysis of future stakeholders' requirements.
- WP2 – Functional Analysis.
- WP3 – Counterfactual Impact Analysis.
- WP4 – *Enabling Framework* Identification.

There is a detailed report covering each WP, and the overall project methodology. As part of this work, documents exploring the project opportunities from five stakeholder perspectives have been developed and are included as appendices. This document brings together this work into a single synthesised report.

1.2 The whole-system includes generation, storage, networks, and demand

The 'whole power system' encompasses elements beyond those that are traditionally seen as part of the power system. As well as traditional generation and networks, it also includes the end use of power, storage, and distributed generation. The implication is that electrical technologies within customers' properties are considered part of the system.

> "As well as traditional generation and networks, the whole-system includes the end-use of power, storage and distributed generation, and technologies within customers' properties"

The whole power system includes the many layers of the organisation and infrastructure of the system, including physical, commercial, policy, data, regulatory, consumer and other aspects of the complete electricity system. It also includes the system's interaction with other energy systems, including power systems internationally.

[1]The FPSA1 International Study can be found here: www.theiet.org/sectors/energy/resources/modelling-reports/fpsa-international-study.cfm?type=pdf. A further international example is the Brooklyn Microgrid, in New York: http://brooklynmicrogrid.com.

1.3 The whole power system stakeholders are many and wide-ranging

The stakeholders of the whole power system include existing and new parties:

- Generators and storage operators – from large traditional power stations, through distributed generation and storage to individual building scale generation.
- Users – from domestic and SME customers through to larger industrial and commercial customers to energy-intensive users.
- User group representatives, suppliers and intermediaries – such as traditional suppliers, non-traditional business model service providers, virtual power plant operators, aggregators, and geographical, dispersed, and virtual energy communities including smart cities.
- Technology and service providers – including electrical technologies within user premises such as smart metering system consumer access devices, smart energy systems, providers of electric vehicles (and their charging systems), and providers of comfort and security services.
- Network operators – including transmission, distribution, and local-scale networks.
- Supply chains – for the manufacture, supply and ongoing development of the components of the power system.
- Government and wider society – which depend on the power system for delivery of energy policy and the overall needs of society.

All of these parties have an increasingly important part to play within the power system, which will be enabled by new technologies and service provision opportunities.

2. The Changing Landscape is Driving Change in the Power System

The aim of the power system is to provide for the requirements of customers and society, while constrained by the trilemma.

The functionality required of the power system is changing, which means that the power system will need to change and develop as well. There are several key drivers of change for the power system in GB, including the trilemma itself, and the changing requirements of customers and stakeholders of the system. These are explained further in the sections below.

2.1 The trilemma: driving for sustainable energy, cost-effectiveness, and security

2.1.1 The drive for sustainability and decarbonisation – the imperatives of the Climate Change Act

The focus on decarbonisation and sustainability is a key driver for change in the power sector, underpinned by legal commitments to reduce UK carbon emissions by 80% compared to 1990 levels, by 2050. The pathway to meet this commitment is defined as a series of five-year 'carbon budgets'. The fifth carbon budget covers 2028-2032 and has been set at 1752 $MtCO2$ - 57% below the 1990 level. Implicit in this target are major changes in the way energy is produced and consumed. There is also a focus on improving air quality, particularly in urban areas.

This has significant implications for the present and future power generation mix. Existing coal fired power stations are closing, driven by the restrictions of the Large Combustion Plant Directive, and then the Industrial Emissions Directive. New generation is likely to include low carbon choices including new nuclear generation, renewables including those connected to the distribution system, and potentially carbon capture and storage.

Many renewable generation technologies present challenges; they are often weather dependent, and smaller units often cannot be observed or controlled in the same way as traditional centralised fossil fuel plant. Distributed renewables often impact the shape and direction of power flow on the system, adversely altering the operational character of the national power system, as set out in National Grid's System Operability Framework reports.

Decarbonisation is also driving a change in energy use with the electrification of heat transport from direct fossil fuel consumption. This change is already having an impact on the power demand today.

2.1.2 The drive for cost-effectiveness – the imperatives of the Industrial Strategy

While it is difficult to define the term 'affordability', it is a key objective of energy policy to keep prices down to reduce burdens on businesses and households. The cost of energy, along with its environmental costs, is significant in developed economies. There is a large number of households which are formally classed as being in fuel poverty, or who are in the wider category of 'vulnerable customers'. It is a key driver of society to lift as many out of fuel poverty as possible, and one of the best ways to do this is to ensure that the power system and its stakeholders, are able to fully exploit advantageous new technologies and new business models, and by encouraging competition to drive down costs.

> "A key driver is to fully exploit new technologies, new business models, and competition to drive down costs"

This drive can interact with, and sometimes partially oppose, the drive for sustainability and decarbonisation. For example, renewable generation technologies are not necessarily the lowest cost options at current carbon pricing, particularly while they are not as developed or wide spread as fossil fuel generation. However, the costs of renewable energy technologies are reducing as they grow in maturity. The increasing complexity of the future power system will also bring challenges in providing sufficient data to ensure that network charges can be made/modified to remain appropriately cost-reflective.

Cost-reflective pricing, e.g. facilitated by smart meters and time of use tariffs, can act as an incentive on customers to help improve the cost-effectiveness of the power system. However, care will be needed to protect fuel-poor and vulnerable customers who may not have the capability to take advantage of such tariffs - e.g. due to their particular needs which limits their flexibility to change their pattern of energy usage, or because they are unable to afford 'smart' appliances.

> "The increasingly complex power system will require sufficient data to ensure network charges remain cost reflective"

The Industrial Strategy green paper (January 2017) stresses that the 'transition to low-carbon – and the securing of our energy supplies – must be done in a way which minimises the cost to business and domestic consumers' (page 91).

> "Transition must be done in a way that minimises the cost to business and domestic consumers"

2.1.3 The need to maintain stability and security – the imperative of energy policy

The power system must deliver a supply that is stable and resilient, minimising interruptions for customers, and which is also of adequate quality, e.g. within acceptable voltage limits. This is a key imperative for energy policy, as energy security is fundamental to the health of the economy and the lives of people and society.

Today's GB power system is very reliable, with interruptions of supply and power quality issues being rare occurrences, other than localised failures, for example during severe weather in rural areas. The reliability and stability of the system must be maintained when implementing new technologies, techniques and business models at scale.

An increasing contribution from weather-dependent generation will lead to new challenges in matching system demand and system generation, whilst the displacement of synchronous generation will lead to new challenges in respect of frequency management, power quality, and transmission protection co-ordination. The wide deployment of distributed generation is already resulting in constraint management challenges for both distribution and transmission networks, whilst new home technologies such as electric vehicle chargers, heat pumps and microgeneration will create voltage and load management challenges for distribution systems. Taken together these developments will also create significant new challenges for system recovery following prolonged wide-scale, and local, power outages.

> "New risks arise from step changes in future demand"

There is already a take up of some smart home technologies and connected devices, and this is likely to increase, particularly with the rollout of smart metering and flexible tariffs. This presents new risks in the form of step changes in demand across large numbers of loads due to outside triggers such as a change in tariff price. There is also an increase in risk of malicious interference with the power system, which will require particular attention to cyber security. However, if properly managed and co-ordinated, these developments have the potential to facilitate system matching of demand and generation at a local level as well as nationally, reducing the need for generation and network capacity investment, and reducing the overall cost of Britain's power system.

2.2 Changing customer and stakeholder requirements and behaviour

There is considerable uncertainty around the future requirements and behaviours of customers and other power system stakeholders. Within FPSA2, there has been significant work to deepen the engagement with existing stakeholders, and undertake research to anticipate views of future stakeholders, to bring the best understanding of these trends[2].

2.2.1 Domestic and smaller scale commercial customers – technology adoption and engagement through other parties

Change in customer behaviour, including the uptake of technologies such as electric vehicles, heat pumps, energy information and management devices, and generation and storage, is already affecting the power system by changing traditional demand patterns.

Many of these changes are being driven by the focus on decarbonisation and sustainability, and by the incentives

> "Change in customer behaviour is already affecting the power system"

and encouragement that are motivated by government targets. However, there is also a change in attitude of some customers: the stakeholder research work within FPSA2[3] shows that there is significant interest in future home energy systems, e.g. solar panels, battery storage, and electric vehicles. This suggests an emerging appetite for the transition to smarter energy systems and 'connected homes'. There is also significant interest in alternative supply approaches, such as local, not-for-profit suppliers, self-sufficiency, or green energy tariffs, as well as simply wanting a low cost supply. However, there were several notes of caution, in particular over the rate and level of take-up by customers. The evidence highlights the need to make innovative market propositions attractive and easy for customers to understand and use.

The increasing trend in the uptake of low carbon technologies is being supported by the development of products such as electric vehicles and smart heating with energy management, designed to be attractive and convenient consumer lifestyle products in their own right so that they can become more mainstream.

Most domestic and small scale customers do not consciously interact with the power system directly; there is currently little need and it is not how most individuals would want to spend their time. However, there is a growing opportunity, enabled by the prevalence of communication and connected technologies, in having engaged customers who can, for example, provide demand-side response services, and react to time of use or dynamic tariffs. It is likely that this will be largely enabled by the automation of some day-to-day energy management decisions – most customers of this scale are not interested in becoming energy managers, but they are more likely to opt-in to a service which manages their energy for them. Services may offer additional motivation through collective action with family and social groupings. New parties, such as aggregators and community energy enterprises, are enabling this.

[2] Work Packages 1A and 1B in FPSA2 were focused on requirements of power system stakeholders in the future. Reports can be found: www.theiet.org/FPSA and https://es.catapult.org.uk/FPSA

[3] A detailed consumer panel and stakeholder engagements were undertaken as part of Work Package 1A, which is detailed here: www.theiet.org/FPSA and https://es.catapult.org.uk/FPSA

> **“**Small customers are more likely to opt in to services that manage their energy for them**”**

2.2.2 Large customers – drive for energy efficiency and engagement

Larger customers, e.g. industrial or large commercial premises, are more likely to be already engaged with the power system. This engagement has historically been carried out on an ad-hoc basis, where customers are large enough, or strategically placed, to have an impact on the system.

There has been a recent increase of emphasis on low carbon and sustainability, driven mostly by initiatives and incentives from the government. However, there is also a societal pull where sustainability has become a selling point for many organisations. A focus on reducing energy costs and improving sustainability has also resulted in energy efficiency savings – in general cutting carbon results in innovations that also cut cost. This driver is expected to increase the level to which larger customers are opting in to engagement with the power system, either individually, or enabled by new parties within the system.

> **“**Large customers could provide a base around which an energy community can be formed**”**

Larger customers could provide a major drive behind innovation, with the focus necessary to make the most of new technologies such as storage or market mechanisms such as peer-to-peer trading. Larger consumers could provide a baseline of flexible demand around which communities of consumers and generators can be formed into an energy community.

2.2.3 New parties – representing groups of customers resulting in co-ordinated behaviour and goals

New organisations and parties are emerging, such as aggregators, smart connected technology providers, and community energy enterprises, who can represent groups of customers and their interactions with the rest of the power system. The members of these groups may be physically proximate, or bound by some other commonality, such as ownership of the same make of electric car. These parties can act as a gateway for individual customers to engage in the power system, without customers having to become experts or dedicating much time and effort. The system benefits by being able to co-ordinate with a single point of contact, with access to many different potential services. Customers may benefit from innovative tariffs and/or contracts and controls, helping them tailor their energy usage to their lifestyle.

There is also a need to test, in real market conditions, the degree to which collective action through family or social groupings can increase engagement by creating new social norms that draw people to something that they wouldn’t otherwise have considered.

> **“**Customers may drive new market mechanisms such as local trading**”**

The group of customers being represented may exhibit aggregated and co-ordinated behaviour and drive new market mechanisms such as local or peer-to-peer trading, and so could play a significant role in system balancing and provide other essential services such as frequency response. Working together, groups of customers could form the basis of new approaches to local trading to create virtual networks around which local energy markets could grow. On the other hand, they could have a destabilising effect on the system, nationally or locally, if not suitably co-ordinated.

These new power system participants are increasing in number, and there is potential for significant further increase. They will require new modes of interaction within the power system that reflect opportunities for their active participation while mitigating the risk that they may create destabilising effects.

A number of the new and emerging parties who are already active have been consulted in FPSA2, bringing in their experiences and requirements to the project. These parties, with their new services and products, are among the key drivers for change - requiring new power system functionality, without which it will not be possible for these initiatives to be deployed at scale or with maximum benefit.

3. New and Enhanced Functions are Required in the Future Power System

The changing needs that society has for the power system means that the functionality it provides must also change. The approach to exploring this future functionality is described in the sections below.

3.1 The future power system requirements are continually evolving

The functionality that the system will be required to provide must adapt to remain fit for purpose, providing the needs of society and addressing the trilemma of sustainability, cost-effectiveness, and security of supply.

Therefore, it is not appropriate to define a detailed 'future state', with a rigid set of requirements and activities at which to aim. However, the speed of change in the energy sector is such that if we wait for certainty before we act, it is likely that the development of the system will not be quick enough to respond to changing stakeholder requirements, and the functionality of the system will become inadequate for the needs of society. Despite the uncertainties, it is possible to draw conclusions about the likely future requirements of the power system, and this can be used to identify a direction of travel for innovation and development. This then becomes part of an iterative and self-improving pathway which, combined with the activity of tracking trends that drive new functionality, will provide the flexibility and agility to respond. This will need to be undertaken while maintaining safety, sustainability, cost-effectiveness, and security of supply.

> "The functionality of the system will become inadequate for the future energy needs of society"

The FPSA programme has identified a set of new or significantly enhanced functions that the future power system must provide. These functions are a best view from today's perspective, and as requirements, challenges, and opportunities of new technologies are continually changing, the required system functionality is also likely to evolve.

3.2 FPSA has identified *thirty-five* future power system functions based on a best view of trends

FPSA has had a clear focus on the future functions for the GB whole power system, taking a focal point of 2030. It has identified *thirty-five* functions that are either entirely new, or are significantly extended from functionality which exists in some form today[4]. These have been identified, consolidated, reviewed and validated. A strong evidence base has been established to demonstrate the robustness and coherency for these functions.

The *thirty-five* functions address those aspects of the power system that will change in the future compared with the way in which the sector operates today. They do not describe the primary activities such as generation, transport, and supply of power, which will, of course, continue. Also, they do not provide detailed technical designs, but rather set out the functionality that must be delivered.

These functions are described at relatively high level, so that they are agnostic to future organisational or technical landscapes, which may differ significantly from today. For example, there is no assumption of whether each function should be delivered centrally by a single organisation, be dispersed geographically or among many organisations, or by the open market. Indeed, the optimal solution in many cases could be a mixture of these.

The functions extend across the timescales of investment planning (typically three-five years ahead of commissioning new equipment), operational planning (typically a few days to a couple of years ahead), real-time and balancing (on-the-day operation of the system), and markets and settlement (post real-time, typically over a period of weeks). In some cases, an equivalent function will appear for more than one of these timescales. In this case, the functions interact directly, as they make up facets of the same high level functionality.

The *thirty-five* functions have been categorised into eight groups, based on the role they will provide in the power system.

Group A

Design a competitive framework to address the energy trilemma

This category consists of a single function which is responsible for the provision of means to model the increased complexity of various energy system portfolios against GB trilemma policies and assist with the design of competitive frameworks that best achieve the trilemma objectives of sustainability, security, and cost-effectiveness of supply. These portfolios could include a combination of centralised and distributed generation, energy storage and demand response.

Group B

Manage the interface with connected energy systems

This group consists of five functions that are concerned with interactions between power system stakeholders and activities across the whole power system. It also includes interaction between the power systems and other energy systems, such as EU interconnected power systems or other energy vector systems (e.g. gas or heat). The functions include co-ordination, engagement and collaboration with these parties to optimise power system planning, operation, response to incidents and market behaviour.

Group C

Form and share best view of state of system in each time scale

Seven functions make up this group and each is responsible for understanding and sharing information on the state of the power system. This includes functionality for forecasting and observing, and for the sharing of information on availability and performance of power resources. Information on real-time availability of assets is acquired for system balancing, and dissemination of actual performance that informs settlements.

[4]The *thirty-five* functions are explored in more detail by Work Package 2 of FPSA2, details of which can be found here: www.theiet.org/FPSA and https://es.catapult.org.uk/FPSA

Group D

Use smart grid and other technologies to accommodate new demand, generation and energy resources

This group consists of a single function that is responsible for accommodation of new connections and organic load growth across the power system by any appropriate means, including the use of smart grid technology and other innovative arrangements, to maximise capacity.

Group E

Enable and execute necessary operator interventions

The eight functions in this group are concerned with enabling necessary operator interventions such that they can be executed reliably, as and when necessary. Primary enablers for operator interventions include adequate monitoring and control capability, and understanding credible events/faults and planning remedial actions.

Group F

Monitor trends and scan for the emerging risks/opportunities on the power system and implement appropriate responses

The four functions that make up this group involve ongoing monitoring and periodic horizon scanning activities. This ensures new developments, such as customer behavioural changes, threats to operability and cyber security, are managed effectively. Function F1 is an overarching function that manages these changes and identifies and implements solutions as necessary, where whole power system co-ordination is required.

Group G

Provide capabilities for use in emergencies

The three functions take account of power system operation in emergency situations and planning the actions and capabilities that will be required during these periods. This includes planning the restoration of supplies following a partial or total shutdown, and the provision of emergency procedures either to avoid loss of supplies or to facilitate restoration.

Group H

Develop the market to support customer aspirations and new functionality

This group covers six functions that focus on the provision of a market structure, market mechanisms and aligned financial incentives to offer a range of choices to customers on how they interact with the power system, balancing competition with social objective, such as protection of vulnerable groups or low income households.

The functions are presented in the next two pages, colour coded by group[5].

[5]The functions are referenced using the FPSA2 numbering. There are equivalent FPSA1 references and corresponding function wording detailed here: www.theiet.org/FPSA and https://es.catapult.org.uk/FPSA

Figure 2: FPSA functions, arranged and coloured by category.

	Investment Planning	Operational Planning	Real-Time and Balancing	Markets and Settlements
A	1.1 Provide mechanisms to model portfolios of generation, other energy resources, EU interconnection and ancillary services to measure these against the GB carbon reduction, security of supply and energy affordability policy objectives and plan for the delivery of those portfolios that best meet these objectives. **A1**			
B	3.1 Account for the impact of operational interactions (potentially including cross-vector, cross-border and intra-power system) in system planning and forecasting of demand, generation, energy resources and ancillary services on the power system. **B1**			
B	5.1 Provide mechanisms by which planning can be co-ordinated between all appropriate parties (potentially including cross-border, cross-vector, and intra-power system operational interactions) to drive optimisation, with assigned responsibility for security of supply. **B2**	9.1 Provide operational planning processes that facilitate engagement with all affected stakeholders (potentially including cross-border, cross-vector, and intra-power system operational interactions), taking account of the appropriate level of engagement for different stakeholders. **B3**	13.1 Enable the delivery of demand control, generation constraint, co-ordination with other system operators (potentially including cross-border, cross-vector, and intra-power system operational interactions) and other actions in response to all system incidents. **B4**	15.4 Collaborate with other energy sectors (potentially including cross-border, cross-vector and intra-power system operational interactions) in order to allow the market to operate across multiple sites and vectors. **B5**
C		6.1 Collate and distribute information throughout the power sector on the availability and performance of the generation, other energy resources and ancillary services, and any associated operational restrictions. **C2**		
C	3.2 Forecast all demand, generation, other energy resources and ancillary services across all voltage levels within the power system. **C1**	7.1 Collect outage information from all parties of significance within the power sector, co-ordinate with affected parties, identify clashes and resolve, with assigned responsibility for security of supply. **C3**	10.1 Identify available generation, other dispatchable energy resources and ancillary services and associated operational restrictions in real time. **C5**	14.2 Collate and distribute information throughout the power sector on the performance of demand, generation, other energy resources and ancillary services in order to enable settlement. **C6**
C		8.1 Forecast and model all generation and other energy resources and ancillary services with operational, cost, and security implications for the power sector. **C4**		16.3 Monitor and settle the delivery of contracted demand, generation, other energy resources and ancillary services. **C7**
D	4.1 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. **D1**			

Key

A	Design a competitive framework to deliver the energy trilemma.
B	Manage the interface with connected energy systems.
C	Form and share best view of state of system in each time scale.
D	Use smart grid and other technologies to accommodate new demand, generation and energy resources.

E	Investment Planning	3.3	Ensure that monitoring is in place to support the use of active system management.	E1
E	Investment Planning	5.2	Review the Power Sector's developing operational characteristics to validate the assumptions made during the investment planning process.	E2
E	Investment Planning	8.2	Provide the capability to observe energy resources across the whole system and mechanisms for intervention.	E3
E	Operational Planning	9.2	Identify by modelling and simulation constraints arising from credible events/faults, and plan remedial action.	E4
E	Real-Time and Balancing	11.1	Monitor the effectiveness of, and execute as required, remedial action (including market mechanisms and smart capabilities for the delivery of demand control, generation constraint and other actions) in response to all events/faults.	E5
E	Real-Time and Balancing	11.2	Co-ordinate demand, generation, other energy resources and ancillary services within the power system to deliver system security and maximise the use of low carbon generation at optimal overall cost.	E6
E	Real-Time and Balancing	12.1	Provide monitoring and control of those parts of the system under active management, including network assets, demand, generation and other energy resources and ancillary services.	E7
E	Markets and Settlements	14.1	Provide automated and secure management of demand, generation, other offered energy resources and ancillary services, including Smart Appliances, HEMS and BEMS.	E8
F	Investment Planning	0.1	Enable the Power Sector to manage necessary changes across the sector when faced with new developments or changes to its objectives and operating environment.	F1
F	Investment Planning	2.1	Identify, counter and learn from threats to operability of the power system from all parts of the power sector both above and beyond the meter.	F2
F	Investment Planning	2.2	Monitor the impact of customer behavioural changes on system operability and propose solutions to resulting operability issues as necessary.	F3
F	Investment Planning	2.5	Identify and protect, on an ongoing basis, against cyber security threats to the operability of the power system which originate from inside and outside the power sector. Detect and respond to existing, new and unforeseen cyber security incidents promptly as required.	F4
G	Investment Planning	2.3	Plan for the timely restoration of supplies following a pro-longed local failure (Cold Start).	G1
G	Investment Planning	2.4	Provide the ability to move between different modes of overall operation in the event or threat of a system emergency.	G2
G	Investment Planning	2.6	Plan for the timely restoration of supplies following a total or partial shutdown (Black Start).	G3
H	Markets and Settlements	15.1	Provide aligned financial incentives across the power sector (e.g. innovative or flexible tariffs) encompassing power, energy and ancillary services which provide appropriate signals to users and do not distort competition while giving consideration to their impact on customers.	H1
H	Markets and Settlements	15.2	Enable settlement for all existing customer profile classes to support flexible tariffs, e.g. half-hourly using smart or advanced meters.	H2
H	Markets and Settlements	15.3	Implement and co-ordinate a framework where the roles and value propositions of all significant stakeholders across the power sector can be managed.	H3
H	Markets and Settlements	15.5	Provide market mechanisms e.g. peer-to-peer trading, to allow all customers to access the value realised by their actions.	H4
H	Markets and Settlements	16.1	Provide a market structure that enables customers to have choices within the power system.	H5
H	Markets and Settlements	16.2	Enable customers to choose from a full range of market options which determine how they interact within the power system including individual, community and smart city services.	H6

Key

E	Enable and execute necessary operator interventions.
F	Monitor trends and scan for emerging risks/ opportunities on the power system and implement appropriate responses.
G	Provide capabilities for use in emergencies.
H	Develop market to support customer aspirations and new functionality.

3.3 The functions interrelate and should not be considered in isolation

The FPSA functions are described separately, but many are critically interrelated and have interdependencies with (or dependencies on) each other. These functions cannot be delivered independently, but rely on and interact with the delivery of other functions. For this reason, they cannot be considered in isolation.

> "The functions have interdependencies and cannot be delivered independently"

The order and timescales of implementation of each function and the needs within them may change the nature of what is required, including negating the need for some functions and replacing them with others. There may be partial implementation of functions in order to deliver other functions.

3.4 These functions were further explored and validated through research

Within the FPSA2 project there was focused research of present and anticipated future stakeholders and their requirements within the power system[6]. A significant number of requirements and obstacles were identified through this work and insights gained which were used to refine and validate the functions. This work did not uncover any areas of functionality that were not covered either by the functions themselves, or by a wider list of prerequisites and underlying approaches relevant to the power system, as described in the list below:

- Greater agility in functional change – there is a need for faster, more agile decision-making and change within the power system, to enable reaction to emerging threats and opportunities.
- Customer requirements and preferences – customer requirements and preferences should explicitly shape the direction of change in the power system through inclusive processes.
- Customer engagement – a more engaged customer base should enable more efficient and responsive system operation. There is a need to make new market propositions attractive, and easy for customers to understand and use. This is likely to mean that a substantial amount of engagement in the system is automated, where customers opt in to services that make some everyday energy management decisions for them. Attention may also need to be paid to how new social norms around engagement are created. Individual customers need to come to feel that engaging with new market mechanisms is something 'that people like them do'.
- Access for parties and technologies – there is a need for a level playing field in markets, including access for all types and sizes of participants and technologies. In today's power system, the large existing incumbent players have the most resources to influence decisions, often leaving smaller, newer parties at a disadvantage.
- Access to information – there must be easy and appropriate access to information across the whole power system, including between all parties who need it.
- Innovation and implementation – there is a need for continual innovation, both technical and commercial, and a route to implement promising innovation into the system landscape.
- Required skills – the smart and flexible system envisaged will require enhanced skills, particularly cross-sector and multi-disciplinary skills, in the specialists that specify, implement, manage and evaluate the more complex systems expected.
- Consideration of environmental performance – the environmental and air quality performance of the power system, in the context of national, regional and local targets, will be an important consideration.

Implementing new functionality will require support, such as establishing new change processes and developing tools and models. It is important to understand the functional needs so that the scale of the change, and the ability of the system to cope, is understood, as well as to assess barriers to implementation and how they may be overcome.

These needs can be described in the following categories:

- Process needs – this includes the large variety of activities undertaken to ensure that the elements

[6] Work Package 1A and 1B of FPSA2 explored the customer and stakeholder requirements on the future power system, which is reported in detail here: www.theiet.org/FPSA and https://es.catapult.org.uk/FPSA

of the whole power system can be enabled, operated and managed effectively. This category of needs encompasses a wide variety of rules, processes, policies etc. that govern how the power system is planned, built, operated and managed, and how power system stakeholders co-ordinate their activities. These processes are central to the way in which individual organisations are run and how organisations interact. Processes will need to be developed which are adaptable in response to a deepening understanding of customer and wider stakeholder needs and how they respond to market signals.

- Infrastructure needs – this includes physical assets and software needed to implement the functionality. Examples include novel use of network assets, IT software and hardware, communication infrastructure, and monitoring and metering infrastructure.
- Modelling capability – many functions have a need for modelling capability and tools, e.g. for decision support. This need has both process and infrastructure elements: software is required to undertake the analysis, and a process will be defined which determines how that software is used, from where data is sourced, and how results are quality controlled and interpreted.

> "The interaction between functions is a vital part of understanding their implementation"

The interaction between functions is a vital part of understanding their potential implementation – some functions will be prerequisites for the implementation of others, while some will need to be implemented in parallel so that they can grow and develop together.

3.5 Three case study functions provide examples of function descriptions

To explore the concepts being developed within FPSA2, three case study functions were selected and are referenced further in this report. These functions were selected for deeper consideration through the FPSA2 project to illustrate the initial stages of identifying needs, barriers and enablement options as part of the overall process of bringing new functions from concept through to delivery:

- Function G3: Plans for the timely restoration of supplies following a total or partial shutdown of the national power system. This restoration process is known as Black Start and operationally is particularly challenging and involves many parties.
- Function H5: Provides a market structure that enables customers to have choices within the power system, e.g. engaging with new energy product or service providers.
- Function H6: Enables customers to choose from a full range of market options that determine how they interact within the power system including individual, community and smart city services.

> "Three case study functions were selected to test the extremes of the range of functions"

The functions were selected to test the extremes of the range of functions described within FPSA. Function G3 deals with restoration after a system shutdown, and is a technical function that already exists in today's system with significant legacy systems and thinking, but with undoubted future challenges. H5 and H6 are both market-based and refer to providing customer choice and enabling participation, which directly includes new functionality and, very likely, new players. H5 and H6 were selected because they can be considered a function cluster, with closely related and interacting functionality; H5 covers the overall market structure, and H6 the development of market options that align with this structure.

As functions cannot be considered independently, the relationships and interdependencies with other functions were also explored.

3.5.1 Function G3: Plan for the timely restoration of supplies following a total or partial shutdown (Black Start)

The requirement is to have a Black Start capability under all credible future generation portfolio and demand scenarios.

There is an established method of providing Black Start for the British power system, which includes reliance on large, centralised power stations. As the generation mix changes to include more distributed energy resources, the current means of providing Black Start will need to be reviewed. Co-ordination of parties providing support under Black Start conditions will be complex as they will be both more numerous and diverse than today.

What is needed in order to implement function G3?

- **A process** which governs planning for Black Start.
- **A process** that procures Black Start services from providers.
- **A process** to set out the technical criteria that Black Start providers need to fulfil.
- **A process** to link individual Black Start providers to form "power islands".
- **Modelling capability** that can assess the viability of different Black Start plans to support evaluation.
- **Provision of infrastructure** for robust communications and control for controllable energy resources.

There are key interactions with other functions, the need for new Black Start capability will be informed by other functions such as F2 which will highlight operability threats and E2 which will identify where assumptions have changed. The modelling will be informed by network planning (B2), forecasting (C1) and historic data (C6).

3.5.2 Function H5: Provides a market structure that enables customers to have choices within the power system

The requirement is to promote the active engagement of customers by enabling different market options through which they can participate e.g. smart cities or community energy schemes.

This function would provide the necessary technical integration of power system stakeholders such as active customers, aggregators, and energy communities. This function is needed to prevent unnecessary investment in network and generation capacity through failure to fully leverage the potential for local trading and the demand management capability of customers and other stakeholders.

> "Technical integration of power system stakeholders will avoid unnecessary system investment"

What does function H5 need in order to be implemented?

- **A process** that governs the end-to-end optioneering, evaluation and administration of new more distributed market structures.
- **Modelling capability** to support the evaluation of more distributed market development options, including costs and benefits across the whole power system.
- **Processes and mechanisms** for implementation of new market structures.
- **Processes and mechanisms** that allow customers and stakeholders to interface with the market.

There are key interactions with other functions, e.g. the market design will need to be considered with wider policy objectives (A1) and operability threats (F2) in mind, as well as the overall framework of valuable propositions (H3) and realising customer value within new market mechanisms (H4). Modelling will utilise data about energy resources (C6) and forecasts (C1).

3.5.3 Function H6: Enables customers to choose from a full range of market options which determine how they interact within the power system including individual, community and smart city services

The requirement is to afford customers the choice of a full range of market options in regard to how they interact with the power system e.g. individual or smart city.

This function is market focused and is in Group H (Develop the market to support customer aspirations and new functionality). This function is needed as customer engagement will be more widespread if customers have access to a diverse range of system and market integration mechanisms.

What does function H6 need in order to be implemented?

- **A process** for developing new market options.
- **Modelling capability** to determine the viability of new business models.
- **Mechanisms** for engaging with customers.

There are key interactions with other functions, e.g. market options will need to fit alongside the wider market structure (H5), settlement processes (C7), framework of value propositions (H3), financial incentives (H1) and domestic scale market mechanisms (H4). Modelling will utilise data about the performance of energy resources (C1) and forecasts about the future (C6).

4. Today's Sector is not Conducive to Timely Delivery of New Functions

4.1 There are significant barriers to the implementation of new functions

Barriers to implementation of new functionality in today's power system landscape can be considered in the following high level groups:

Technical barriers – including limitations to the technical functionality of the system, the technical challenges of implementation, the degree of upgrading required to the physical infrastructure (including power system assets and IT and communications capability), and the requirements for new technical standards or codes.

Governance barriers – encompassing policy and legislation, the regulatory framework, and sector code governance processes which are unsuited to dealing with rapid and continuous changes to technical or commercial codes (or introduction of new codes).

Commercial barriers – including limitations and anomalies in the commercial framework and market structure that act as a barrier to new functionality. For example, the uncertainty over the status, ownership and operation of energy storage which if unresolved could limit its contribution to support a number of functions. Functions that require information sharing between parties will require attention to the treatment of commercially sensitive data.

Societal barriers – accommodating customer requirements and being able to integrate new parties such as energy communities and smart cities into the power system. The existing one-way transactional relationship between the power system and consumers creates a set of expectations that make it difficult for individual customers to envisage change, which can be a barrier for new services to becoming established. Distrust of energy sector parties, risk aversion, or simply lack of awareness, might also be a barrier to the take-up of new service offerings and consumers allowing automated control of their electrical appliances as a means of providing system balancing and ancillary services. The inertia generated by current social norms around customer engagement with the energy system, as outlined above, provide an important challenge for all involved in developing new functions within the future system.

"The existing industry governance processes are no longer fit for purpose"

All *thirty-five* functions were found to have significant barriers to their implementation and whilst the issues to be dealt with are unique to each function and barrier, common themes are evident. The most prevalent barriers are those associated with existing industry governance processes which are no longer fit for purpose, the increasing degree of technical complexity, and the regulatory and commercial frameworks, which are not suited for new business models.

"Code governance in future will involve a significantly wider range of stakeholders"

4.1.1 Key barrier category: Existing industry governance processes

Effective code governance in future will involve significantly larger numbers and wider range of power system stakeholders, including new or emerging parties such as aggregators, energy communities, and providers of energy management and connected technology systems. Some stakeholders will have newly defined roles and responsibilities. Many functions will involve greater co-ordination of planning and sharing of information across the whole power system, and some with other interconnected systems.

Implementation of some functions will require significant changes to technical and market codes, and whilst code reviews must be given sufficient time in order to consider and consult on a change, a significantly more agile approach will support rapid reaction to changing requirements.

Whilst acknowledging Ofgem's proposed review of code governance following recommendations from the Competition and Markets Authority, the existing process of industry code governance is neither sufficiently agile nor flexible enough to respond to the degree and pace of future change envisaged. Relatively minor functionality changes can take months or even years to implement under today's processes, particularly where they require changes to multiple codes. Also, small players are often unable to dedicate the resources to be as effective as larger incumbents in the industry's governance processes.

4.1.2 Key barrier category: Extent of technical change required

A range of significant technical implementation barriers for FPSA functionality has been identified through the FPSA2 impact analysis. These are outlined below:

- **Modelling and forecasting capability need enhancement** – a number of industry studies have identified that existing modelling and forecasting capability is a barrier to capturing the full value of distributed energy resources and future flexibility services, whilst ensuring security of supply and cost optimisation[7].

"Greater power system and energy modelling capability is now required"

  There is insufficient capability in whole power system modelling and in modelling interactions with other energy vectors, to support co-ordinated planning and operation. Forecasting may be challenging for new parties with limited historic data or predictive modelling capability. There are also significant new data processing and interfacing implications to enable forecasting and modelling for an increased volume of distributed energy resources across the system.
- **Existing system monitoring, control and communication is limited** – existing monitoring, control and communications systems are not at the level of sophistication and resilience required for a number of functions. There is limited monitoring and control, particularly at lower voltage levels of the distribution networks, and limited interoperability between metering and home or business energy management systems and 'consumer access devices'. Existing control

[7]IET GB Power System Modelling Capability Reports: http://www.theiet.org/sectors/energy/resources/modelling-reports/

and communications strategies, particularly at distribution network level are not sufficiently developed to manage more complex local system balancing, or enable response to major system events, which will be needed, particularly with an increased number of distributed energy resources.

"Existing control and communications strategies are not sufficient for future complex local systems"

- **There is insufficient development, adoption and co-ordination of standards** – this applies to many areas of future functionality, e.g. cyber security, data access, control interfaces and interoperability. Standards, which are enablers for co-ordination, competitive procurement, and customer choice, are necessary to support the significant increase required in communication links and data interoperability between parties within the wider power system, and to other interconnected systems. Industry standards will need to be implemented to address the resulting increase in cyber security risk to critical power infrastructure. There are also significant implications for consumer data privacy protection. Current standards for network control, protection and automation are not necessarily compatible with smart technologies in customer properties, and the technologies within customers' properties are not necessarily compatible with each other.

While this work is making progress in meeting some aspects of these challenges, they are not sufficient to overcome them in a holistic way. For example:

- BEIS and Ofgem are seeking solutions that will enable greater transparency within the power sector of aggregated half-hourly metered consumption data, and which are compatible with relevant data protection regulations without imposing disproportionate costs or complexity to industry.
- There is an ongoing review of cyber security for Critical National Infrastructure (CNI), but it is not clear whether this will holistically consider the security requirements of, e.g. Internet of Things (IoT) developments that will result in controlled customer devices that have the capability to interact with the whole power system.

"The regulatory framework is a significant barrier for function implementation"

4.1.3 Key barrier category: Regulatory frameworks

The regulatory framework has been identified as a significant and prevalent barrier for function implementation – in particular, barriers relating to governance, the commercial framework, policy and legislation. The key themes are:

- **Existing licensing and regulatory arrangements do not account for new parties and new business models** – the existing framework for regulation has been designed and implemented iteratively since the 1980s, and reflects the roles and responsibilities of traditional industry parties that have evolved over time. However, emerging new parties and business models that are key to the delivery of some of the functions fall outside the scope of the existing regulatory framework.
- **The whole power system (and its interaction with other energy vectors) is not considered holistically within the regulation regime** – in order to promote a whole-system approach within the power system (and wider energy sector), holistic whole-system thinking needs to be reflected in regulatory approaches. The need for alignment of business plans across the power system (e.g. transmission and distribution) is acknowledged but this will need to extend to a wider range of sector parties, e.g. distributed generation, energy storage, smart cities, energy communities, and other vector or interconnected systems. A more holistic and co-ordinated approach to regulation across energy vectors will also reduce the risk of unintended consequences arising from vector-specific changes to codes, legislation, policy and regulation. An example of unintended consequences might be investment being made in electricity systems to relieve distributed generation export constraints, that are subsequently rendered 'stranded' assets by the introduction of attractive technical and commercial arrangements to convert electricity generation to heat for local storage as part of a drive for greater home energy efficiency or decarbonisation.
- **The regulatory framework needs to balance**

flexibility and agility with long-term certainty – the existing transmission and distribution regulatory price controls cover eight years with a midpoint review (although this is now under review by Ofgem for RIIO ET2 and ED2) combined with specific uncertainty (reopener) mechanisms and an innovation roll out mechanism. This approach was designed to create stability and certainty in the sector in terms of use of system pricing and cost of capital, whilst allowing sufficient flexibility to allow for technological evolution and economic forecasting uncertainty. However, the increased pace and extent of change now envisaged will require a regulatory framework that can respond more flexibly to changing circumstances whilst providing sufficient longer term stability to enable necessary investment.

- **There is a lack of data access for new parties** – many functions will involve greater collation and distribution of a wide range of new sources of data across the whole power system. This introduces potential risks around commercial sensitivity, data security and anonymity, particularly if sharing of data between multiple parties is required. Data accessibility may be particularly challenging in instances where commercial competitors (including suppliers and generators) could gain market advantage from having access to commercially sensitive data.

This work is exploring aspects of potential solutions, but this effort needs to be co-ordinated and built upon to provide a complete solution. For example, BEIS and Ofgem are currently taking steps to address the need to account for new parties in the licencing and regulatory arrangements through their call for evidence on 'A Smart, Flexible Energy System', as well as through Ofgem's work on Non-Traditional Business Models and their establishment of the 'Innovation Link' and a 'Regulatory Sandbox' for trialling new business models.

4.1.4 Key barrier category: Commercial frameworks

The commercial framework barriers relate largely to new commercial models that cannot be adopted under the current market structure. They can be summarised as follows:

- **Existing commercial arrangements can sometimes act counter to core policy objectives** – for example, the potential value of energy storage in supporting the power system balancing and improving the effective capacity factor of intermittent renewable generation is well understood. However, the current structure of network and system balancing charges, coupled with double charging of renewable energy levies, can have an adverse effect on the business case for energy storage. Energy storage is a resource that has a complex value stack, which makes it potentially attractive to a range of sector stakeholders including the GB Systems Operator (GBSO), suppliers, generators, aggregators, network operators and end-customers, provided commercial arrangements are in place to enable such parties to access its value. For example, current licence limitations on network operators regarding the ownership and commercial operation of energy storage might act as a barrier to its use as an effective means of network constraint management.
- **Commercial frameworks fail to realise potential synergies** – insufficient transparency, liquidity and co-ordination of existing markets (e.g.energy markets, capacity mechanism, balancing services, network constraint management services) can be a barrier to full commercial exploitation of distributed generation, storage and other distributed energy resources. For example, network operators will sometimes contract demand side response services as an alternative to costly network reinforcement.

> "There is no mechanism to co-ordinate between local and national energy services and resources"

These resources are normally procured to meet a specific locational requirement but there is no mechanism to co-ordinate between these services and the national scale incentives to meet wider system needs, such as short-term operating reserve. Indeed, circumstances might arise where the markets operate in conflict: e.g. a signal sent by the national system operator to increase demand (say to balance a surge in wind generation), may result in a local network constraint, which is then nullified by the Distribution Network Operator (DNO) implementing a local demand reduction action - resulting in two payments but a combination of effects that cancel each other out.

- **New commercial models are required to deliver some of the functionality required by the power system** – one current example is the absence of half-hourly settlement, although this should be implemented for all profile classes once the smart meter rollout is complete. New commercial models will be needed to maximise the effectiveness and efficiency of local trading and local energy markets. New commercial models might also be required to deliver functionality in the regulated segments of the value chain. For example, existing services may not be sufficient to support the system in the event of a Black Start. An Energy Emergencies Executive Committee (E3C) task force has been set up to consider the changing needs for Black Start.
- **Current commercial frameworks are not geared towards offering accessibility to markets for new entrants** – in particular, new entrants without deep prior experience, market knowledge and administrative and commercial strength. There is a need to balance risk to the system and customer against the need for innovative new value-adding service offerings, and the value of greater competition and local knowledge available from smaller and more localised parties.

4.2 Failure of timely implementation has consequences for energy policy delivery

Analysis was undertaken in FPSA2 to understand the impact of these barriers in terms of the consequences to energy policy of not delivering the functions[8]- i.e. the extent to which late or non-delivery of functionality will impact sustainability, cost-effectiveness, and security of supply objectives.

Consequences of non-delivery of functions on sustainability of energy – this includes failing to accommodate low carbon generation options, low carbon demand technologies, energy storage, and enabling techniques and procedures.

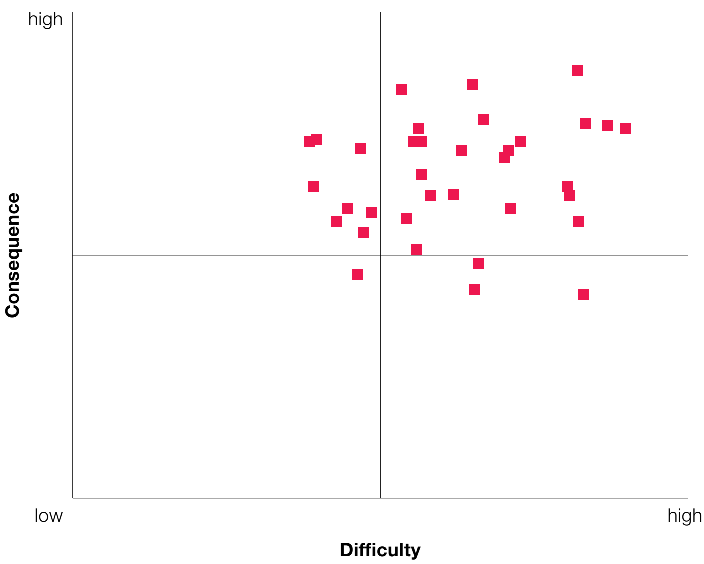
Consequences of non-delivery of functions on cost-effectiveness of power supply – this includes unnecessarily high operational or capital costs of network and generation capacity (including potentially stranded or poorly utilised assets) and failure to introduce new business models and propositions which might serve to promote competition, providing customers with more choice, and with services which better suit their needs.

Consequences of non-delivery of functions on security of power supply – this includes higher risks of interruptions to supply and/or delayed recovery from system outages, or failing to maintain power quality within statutory or licence requirements.

The impact analysis revealed potentially significant consequences to system security, sustainability and cost-effectiveness, ultimately risking delivery of GB energy policy, and confidence in the sector and its institutions. The risk to GB energy policy can be considered as a function of the difficulty of delivering functionality, and the consequences of late or non-delivery.

Figure 3 illustrates the results of this assessment for each of the *thirty-five* functions. It demonstrates (viewed here at a high level) that many of the functions have both a high degree of difficulty (low probability) of timely implementation, and a significant consequence of late or non-implementation.

Figure 3: Difficulty and consequence analysis of the *thirty-five* functions shows that the functions, presented as a group, show a high degree of difficulty, and a high consequence if not delivered.



[8]The impact of the barriers to implementing the FPSA functions were analysed as part of Work Package 3 in FPSA2, and reported in detail here: www.theiet.org/FPSA and https://es.catapult.org.uk/FPSA

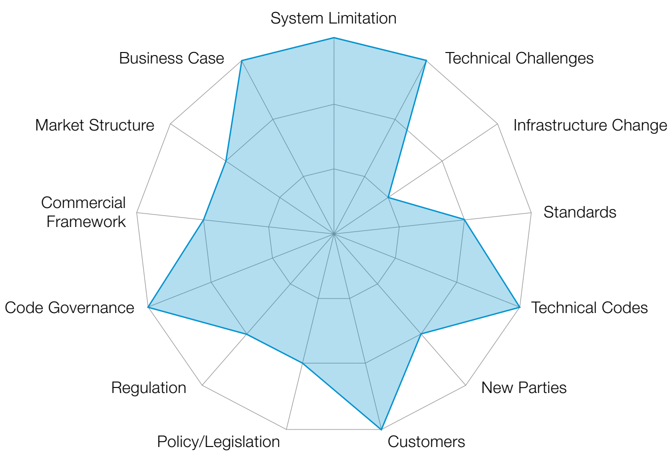
4.3 Three case study examples of function barriers and consequences of non-delivery

In order to explore the impact analysis in greater depth, the three case study functions introduced in section 3.4 of this report, were analysed in more detail. The sections below summarise the barriers and consequences of non-delivery for each of these three case study functions in the form of radar plots where a score closer to the centre indicates a low impact of a barrier or consequence, and a score at the circumference of the plot indicates a high impact. Key example barriers and consequences are picked out and described in each case. Note there is further information about this analysis in the separate WP3 report.

> "Analysis shows high implementation difficulty, and high consequences if not delivered"

4.3.1 Function G3: Plan for the timely restoration of supplies following a total or partial shutdown (Black Start)

Key barriers to implementing function G3 in today's power system

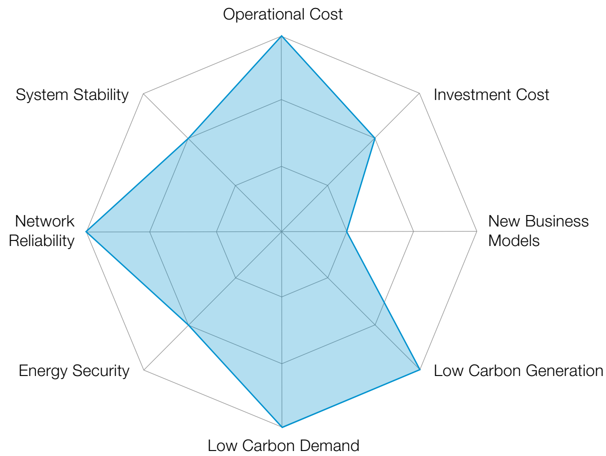


Technical Challenges – there is a need for sufficient resilient energy resources to recover the system, and for reliable communications under Black Start conditions.

Technical Codes – existing performance requirements for Black Start in the Grid Code might be a barrier to some parties who could potentially provide valuable Black Start services.

System Limitation – there is uncertainty of the future Black Start capability with decreasing levels of large centralised fossil fuel generation.

Consequences of not implementing function G3 to the future power system



Network Reliability – there is a risk that Black Start procedures become inadequate, resulting in a significant risk to system restoration.

Operational Cost – lack of long-term incentives could reduce investment in Black Start capability, potentially resulting in a smaller market of providers and thus higher costs of Black Start services.

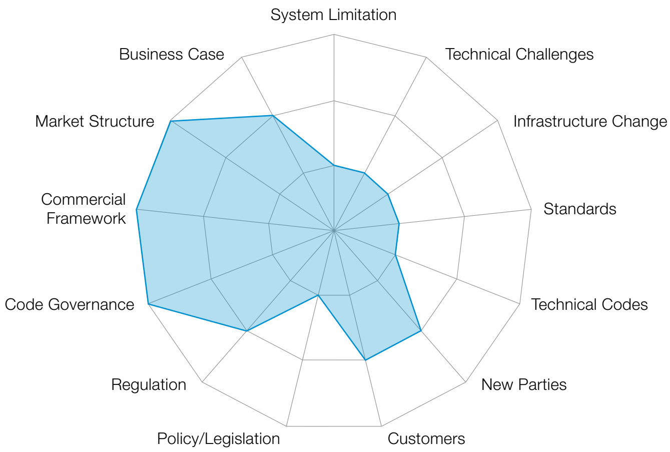
Low Carbon Generation – if low carbon generation is not able to provide Black Start services, then the level of penetration may be limited to ensure Black Start capability is sufficient.

4.3.2 Function H5: Provide a market structure that enables customers to have choices within the power system

Key barriers to implementing function H5 in today's power system

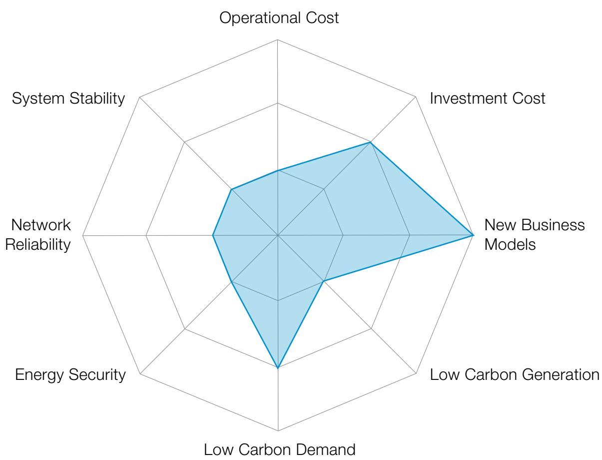
Market Structure – today's market structure does not support some innovative new products that participants may want to offer to consumers.

Commercial Framework – commercial models to accommodate consumer-led or community energy propositions are at an early stage of development. Access to data might be a barrier to new parties to identify and develop new business models.



Code Governance – the evolving market structure and accommodation of new parties may require significant updates or changes to existing industry codes involving a wide range of stakeholders. Code governance processes can be fragmented and generally do not take a whole-system view.

Consequences of not implementing function H5 to the future power system

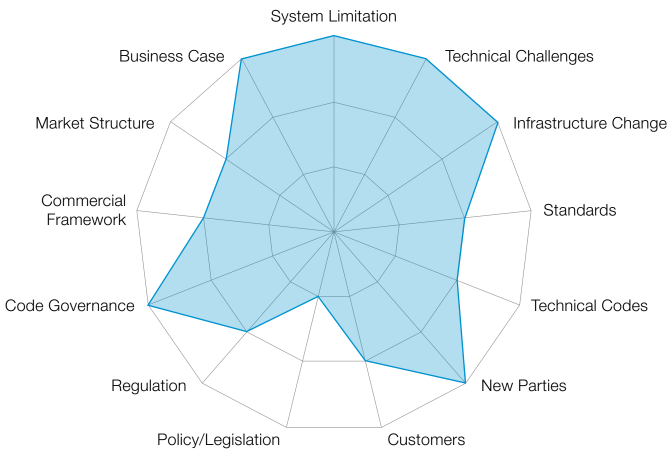


Investment Cost – market arrangements that are overly complex might limit innovation and result in inefficient investment to provide network capacity.

New Business Models – an unsupportive market structure might expose customers to more risk and reduce their appetite for new business models.
Low Carbon Demand – low carbon demand is still likely to connect; however, there may be reduced value to customers in an unsupportive market so uptake could be slow.

4.3.3 Function H6: Enable customers to choose from a full range of market options which determine how they interact within the power system including individual, community and smart city services

Key barriers to implementing function H6 in today's power system



System Limitation – system functional limitations might result in a lack of smart services, leading to network capacity constraints and limiting the range of market options available to customers.

Business Case – setting up new market options may require significant investment, and the business case is challenged by uncertainty and risk. There are also issues of scale and availability of start-up funding.

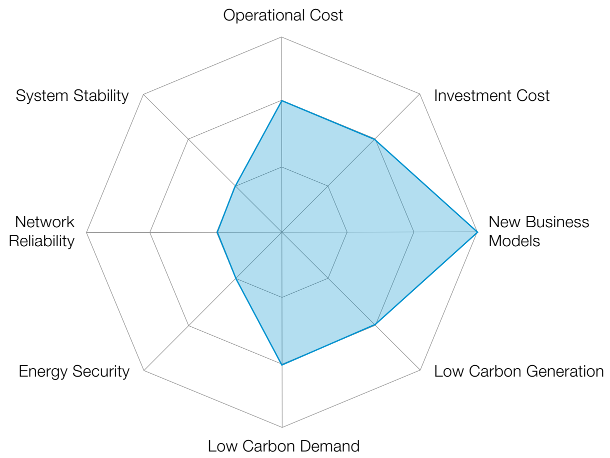
New Parties – services may be offered by a wide range of parties. There is a challenge in implementing appropriate codes and standards to co-ordinate their activities and ensure stability and security of system operation.

Consequences of not implementing function H6 to the future power system

New Business Models – the lack of market options for consumers may deter the development of new, innovative propositions.

Investment Cost – whole power system investment may be inefficient due to a lack of customer options that enable contributions to management of existing grid capacity.

Low Carbon Generation – options such as community energy schemes supporting low carbon generation may be limited.



5. *Enabling Frameworks* Provide a Mechanism to Implement Functions

5.1 There's an identified need for a new approach beyond today's sector arrangements

As described in section 4.1 of this report, the work of FPSA2 indicates that a new scale of change is needed beyond that currently supported by industry change processes. The barriers identified to implementing the FPSA functions are complex, and often relate to key parts of the current industry institutional arrangements, including the change process itself, governance and market structure.

The commercial and technical solutions that are considered viable from an economic and risk perspective are dependent on the market structure and governance arrangements that they operate within. As today's arrangements consider much of the power system in discrete market segments, or silos (e.g. regulated transmission and distribution), and activity on the customer side of the meter is not considered part of the power system. The ability to take account of the potential of new business models and solutions across these different silos is sometimes challenging or impossible.

"A new approach is needed beyond today's arrangements"

Taken together, this indicates that a new approach is needed beyond today's power sector arrangements. This new approach will need to have key differences to today's mechanisms, in particular, the active inclusion of all stakeholders who consider themselves to be part of the wider whole power system, and enablement of dynamic and ongoing change. A key aspect of this approach is that it must be capable of enabling a wide range of functions to be implemented, whether they are part of the *thirty-five* FPSA functions that have been identified and developed, or new functionality identified in the future as the requirements of the future power system develop and evolve.

Therefore, within FPSA2 the new approach is referred to as ***Enabling Frameworks* (*EFs*)** – this approach will not prescribe the future energy solution, rather it will be the framework that will enable the future power system solution to be developed and improved on an ongoing basis by relevant parties, both existing and new.

EFs should be developed with the requirements of society's future needs and aspirations at its core. As described earlier, this is translated into system functionality[9] that will need to be implemented to meet those needs, and the barriers[10] to implementation in today's power system environment, which must be overcome without adding others. This cannot be achieved unless all power system stakeholders are given the opportunity to be engaged and recognise their input into the resulting solution. *EFs* will promote the integration of iterative continuous learning and leveraging learning from other sectors. Using this approach, the following aspects have been identified as the foundation and guiding principles for the development of *EFs*:

- Foundation principles – these are informed by requirements that are mandated by UK legislation:
  - Facilitating decarbonisation.
  - Supporting competition and championing consumer interest.
- Guiding principles – these are built with reference to the requirements of the system and its stakeholders, using the evidence built up within FPSA2.
  - Stakeholders integrated in the process.
  - Enhanced co-ordination and facilitation.
  - Maximise synergies.
  - Facilitate conflict resolution.
  - Transparency and visibility.
  - Innovative approaches to accelerate decisions and support system change.
  - Ongoing feedback from and iteration of all activities – an iterative learning and adapting ecosystem.
  - Support and harmonise technical and economic evaluation.
  - Strive for simplicity at the point of use.

> "An open and flexible environment requires a different approach"

A framework that creates an open and flexible environment requires a different approach to the linear and predictable processes that are more familiar to many. Such approaches have been successfully used in other applications where this flexibility is needed. For example, the US military application of CONOPS (Concept of Operations) is used to prepare for ambiguous, uncertain and volatile environments. The goals in military CONOPS often change midway, and the personnel are equipped with training in tools and approaches that will allow them to prepare, and have instilled in them the idea that what is considered a success may change.

Taking best practice from other sectors has been a key approach of building the *EFs* concept that is described here, 'fuzzy goals'[11] have been used in software development for many years and have proved to be a good way of managing uncertainty and interdisciplinary challenges while developing solutions.

The following characteristics will be important when considering *EFs*:

- **Goals and work approach** – there is significant uncertainty regarding the end goal(s) of the future power system, and hence there is a need for agility and flexibility in approach. 'Fuzzy goals' provide motivation for the general direction of change without placing unnecessary constraints and inflexibility. This approach does not mean that the outcomes will be less tangible or useful, but that they will be formed and refined over time, ensuring that they are successful and relevant to the time they are delivered.
- **Relationships and communication** – co-ordination and participation of a wide range of stakeholders would traditionally create significant complexity. It is therefore critical that tools that support this working approach are used, e.g. a network-based working environment that would enable diverse and varied communications and relationships. These tools will allow stakeholders to be guided and supported in what for many will be a new way of working. Interactions and activity would be actively managed to support and measure inclusion.
- **Flexibility and responsibility** – there is a need

[9]The FPSA functions have been explored and reported in detail by Work Package 2, which is reported in detail here: www.theiet.org/FPSA and https://es.catapult.org.uk/FPSA
[10]The barriers to implementing the functionality in today's environment have been explored and reported in detail by Work Package 3 here: www.theiet.org/FPSA and https://es.catapult.org.uk/FPSA
[11]Alan Blackwell from the University of Cambridge in his research "Radical Innovation: Crossing boundaries with interdisciplinary teams" refers to 'fuzzy goals'. He highlights the importance of providing motivation for the general direction of work without placing unnecessary blinders or burdens on the innovation team as this may mean that they miss out on great opportunities that may arise during their work.

> “Flexibility and inclusiveness for a wide range of stakeholders ”

for flexibility and inclusiveness of a wide range of stakeholders, which requires a flexible approach, and also for assigned responsibility for the system and its operation. These potentially conflicting aspects must be core characteristics in the framework.

5.2 *EFs* – a new process for delivering new functionality

Within FPSA2, the concept of *EFs* has been developed and described at a high level. It is important to understand that the description below is outlining a new process and is not, at this point, trying to allocate roles and responsibilities, accountabilities or funding streams. This will need to be decided in the next iteration of FPSA as there are many key considerations to take into account, including transitional arrangements for migrating to a significantly different approach while respecting the relationship between existing and new organisations, businesses and government.

Highlighting the needs and barriers today, exploring the enablement process at the potential interfaces, and identifying the complexity that it is trying to deliver, provides an insight into the potential direction of travel.

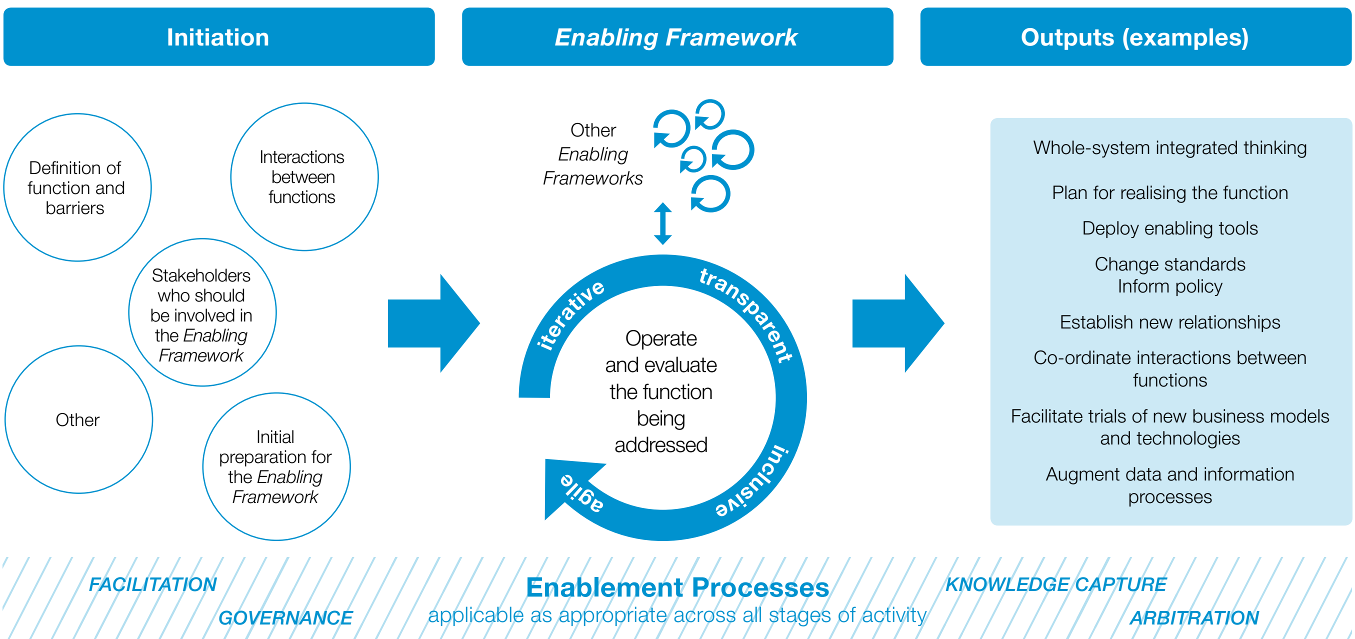
This allows early consideration of aspects such as how different organisations may map onto this process, the possible need to review roles, and highlighting responsibilities and accountabilities. The next steps, to develop this work beyond FPSA2, is described in Section 6 of this document.

Individual *EFs* will be set up to implement and maintain a particular area of functionality that is not currently being met or is in need of significant enhancement. This functionality can be identified through a number of routes, including through the identification of a newly identified need or a barrier that has to be removed; this may stimulate innovative new concepts or adapt and improve current solutions.

Within FPSA2, the *thirty-five* identified functions make up the first list of required functionality that can be discerned from today's known needs. It will be a key feature of the *EFs* that new functionality can be brought forward easily by any party, therefore not restricting the driving of this process to the major existing system participants or government.

Each individual *EF* will then continue to maintain the functionality as system requirements and landscape change and evolve, ceasing only when the need for the function goes away or is superseded.

Figure 4: An *Enabling Framework* is an ongoing iterative process that is initiated with its function definition, identification of a stakeholder group, and basic preparatory work



5.2.1 A Stakeholder Network will have a significant role in decision-making and creation of new functionality

The *EFs* process will involve a group of relevant and engaged stakeholders, the Stakeholder Network, who play a significant role in developing the approach and in decisions about new and enhanced functionality. All relevant stakeholders across the industry, market, and society will be represented, including new players such as energy communities, those who are currently at the periphery such as providers of connected consumer technologies, and representatives of customers and other system users. Participation of these stakeholders is vital to give the process legitimacy and ensure that the new power system functionality is developed to meet all of society's needs.

The participation of these stakeholders will need to be carefully co-ordinated, to ensure that all stakeholders have the opportunity to contribute, appropriate to their expertise, interaction with the function being enabled, and role within the whole power system. Stakeholder engagement will need to be designed to ensure that a wide range of parties are able to be involved even if their resources may be limited. The interaction of these participants may be through a mix of methods that can enable a collaborative approach and continuous information sharing.

> "An iterative process, with transparency and standardised practices"

Transparency and standardised working practices will be essential to enable the stakeholder network to effectively make decisions. For example, this could be managed by a network-based working environment supported by online tools.

An involved and effective Stakeholder Network is critical to the speed, efficiency and effectiveness of *EFs*. Members of the Stakeholder Network brought together to address a particular function might include some or all of the following (this listing is not necessarily exhaustive and will depend on the nature of the function under consideration):

The stakeholder group will need to interact with the other *EFs* that are taking place in parallel, in order to co-ordinate changes and manage the implications across the whole power system. They will also need to interact with over-arching streams of activity that are common to all *Enabling Frameworks*, such as legislation, regulation, and safety. These streams of activity are called *Common Enabling Frameworks*; they set some critical cross-cutting and manadatory requirements on the *EFs*, and because of the ongoing interaction with all *EFs*, these changes will be consistent for all functions and the implications between functions will be clearly understood.

Stakeholders
- Consumer representatives
- Industry bodies
- Government
- Vendors
- Utilities
- New entrants
- Other energy vectors

***Common Enabling* framework topics**
- Legislation
- Regulation
- Standards
- Safety and security
- Industry processes

> "The *Common Enabling Frameworks* set critical cross-cutting and mandatory requirements"

Owing to the complexity of the different interactions between multiple stakeholders, market structure, commercial contracting, and technical solutions, there is a need to enable and co-ordinate this activity. It will be important to bring continuity to the evolving and changing activities of the *EFs*, in order to be able to focus on the details that are important, retain learning and provide essential arbitration.

Within FPSA, this role is referred to as the *Enablement Organisation*, it is important to consider this as a core facilitator and moderator of different organisations, therefore could be made up of a number of different disciplines and existing organisations (note the term organisation is not necessarily meant to convey a singular body, although it is not precluded). The *Enablement Organisation* would carry out the following activities:

- **Facilitate change** – the *Enablement Organisation* will set the foundations and conditions for change and monitoring progress, by facilitating the initiation of new *Enabling Frameworks* and monitoring their success.
- **Governance** – the *Enablement Organisation* will ensure adherence to guiding principles of *EFs*, and provide independent validation and assurance of measurement.
- **Knowledge** – the *Enablement Organisation* will ensure knowledge and information is provided, captured, and shared where appropriate, and ensure harmonisation of approaches and measurement through tools and benchmarks.
- **Co-ordination** –the *Enablement Organisation* will ensure that various activities and parties come together effectively in the delivery across the *EFs*, and facilitate activities related to the *Common Enabling Frameworks*.
- **Arbitration** – the Stakeholder Network will be designed to take decisions for the management of the activities, preferably through consensus or weighted discussion and democracy. It is recognised that some issues may not be able to be resolved by the stakeholders themselves, and the *Enablement Organisation* will need to take into account the views of stakeholders, ensuring that decisions are taken in the best interests of all societal needs over the long term.

"The *Enablement Organisation* does not dictate the outcomes of the *Enabling Frameworks* "

Note that the *Enablement Organisation* by design does not dictate the activities or outcomes of the *EFs* – this is carried out by the stakeholder groups. Where there is a dispute, the *Enablement Organisation* would attempt best efforts for consensus or conciliation, before arbitration. The *Enablement Organisation's* main activities are in facilitating and providing tools for the *Enabling Frameworks* to be able to carry out the activities. An important topic for closer examination in FPSA3 is the clarification of where accountabilities should be best assigned. There are critical issues that require unambiguous accountability for delivery and oversight of new functionality.

A key characteristic of the *Enablement Organisation* will be that it is capable of providing balanced and supporting capability for the *EF* activities and, most importantly, for all stakeholders in the industry.

The governance model, decision-making, funding approaches and accountability aspects of *EFs* including that of the *Enablement Organisation*, has not been considered in full as part of FPSA2, these will be a key focus of the next phase of work. Some further detail of current thinking is however provided in the separate WP4 report.

5.2.3 Initiation and ongoing maintenance of Enabling Frameworks

The set-up of *Enabling Frameworks* includes the concept of pre-structuring activities. During this activity, key aspects of the required functionality are explored and tested, to firstly validate the need for them and the benefit they would deliver, and also to ensure that the *EF* is set up in an appropriate way – with the most suitable stakeholders involved and with the required research, tools and capabilities available to ensure a validated, coherent and speedy start to the process.

The aspects that will be defined and explored during this pre-structuring activity include:

- **The function definition** – including understanding the range within which the function needs to operate and the complexity of change in functionality required.
- **The function needs** – the processes and tools that that will be needed to enable the function to be implemented.
- **The function barriers** – the identified barriers to the implementation of the function.
- **The stakeholder group** – the stakeholders who are affected or will interact with the function, who should be involved in the enablement and implementation of it.
- **Interactions with other *Enabling Frameworks*** – the dependencies and interactions that this function has on the other functions being enabled, and the *Common Enabling Frameworks*.
- **Prestructuring of the *Enabling Framework*** – any work or thinking that can be done in order to support the set-up and kick-off of the *EF*, e.g. a literature review of any related projects or

research, and identification of tools that could support the delivery.

Once an *EF* is set up, it becomes an ongoing activity continually working to provide the required functionality and update this provision as new opportunities arise, or as the wider landscape changes (e.g. other *EFs* make changes that have implications for the function under consideration). This activity continues for the life of the function, being agile and iterative to change, until the need for the functionality no longer exists or is superseded by other activities.

5.2.4 Enabling Frameworks and innovation

Innovation is an integral part of *EFs*. New needs or barriers can be identified by any party, and this includes innovators with ideas of how to overcome barriers and those that can identify new ways of delivering existing functionality to increase competition or widen customer choice. In this case, the pre-structuring activities will test the viability, suitability, and potential benefits of the innovation.

> "The *Enabling Frameworks* can test innovations and their implementation"

All *EFs* are set up to implement certain functionality, and the means by which they do this can involve testing new innovations, bringing them to trial, and their implementation. Therefore, innovation can be considered in the ongoing *EFs* as well as their initiation.

It should be noted that an *EF* does not replace the need for early technology readiness level (TRL) research. However, it does provide clarification of real needs on the system, and therefore identifies tangible problems to solve. It also provides a clearer route for research ideas, once developed, to find traction towards widespread implementation.

5.3 The transition to *Enabling Frameworks* requires care for safety and security

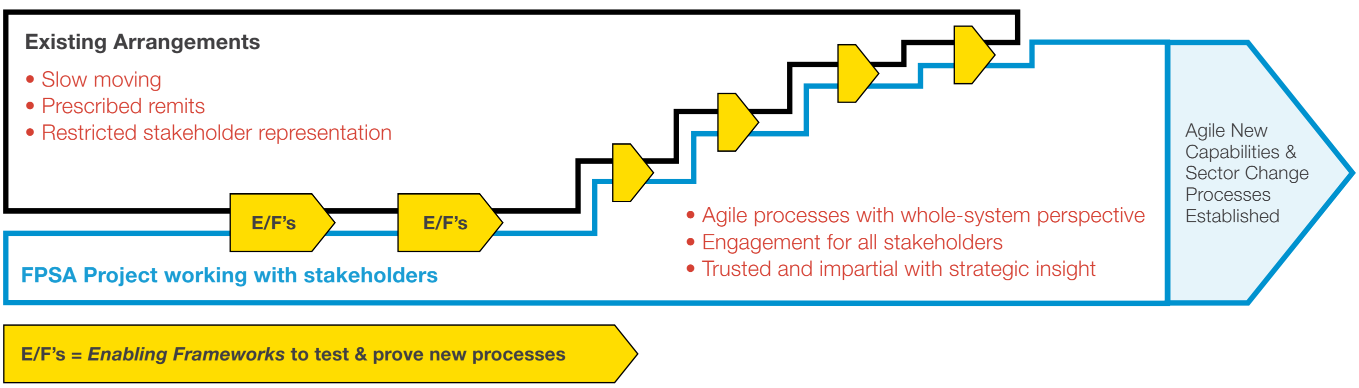
It will be important that any change to *EFs* is managed carefully, in order to maintain safe, secure supply of power to GB society. A likely approach would be that *EFs* would be adopted gradually to enable change from the existing processes to future processes. Through this process, the *EFs* undertake sequential demonstration and implementation where learning is used to develop the framework itself, and ensure that it is capable of meeting the needs of the system and of society.

> "The transition needs to be managed with care, building trust and credibility"

This will build trust and credibility in the process and demonstrate if the process of *EFs* is delivering the desired results. It is therefore necessary to retain organisational knowledge given the time it is likely to take for the new power system to be implemented. This need to ensure corporate memory and build new capacity as new disciplines are required is another reason that the *Enablement Organisation* is necessary.

This process of transition in context from existing to future processes is illustrated in Figure 5 below and summarised in the following key points:

Figure 5: Transition from existing to future processes facilitated by *Enabling Frameworks*



- New arrangements work with and adjacent to existing arrangements.
- Over time, new arrangements supersede the current arrangements.
- The *EFs* are the mechanisms for change.
- The end goal is a new set of change processes and capabilities.

> "The end goal is a new set of change processes and capabilities"

5.4 Three case study functions that explore and test *Enabling Frameworks* in detail

In order to explore the concepts being developed within FPSA2, case study functions were studied in more detail. Section 3 above includes the first part of this case study function work for three functions, i.e. a detailed function description and identification of what the function needs in order to be implemented. Section 4 summarises the barriers and consequences of non-delivery for each of these functions.

> "The case studies confirm the importance of all the elements of an *Enabling Framework*"

The sections below explore elements of the *EFs* for each of the case studies. The testing of the three case studies has confirmed the importance of all elements involved in the *EF* creation process and the roles they play. It has also informed further details within these *EF* elements and their requirements.

The next steps to develop the work on *EFs* beyond FPSA2 are described in Section 6 of this document.

5.4.1 Function G3: Plan for the timely restoration of supplies following a total or partial national power system shutdown (Black Start)

The context: The advent of large amounts of distributed generation and intermittent sources that are not able to be controlled in the same way as a conventional large power station and the associated fall in the running of existing black start stations will present significant new challenges to the management of a Black Start. This will be compounded by new demand types that could put unacceptably high loads on the system instantaneously when supplies are restored (e.g. electric vehicle charging, heat pumps, local storage).Further, public tolerance to owning generation and yet not being able to use it, perhaps for days (as might be necessary if there are safety issues for the network) could be a challenge for all parties. Hence examining this function provides a demanding context for testing the *EF* process to understand how it could develop innovative, secure and safe approaches to this issue. It exercised the process on many different levels from governance to technical integrity.

How could the *Enabling Frameworks* approach address function G3?

Features of the *Enabling Framework* – the *EF* would identify and plan a suitable approach to Black Start which would address the range of needs and barriers identified, and work to drive any actions to prepare the system to implement this plan.

> "Black Start options are affected by the rapid developments in the energy system"

As Black Start options are affected by rapid developments within specific aspects of the energy system as well as across the whole power system and its architecture, ongoing horizon scanning and monitoring of other functions is particularly key in this function.

Stakeholder Network – there is a set of stakeholders who are involved in the Black Start procedures today, who should be prominent in the stakeholder network. However, the impacts and potential interactions of this function are far reaching, and therefore there should be an aim to advertise, inform, and recruit a breadth of potential stakeholders for inclusion in the network beyond the traditional stakeholders.

Role of *Enablement Organisation* – this will include a key role in prestructuring, set-up, and facilitation of the *EFs*. Function G3 is likely to have impacts on existing and new commercial services, and so the stakeholder group is likely to include vested interests, and changes may result in 'winners' and 'losers'. Therefore, a particular role of the *Enablement Organisation* in this case will be to provide arbitration and robust decision-making, potentially based on a suitably democratic process.

Common Enabling Frameworks – the steps necessary to overcome the identified regulatory and commercial barriers will influence the selection of the preferred Black Start option. Cyber security, communications with stakeholders and societal impact in terms of customers' expectations and attitudes are also an important area. Interaction with *Common Enabling Frameworks* that impacted and influenced these areas would therefore be important. Subsequently the *Common Enabling Frameworks* would receive instruction from the *EF* for G3 to develop and implement the necessary changes to support the adopted approach.

Prestructuring – this will include developing and defining the description and detail of the function, and identifying stakeholders who should be part of the Stakeholder Network. For function G3, this should also include establishing the baseline through review of existing GB and international approaches to Black Start.

5.4.2 Function H5: Provide a market structure that enables customers to have choices within the power system

The context: A characteristic of the transformative change facing the power system is a great expansion of new energy products and energy services for customers, especially residential and small commercial parties. These developments are taking place 'beyond the meter' in customers' homes and involving commercial parties entirely new to the sector. The drivers for this closer engagement by customers include better information (for understanding costs and energy usage), energy efficiency (such as through more intelligent control of heating and cooling), convenience (by accessing attractive energy automation controls), more affordable energy (e.g. by being rewarded for offering flexible timing of demand, such as for EV charging), a desire to engage with more sustainable energy practices (e.g. through distributed generation or storage), and a shift towards closer engagement with local community energy enterprises. All of these activities require access to necessary data, commercial frameworks, and 'interoperable systems' that ensure customers have choice and are not locked in to a single provider.

How could the *Enabling Frameworks* approach address function H5?

> "The *Enabling Framework* would identify, evaluate, select, and implement new market structures"

Features of the *Enabling Framework* – the *Enabling Framework* would identify, evaluate, select, and implement new market structures and their data requirements. These market structures must allow new parties to bring new opportunities to the market. The market design therefore needs to be flexible to accommodate emerging future and unknown requirements.

Stakeholder Network – function H5 is driven by legislative enablement. However, technical and societal aspects remain as significant influences. This highlights the importance of a diverse stakeholder network to make sure that all perspectives are taken into consideration.

Role of the *Enablement Organisation* – this will include a key role in prestructuring, set-up, and facilitation of the *EFs*. It is identified that new aspects of market design, such as peer-to-peer trading, may not be brought to bear by traditional participants within the industry and it is therefore important that the *Enablement Organisation* facilitates appropriate involvement of all stakeholders who are needed in the Stakeholder Network.

Interaction between *Enabling Frameworks* – to a large extent, the function H5 *Enabling Framework* is a facilitator for the customer choice enabled through function H6, and as such it must also inform function H6 with regards to the feasibility of choices. Interaction with other functions is also particularly important within the *EF* for function H5, as the market design will have impacts across the whole power system.

5.4.3 Function H6: Enable customers to choose from a full range of market options which determine how they interact within the power system including individual, community and smart city services

The context: The new energy products and energy services described above in practice are located in a much wider context. For example, demand flexibility may be an attractive way of accessing more affordable energy (say, through Time of Use tariffs or provision of flexibility services 'on-demand'). However, this flexibility may be of value to the local network or the national network, and may interact with local community energy or smart city developments. For these new products and services to work seamlessly, and be simple to operate at the point of use, considerable attention will be needed to their functioning within the home and across multiple system interfaces and parties. This smooth interaction with the wider power system is provided by function H6.

How could the *Enabling Frameworks* approach address function H6?

Features of the *Enabling Framework* – the development of new propositions will be driven by potential suppliers and other actors who wish to be incorporated into the system.

> "New propositions will be driven by potential suppliers"

Therefore, the role of function H6 *EF* is not in the detailed development of propositions. Where function H5 focused on the commercial market requirements, function H6 needs to enable a plethora of new innovation at the household level. Some of this new functionality will be enabled by other *EFs*, for instance those that provide smart electric vehicle charging or those that provide heat pump automation. Therefore, this function will require an understanding of what functionality already exists in other *EFs*, what new functionality is required and how these interactions and integration issues can deliver the required outputs that will allow new offerings at an individual, community and smart city level. It is likely that the *EF* for function H5 will play a significant part in this.

> "The stakeholder network must draw on alternative thinking"

Stakeholder Network – the stakeholder network will need to be carefully constituted to ensure access to a wide knowledge and representation of the whole industry in order to facilitate the identification and assessment of propositions and needs, such as the need for alternative thinking or solution provision of functionality.

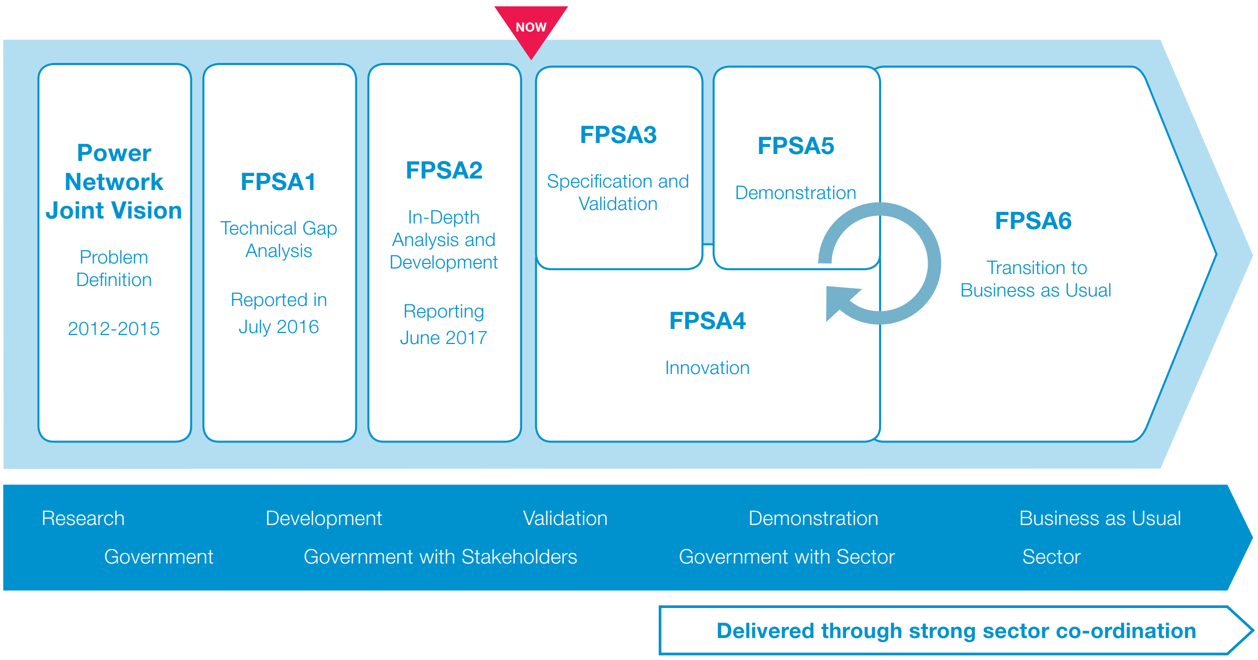
Interaction between *Enabling Frameworks* – interaction with other *EFs* is particularly important, both to inform evaluation of propositions, and to enable implementation of identified changes.

Role of *Enablement Organisation* – this will include a key role in prestructuring, set-up, and facilitation of the *EFs*. It is identified that function H6 requires a wide range of stakeholders to be involved, and the recruitment, facilitation, and interaction tracking of this will be a key role of the *Enablement Organisation*.

6. Significant Work Lies Ahead, Critical to Achieving Successful Outcomes

The FPSA journey is illustrated in Figure 6 below. This shows the key stages of the work, from problem identification through to supporting the sector in responding effectively. Developing a new approach to enabling transition is core to the programme focus going forward.

Figure 6: The FPSA Journey



The work of the FPSA programme to date highlights the importance of acting now to ensure that the power system can adapt to address the complex and uncertain demands that will be placed on it in the period to 2030 and beyond. These demands were identified and documented in the Power Network Joint Vision work, which preceded FPSA.

> **“**This programme will build understanding of functional needs, potential future structures and innovation gaps**”**

The programme seeks to continue its work to further build its understanding of functional needs, potential future structures, innovation gaps and approaches for managing change as the power system undergoes transformation:

- **FPSA1** – undertook deep analysis to identify the functions that will be needed by 2030 to support the anticipated transformation of the GB power network.
- **FPSA2** – confirmed the technical functional needs, determined the barriers to implementing them and proposed *EFs* as an approach for implementing them in an agile, inclusive, collaborative way that seeks to respond to the need to do things at a much greater pace than today’s processes demonstrate.
- **FPSA3** – will build further on the *EFs* activity completed in FPSA2, exploring the issues and perspectives of all relevant stakeholders, and validate this work by developing a Framework (and associated tools and techniques) for a one or more specific use cases (to reflect latest thinkingsuch as supporting wide scale EV deployment). The core activities in FPSA3 will be simulations and research.

> **“**FPSA4 will build and execute a portfolio of aligned projects**”**

- **FPSA4** – will build and execute a portfolio of projects to address innovation requirements and opportunities identified in FPSA2, which are aligned with implementation of the *thirty-five* functions. The activities include innovation investigations and practical projects.
- **FPSA5** – will use the outcomes from FPSA3 and FPSA4 to build a demonstrator or demonstrators that will provide real world experience of applying *EFs* to address a prioritised need and in the process, enable further enhancement of the approach, its structure and operation.
- **FPSA6** – will work to establish the transition of the approach into the business as usual way of operation. By this point the structures should have been established and widely understood and the sector become actively engaged in the migration process from today’s mechanisms that are becoming increasingly unfit for purpose.

It is envisaged that as the work develops there will be a gradual increase of ownership by consumers, industry and governmental stakeholders, working within an overall programme structure.

- **FPSA Programme** – will strengthen the current project approach with a well-defined and structured programme management capability that will sit across all FPSA activities and assure convergence, coherence and alignment in approach. It is likely that engagement with other energy vectors such as gas and heat will become increasingly relevant.

The primary recommendation of FPSA2 is to progress to the next stages of the work drawing more closely to the sector to ensure that there is alignment in purpose and approach. The next stages are described in the section that follows.

6.1 FPSA Programme

The FPSA Programme will provide structure and coherence to the FPSA work, which is particularly important where parallel activity is undertaken. The programme will carry out the following activities:

- **Programme Governance** – provide shared and consistent governance across FPSA activities.
- **Programme development and management** – undertake core programme functions in support of the programme overall, and where FPSA3 and FPSA4 have shared needs, e.g. dissemination and stakeholder engagement needs.
- **Support for FPSA activities** – respond to specific programme and activity needs, e.g. prioritisation of projects in FPSA4.
- **Positioning** – position the programme in supporting the Industrial Strategy, and the opportunities for job creation and markets outside of the UK.

- **Forward planning and engagement** – undertake horizon scanning, engage with other like initiatives and investigate synergies with work in other energy vectors.

6.2 FPSA3

FPSA3 will validate the *EF* structure and its application through an iterative approach. It will determine how new functions can be enabled in the face of barriers to implementation and new needs by establishing a process for supporting transformation. The activities of FPSA3 will include:

- **Continued development and early implementation of *Enabling Frameworks***
  - Validate the *EF* structure and its application through an iterative approach involving industry dialogue, and explore perspectives not yet examined, such as legal and economic issues.
  - Develop aspects including accountability, decision making and funding and create a proposal for the real or virtual organisation that could operate them.
  - Identify the tools and capabilities needed to support implementation; these are expected to include advanced digital collaboration platforms suited to managing large, complex stakeholder engagements.
  - Determine how the *thirty-five* functions will be addressed through *Enabling Frameworks* using desk studies and modelling of use cases/ scenarios.
  - Develop a transition pathway that recognises the coexistence of today's governance mechanisms through an agreed migration period.
- **Proof of concept** – deliver proof of concept validation via a study of sufficient depth and strength to be able to drive initial deployment activities in further phases (a possible use case could be the functions needed to enable EV deployment). Any use case will require consideration of potential wider interactions, such as provision of system flexibility, interaction with community energy enterprises, and smart city developments. The anticipated outcomes would include a report describing the use case, the proof of concept findings and identified requirements and enhancements for *EFs*.
- **Preparation for initial deployment** – prepare for initial deployment in which demonstrations of increasing scale and complexity will be undertaken; preparation will include defining, planning and building the convincing business case for progressing and attracting participants to demonstrators. The initial deployment should be configured to allow for business as usual operation if the trial process is successful.

6.3 FPSA4

FPSA4 will comprise a portfolio of innovation projects undertaken within a coherent FPSA framework that adds value to the *EF* FPSA 3 work. The projects will address requirements and opportunities in areas that are very likely to be needed to enable the future power system. The portfolio will be constructed to enable funding to be pursued through innovation competitions and other approaches.

The nature of what fits into this portfolio will be drawn from analysis undertaken in FPSA2 and will focus on the RD&D and Innovation topics required to enable the *thirty-five* FPSA functions. It is anticipated that the resulting findings will be implemented and become part of the future power system through application of the *EF* process.

> **"** FPSA4 will begin activities to enable the *thirty-five* new functions, through RD&D and innovation **"**

The innovation opportunities developed as part of FPSA2 were identified based on an assessment of their importance and urgency; a criterion applied was a requirement to try to avoid restricting future choice by locking-in the direction of future transitions. This list is being kept under review with items being added as appropriate.

The innovation areas identified include[12]:

- **RD&D and Innovation actions based on Evolutionary Pathways**

[12] This list of RD&D and Innovation topics has been described and developed as part of Work Package 2 in FPSA2, and the detail is reported here: www.theiet.org/FPSA and https://es.catapult.org.uk/FPSA

  - Mechanisms to encourage participation in change processes.
  - Market designs and policy mechanisms for promoting policy objectives.
  - Monitoring impact of customer behaviour on networks.
  - Exploring new options for Black Start and Cold Start including distributed energy resources.
  - Forecasting modelling and scenarios with increased complexity to account for the whole power system including distributed energy resources.
  - Maximising power system capacity through implementing technical and commercial smart grid solutions.
  - Mechanisms for automated and secure management of demand and generation.
  - Mechanisms to enable new market options that reflect customers' needs.
- **RD&D actions based on future functionality and common FPSA themes**
  - Power systems and market modelling capability, including whole-systems modelling accounting for increased complexity.
  - Capabilities for monitoring and metering throughout the whole power system, and use of data for system operation and settlement for services.
  - Future IT, communications and control, and cyber security requirements of the system and develop solutions where needed.
  - Data collection, transport, analytics and use, including 'big data'.
  - New business models being proposed, or those that may be required in the future, including enabling local energy markets.
  - Multi-vector interactions, including technologies and techniques, and their benefits to the whole power system and a wider multi-vector energy system.
- **RD&D actions based on primary research**
  - Customer protection including consideration of engagement materials and channels, including a focus on vulnerable customers.
  - Consumer response to price and the role of social norms in consumer engagement.

6.4 Beyond FPSA3 and FPSA4

The vision of the FPSA programme is to collaborate with others to demonstrate and establish an approach to supporting and enabling required change in the power system.

FPSA3 and FPSA4 will deliver proof points: learning and preparation outputs that will enable demonstration of the approach and its associated structures at appropriate scale. When completed, this will make clear a path for transition to 'business as usual' providing a tested approach that meets the key requirement for achieving coherent, co-ordinated transformative change.

The work of the PNJV and FPSA projects to date has benefited greatly from wide stakeholder engagement across the whole spectrum of electricity production, transmission, distribution, end use and storage, including government, established and emerging industry, academia, consultants and many others. The FPSA2 contact database now exceeds 1,000 interested and active parties. This wide engagement, through workshops and events, and by the Project Delivery Board, gives confidence that the thinking is sound, the evidence presented is strong, and that there is a rising swell of opinion in support of the changes being mapped out. There is significant potential here to bring benefits to all stakeholders and to the national context.

> "There is significant potential here to bring benefits to all stakeholders"

7. Glossary of Terms

Term	Definition
Aggregators	Parties that enter into contractual arrangements with clients to assemble portfolios of energy resources (e.g. flexible generation, demand and/or storage) in order to provide system balancing and other ancillary services to a system or network operator such as network constraint management.
Architecture	The designed and emergent structure of a system, and the manner in which the physical, informational, operational and economic components of a system are organised and integrated.
Common Enabling Framework	Mechanisms for delivering enablement in areas common to multiple functions, such as regulation. They will manifest as programmes of work supporting the broader transformation, however, focussed on their particular domain for efficiency purposes.
Community Energy Enterprise (see also Energy Community)	An organisation trading for social benefit on energy projects, that is owned and managed by members of the community it serves, whether defined by geography or interest. Typical forms of community energy enterprise include Community Benefit Societies, Co-operatives, Community Interest Companies and charities and their trading companies.
Distributed Energy Resource	An electricity generation, storage, or demand technology that is installed at premises that are connected to a distribution system or directly connected to a distribution system and is under stakeholder control, with the potential of offering services to the system such as real or reactive load, voltage response, or storage of excess generation.
Enablement Organisation	The mechanism within the *Enabling Framework* Architecture which facilitates, and in its broadest sense is responsible for, the smooth operation of the *Enabling Frameworks*. The term organisation is not necessarily meant to convey a singular body, although it is not precluded.
Enabling Framework	An *Enabling Framework* is a transformation mechanism or process that seeks to overcome barriers and meet the needs of the required transformation, which is entirely new to the electricity sector. In the context of the GB electricity system, an *Enabling Framework* would be aligned to one or more of the functions that has been identified as necessary in the future energy system architecture.
Energy Communities (See also Community Energy Enterprise)	Parties, including aggregators, Smart Cities, users of common smart connected technology, and community energy enterprises, who can represent groups of customers and their interactions with the rest of the power system. These groups may be physically proximate communities of place, or communities of interest such as owners of the same make of electric car.
Power System Stakeholders	Include existing and new parties: generators at all scales, users at all scales, system and network operators, supply chains, service providers, government, wider society, future users, and all those who interact or could interact with, or could be impacted by, the present or future electricity system.
Prestructuring	Prestructuring is the concept of developing the initial, highly flexible and customisable state of a particular *Enabling Framework* as a starting point for further development in collaboration with the *Enabling Frameworks* Stakeholder Network.

Smart City	Generally used to describe a city in which services, e.g. power and other energy vectors, transport, and communications, are managed together using connected technologies, data and optimisation to the benefit of the city as a whole and the citizens within it. From a power system perspective, a smart city may manage, and potentially have effective operational control of, generation, storage, and use of power, and of private network assets, but as these are managed to meet the objectives of the smart city itself, it may (or may not) have negative effects on the wider power system. To leverage potential benefit of smart cities within the power system, new use cases may be required, lining up control and value sharing for the benefit of the system as well as the city.
Stakeholder Network	The Stakeholder Network is the grouping of stakeholders who directly interact with, or are impacted by, a function, and are therefore engaged in the *Enabling Framework*.
System Balancing	There is minimal inherent storage in the power system, and so there is a need to match supply and demand of power in real time and ensure a series of technical requirements are met.
Whole Power System	Includes the physical, commercial, policy, data, regulatory, consumer owned assets and other aspects of the complete electricity system, and their interactions, including all generation, network and end use aspects, and its interaction with other energy systems, including at the point of end use.
Vector, or Energy Vector	This term is used to describe a mechanism that enables the transfer, in space and time, of a quantity of energy. It may be a system that utilises electricity, heat, natural gas, hydrogen or some other agent.

8. Acknowledgements

This project has been delivered with the essential inputs of a wide range of contracted and volunteer participants. The IET and the Energy Systems Catapult acknowledge these valuable contributions.

The following individuals have contributed their time and expertise to this project. Their participation does not necessarily imply endorsement of the findings of the project by the organisations they are affiliated to. The report is by the IET and the Energy Systems Catapult and addressed to Innovate UK and to relevant stakeholders.

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FPSA Workshops and Stakeholder Engagement Activity Participants
The following list of organisations had representatives at the FPSA project workshop(s) and/or stakeholder engagement activities. These individuals either represented themselves or the organisations they work for. This list is provided to give the reader an understanding of the breadth of engagement across the industry. This report is not representative of the views of the organisations listed below:

Bristol City Council, Centrica, Challoch Energy, Citizens Advice, Dixons Carphone, Energy for London, Electricity North West, Geo, GTC, Highview Power Storage, IBM, KiWi Power, Liverpool City Region Local Enterprise Partnership, National Grid, Northern Powergrid, Open Utility, PassivSystems, Powervault, Push Energy, PWR, Siemens, Smarter Grid Solutions, SmartKlub, Solar Trade Association, Star Refrigeration, Sustainability First, TechUK, Transport for London, Western Power Distribution.

9. Appendices

FUTURE POWER SYSTEM ARCHITECTURE

MEETING BRITAIN'S FUTURE POWER SYSTEM CHALLENGES

The Future Power System Architecture (FPSA) Programme:

Perspectives for the Established Power Industry

Including: SO, DNO/DSO, TNO, OFTO, Large Generators, established networks equipment vendors, key consultancies, technical media.

The power system in Britain is undergoing radical transformation. The Future Power System Architecture (FPSA) programme is taking a holistic and whole-system approach to the evolution of its architecture - considering technical, governance, commercial and societal factors. FPSA is a multi-stakeholder collaboration led by the Institution of Engineering and Technology and the Energy Systems Catapult, sponsored by Innovate UK. This short note explains the importance of FPSA to the established power industry, particularly the asset intensive electricity companies, i.e. networks and large generators, and their traditional supply chain.

Drivers

DNOs (Distribution Network Operators) are evolving into DSOs (Distribution System Operators) with system services already replacing some investment options. Customers will also respond to policy initiatives for the decarbonisation of transport and heat. Through the growth of smart technology customers will both present and expect opportunities to be rewarded for behaviour that supports the efficient operation of the energy system. System operation and its ancillary services will change fundamentally, and become more complex, with an increasing focus on more localised energy markets.

Opportunities and consequences

The growth of more complex, and market driven, customer behaviour presents opportunities for network operators to use this flexibility at all levels within the system, both to save operating and investment costs, and to provide new value streams for customers. It will also change the nature of the existing ancillary services market, requiring existing ancillary service providers to adapt. Existing industry players will need to increase their co-ordination and streamline their joint management of the overall system.

Forward looking businesses will want to anticipate these changes appropriately and position themselves to guide the development of new services etc. and to ensure that customers are not frustrated in terms of the services that they implicitly or explicitly expect from the energy sector. This is a particularly important opportunity for developments that will occur quickly, and at scale.

Increased demand that is attendant on decarbonisation, along with flexibility that customers will bring via smart appliances etc. also brings new risks to power system operation. For example, smart appliances and EVs are capable of co-ordinated actions via market or other signals. This presents some operational risks, but also opportunities to assist the management of the system during emergencies. Particular efforts will be needed in developing appropriate protocols, taking into account customer privacy and cyber security requirements.

How can the FPSA functions help?

The FPSA project has shown that the challenges of future electricity system operation are contained in *thirty-five* functions. Two thirds of these functions exist today, although in a more skeletal form than that which will be required by the 2030s. The challenges of decarbonisation, ever increasing customer requirements, and flexibility, means that the *thirty-five* functions need to be progressively introduced over the next decade.

These functions provide clarity on what sub-functions and processes need to be developed, and highlight the regulatory and governance challenges in doing so. The functions provide a clear base on which detailed approaches, protocols and standards can be developed.

The Network Operator/Large Generator perspective:

The energy sector will change enormously over the next couple of decades. Traditional business boundaries are likely to be swept away, and even where future market services remain similar, there will be a huge shift in the requirements of, and the value placed upon them by, customers of those services. Customers, through smarter appliances etc. will have flexible demand. Without the co-ordinated vision of FPSA it is unlikely that all the value can be unlocked, either for customers or for industry players. Governance of the sector needs to change. The FPSA vision is for a new governance model, known as Enabling Frameworks that is agile, inclusive and timely in enabling the delivery of the *thirty-five* new functions.

Call to action:

The FPSA functions provide a robust and co-ordinated framework to rise to the challenges of the energy trilemma. There is much to do to develop the frameworks etc. within which the functions need to operate. The industry needs to coalesce behind the FPSA vision and work collectively on the technical, legal, regulatory and market changes that the FPSA framework needs.

For more information and to get involved please visit: **es.catapult.org.uk/fpsa** and **www.theiet.org/fpsa**

FUTURE POWER SYSTEM ARCHITECTURE

MEETING BRITAIN'S FUTURE POWER SYSTEM CHALLENGES

The Future Power System Architecture (FPSA) Programme:

Perspectives for Domestic & Micro SME Customers

Including: Domestic/micro-SME customers (and/or representatives thereof), Suppliers and NTBMs (Non-Traditional Business Models) the smart metering community, smart home and energy management services

The power system in Britain is undergoing radical transformation. The Future Power System Architecture (FPSA) programme is taking a holistic and whole-system approach to the evolution of its architecture - considering technical, governance, commercial and societal factors. FPSA is a multi-stakeholder collaboration led by the Institution of Engineering and Technology and the Energy Systems Catapult, sponsored by Innovate UK. This short note considers the view from the grid edge, particularly from homes and small business premises. It includes those who live and work there, those who supply them with energy, and those who offer new 'smarter energy' products and services.

Drivers:

The future power system must allow the creation of new value: firstly, for customers by enabling them to have closer engagement with the energy they buy, use and perhaps sell; and secondly for the new product and service providers. Customers need assurance of simple to use and satisfying new services and technologies, whilst providers need confidence in a seamless and reliable interaction with the power system.

Collective action within communities, alongside family, friends, neighbours, or work colleagues, has the potential to increase engagement by creating new social norms that draw people to something that they wouldn't otherwise have considered. Community Energy Enterprises and Smart Cities may generate greater trust amongst groups of customers by offering local control and a sense of ownership.

Opportunities and consequences:

The extensive opportunities will only become a reality if there is 'joined-up thinking' between the parties and across the sector's many technical and commercial boundaries. The FPSA project has identified *thirty-five* functions needed for the future power system and many of these are directly relevant here.

FPSA analysis identifies drivers for change through the provision of: smart energy choices, energy arbitrage opportunities, options from new low carbon energy applications and resources, added-value services to network operators, and services to Community Energy enterprises.

Without these services, opportunities will be lost across many areas. For example, through lack of understanding of customer preferences and energy usage trends, under-utilisation of smart metering functionality, and opportunities foregone for energy flexibility, there will be loss of value to customers and indirectly increased power system costs through the need for capital investment that could be avoided.

Cross-boundary, whole-system aspects have great importance for these opportunities. New technologies and services require access to data and communications, which may be a local exchange of information say with the local network operator, or may require signalling across a wide area, for example offering flexibility to the national system operator. These data transfers will require a 'common language' (open data protocols) and must be secure against cyber intrusion and ensure data privacy. The FPSA *thirty-five* new functions address these critical issues.

How can the FPSA functions help?

Many of the *thirty-five* power system functions must be fully implemented if these new opportunities are to be rolled out at scale for customers. Proof of Concept trials may usefully be conducted ahead of this, but mass deployment needs scalable systems (e.g. for data handling), which require co-ordinated design, sometimes termed a 'system architecture'. Relevant functionality includes: provision for necessary operator intervention, monitoring of trends and emerging risks, establishing local trading mechanisms, flexible (e.g. half-hour tariffs) and settlement for domestic customers, in-home energy automation, and aggregation of flexibility services including home storage and 'Vehicle to Grid' capabilities.

The home customer perspective: what does this mean for me?

The energy world is changing rapidly and this could offer customers in their homes a huge range of new opportunities. These include much greater clarity of energy use, 'Time of Use' tariffs with home automation to take best advantage of energy price movements, generating their own electricity and storing it or selling it, being rewarded for providing flexibility of their demand or their delivery of power from their home storage or their electric vehicle (Vehicle to Grid). If these new opportunities are to be delivered seamlessly, reliably and backed with top quality service, the wider power system must be equipped for the job - in other words, provided with the necessary new functions identified as key to a smart energy future and to be delivered with a new process, Enabling Frameworks, that is agile, inclusive and timely in enabling their delivery.

Call to action:

For this future to become a reality, many parties must step up and engage with change. This includes existing and new parties, it requires active participation of those who make policy and regulations, and it spans technical, commercial and governance challenges. Home customers have much to gain - and their voice needs to be heard in discussion of the best way forward.

For more information and to get involved please visit: **es.catapult.org.uk/fpsa** and **www.theiet.org/fpsa**

FUTURE POWER SYSTEM ARCHITECTURE

MEETING BRITAIN'S FUTURE POWER SYSTEM CHALLENGES

The Future Power System Architecture (FPSA) Programme: Perspectives for Industrial Customers & Communities

Including: Large Industrial & Commercial Customers, Aggregators, Energy Community Enterprises, Smart Cities, Distributed Generation Operators, Storage Operators, Virtual Power Plant Operators and Virtual Communities.

The power system in Britain is undergoing radical transformation. The Future Power System Architecture (FPSA) programme is taking a holistic and whole-system approach to the evolution of its architecture - considering technical, governance, commercial and societal factors. FPSA is a multi-stakeholder collaboration led by the Institution of Engineering and Technology and the Energy Systems Catapult, sponsored by Innovate UK. Updating the architecture of the power system will enable this group to take advantage of new opportunities that reduce their electricity costs through energy efficiency and active management of demand, generation and storage, and/or derive income from provision of system services.

Drivers:

The decarbonised GB power system must accommodate increasing levels of weather-dependent generation and remain secure at lower levels of system strength. This will place a high value on supporting reserve and ancillary services, and on demand flexibility to optimise system operation at national, regional and local levels. Managed portfolios of energy resources help reduce electricity charges and/or derive revenues from provision of services.

Opportunities and consequences:

Large customers with Building Energy Management Systems and smart technologies linked to communications systems will help unlock demand flexibility. Larger consumers could provide a baseline of flexible demand around which virtual networks could draw in smaller consumers and generators across communities, forming the basis of more localised or virtual energy markets.

Failure to harness opportunities around demand flexibility would result in higher overall electricity consumption and suboptimal electricity demand profiles leading to higher system peak demands requiring additional generation, transmission and distribution system capacity, higher GHG (Greenhouse Gas) emissions due to greater need for peaking plant.

Failure to exploit the capability to provide system reserve and ancillary services would result in a higher cost of system balancing, including frequency management, and lead to inefficient investment in conventional balancing and reserve measures such as central generation.

Energy community enterprises will offer local control and/or local accountability. However, failure to make provision for cost-reflective inter and intra-community trading could undermine the business case for community energy action and smart city schemes.

Management and co-ordination will be required to ensure conflicts are avoided - such as provision of balancing services creating a local network constraint, or delivery of network constraint management services creating a technical or commercial system imbalance.

How can the FPSA functions help?

New power system functions that are core to exploiting the above opportunities include:

- *Enable and execute necessary operator interventions:* providing the means for system operators to exploit flexible demand, storage and generation at all levels within the system.
- *Provide a process that facilitates active engagement of customers within local energy markets, e.g. aggregators, smart city schemes:* markets and settlements provisions to maximise opportunities and manage conflicts.
- *Implement smart grid to maximise system capacity:* securing the scale and speed of response required for system operability at national, regional and local level.
- *Form and share best view of state of system in each time scale:* monitoring impacts of interventions at all levels to assess system operability, security and stability.

Delivering these and other functions in a timely manner will require a new agile stakeholder-inclusive process, which FPSA has described as 'Enabling Frameworks'.

The commercial customer perspective: what does this mean for me?

This stakeholder group has a mutual interest with the energy sector in jointly exploiting inherent opportunities arising from flexible demand, generation and energy storage and will create the infrastructure necessary for the delivery of more localised energy markets. However, co-ordination will be key to maximising opportunities; for example:

- Smart City and Energy Community Enterprises will need to co-ordinate the use of energy resources within their communities to minimise energy costs and maximise value from provision of system services.
- Aggregators and Virtual Power Plant (VPP) operators will need to do likewise - exploiting system services from their customers and virtual communities.
- Large customers will need to take advantage of tariff price signals and contracting through service co-ordinators to provide system services.

Call to action:

The FPSA programme has identified the new functions necessary to deliver the above opportunities, and the current barriers to delivering this functionality. This stakeholder group is encouraged to consider how it might best engage in the next phase of the programme which will explore enabling actions to overcome these barriers.

For more information and to get involved please visit: **es.catapult.org.uk/fpsa** and **www.theiet.org/fpsa**

FUTURE POWER SYSTEM ARCHITECTURE

MEETING BRITAIN'S FUTURE POWER SYSTEM CHALLENGES

The Future Power System Architecture (FPSA) Programme:
Perspectives for Policy Makers & Supporting Organisations

Including: Policy Makers, Academia, and Research Councils (though power sector academia will probably be interested in all templates), non-technical media

The power system in Britain is undergoing radical transformation. The Future Power System Architecture (FPSA) programme is taking a holistic and whole-system approach to the evolution of its architecture - considering technical, governance, commercial and societal factors. FPSA is a multi-stakeholder collaboration led by the Institution of Engineering and Technology and the Energy Systems Catapult, sponsored by Innovate UK. This note considers stakeholders that are making or informing policy or strategy decisions about the future of the GB power system architecture. They will influence whether FPSA progresses to further stages and will make decisions about whether to act on FPSA recommendations.

Drivers:

Drivers of change arise primarily from government policy interventions, including decarbonisation and air quality objectives, the need for a cost-effective energy system as specified in the Industrial Strategy, and the imperative for security and stability of critical national infrastructure. Expanding customer choice and changing sentiment are also factors.

Opportunities and consequences:

There are four main reasons to implement the proposed new functionality:

First, new functionality is necessary to accommodate and optimise the diverse range of generation, demand-side, and storage technologies and new 'smart' techniques at sufficient scale to meet the fifth carbon budget (2028-32) and to be positioned appropriately for further decarbonisation on a pathway towards the 2050 target of the Climate Change Act.

Second, the impact of not having sufficient 'smart grid' capability will mean that the system imposes constraints on customers, undermining policy incentives to use new technologies such as electric vehicles. Alternatively, the system would be over engineered with inefficiently-utilised and costly investment in network capacity and generation. This has significant implications for Ofgem's forthcoming price control reviews and the costs passed on to customers from the capacity mechanism.

Third, several of the new functions are required to maintain the stability, security and resilience of the power system as it becomes more distributed and based on weather-dependent technologies rather than on large scale centrally dispatched power plants. Managing recovery from major outages ('Black Start') will be more challenging by 2030.

Fourth, a flexible, open and agile platform is required to support the development, integration and uptake of innovative new technologies and services, especially 'beyond the meter'.

How can the FPSA functions help?

The primary concern of policymakers is the functioning of the system as a whole, but the main interest in functions would be as follows, approximately in this order of priority:

- Functions that prevent crises, such as those concerned with avoiding black-outs, protecting against cyber threats and recovering as rapidly as possible after failures.
- Functions that keep a downward pressure on rising customer bills and allow increased competition to drive inefficiency and rent-seeking out of the system.
- Functions that are necessary to meet government environmental targets and to meet them cost-effectively.
- Functions that enable new services to customers and accommodate tipping points.

The policy makers' perspective: what does this mean for me?

- **Are the functions really needed?** The thirty-five functions contain process and systems that are substantially more complex than the existing equivalent landscape. Interactions require that they are developed in co-ordinated way to ensure a coherent whole. Some prioritisation will be possible.
- **Is intervention essential?** FPSA analysis demonstrates the barriers to the development of the functions inherent in the current institutional arrangements. Furthermore their scope does not properly encompass the devices and parties 'beyond the meter'.
- **Could existing changes incorporate this?** Current initiatives to adapt the sector do not go far enough. They focus around traditional industry structure, do not create frameworks to support the thirty-five functions, or address the changing demand side capability. They recognise the flexibility imperative, but do not propose structures to help achieve it.
- **What do the new Enabling Frameworks add?** Today's landscape is characterised by protracted and discrete decision-making with a stakeholder representation limited to the traditional industry, recognising the need for change, EFs suggest an approach that is both more agile and flexible, and can engage a much greater number of stakeholders.
- **Government action?** The key policy action is to recognise the fundamental nature of the thirty-five functions and look to design a regulatory framework that supports them explicitly. Alongside this overall sector governance needs to be aligned to the functions which suggest that a transition to a governance model as proposed by EFs is required, although this requires further development.

Call to action:

The FPSA programme has identified new power system functionality necessary to meet major policy objectives by 2030. It will require a systematic effort to deliver these functions on time and without disruption. This requires government to take high-level ownership of the challenge to enhance the GB power system architecture and to commission further work.

For more information and to get involved please visit: **es.catapult.org.uk/fpsa** and **www.theiet.org/fpsa**

FUTURE POWER SYSTEM ARCHITECTURE

MEETING BRITAIN'S FUTURE POWER SYSTEM CHALLENGES

The Future Power System Architecture (FPSA) Programme: Perspectives for Vendors & Supply Chain

Including: Vendors new to the Supply Chain including grid edge products, data and communications systems and service providers, and white goods manufacturers

The power system in Britain is undergoing radical transformation. The Future Power System Architecture (FPSA) programme is taking a holistic and whole-system approach to the evolution of its architecture - considering technical, governance, commercial and societal factors. FPSA is a multi-stakeholder collaboration led by the Institution of Engineering and Technology and the Energy Systems Catapult, sponsored by Innovate UK. This note considers new vendors joining the supply chain to provide products, services and solutions into the power sector. Many businesses are targeted at the utility sector and are familiar with it, while others have a focus 'beyond the meter' and may be oblivious to the influence they have on the local or national power system.

Drivers:

The drivers for this community are varied from delighting your customer, running a viable business, expanding into new sectors, differentiating from your competitors, standing out from the crowd, creating new value propositions, disrupting the current market incumbents to delivering societal benefit without profit. The spectrum of new stakeholders who can now play a role in the power sector is large and expanding.

Opportunities and consequences:

The opportunities to deliver new and exciting products, services and solutions into the power sector has never been so great. The threats that these new stakeholders could create for stability, resilience and reliability are also immense if not considered carefully.

Many new vendors delivering products, services and solutions on the customer side of the meter (e.g. the non-regulated side) may be oblivious to the role they are actually playing in the whole power system. New apps that coordinate millions of devices that may switch load on or off and are unpredictable or unobservable until the point of implementation could create major problems for the power system balance. These are already being deployed, such as electric vehicle charging or ground/air heat source pumps, controlled by apps, etc. and may be synchronised by changes in price between half-hour settlement periods.

The challenge is to provide a vibrant new market with exciting choices for customers to enhance their lifestyle, business performance or environmental impact on the one hand, while delivering a secure, safe and value based solution on the other. The two are not mutually exclusive.

Vendors understand the current and future needs of customers and design new and exciting products, services and solutions to deliver the one or more of the desired benefits. Today's barriers have to be overcome and new functionality released if the desired customer benefits are to become a reality.

How can the FPSA functions help?

FPSA2 has identified thirty-five new functions that will be needed along with a new process, known as Enabling Frameworks, that is agile, inclusive and timely in enabling their delivery.

From a new vendor's perspective, the challenges of understanding the market structure, the commercial rules, the acceptable level of technical products, services and solutions and their main customer base norms, behaviours and procurement processes may be daunting. They may feel excluded from technical code decisions (or may not know they exist) or be unable to interface to the power grid because of a lack of known functionality – e.g. Community Energy vendors and the role this could play in Demand Side Response. Many of the functions defined in FPSA2 will liberate these types of solution, while the *Enabling Frameworks* is trying to provide an inclusive, agile and timely process to allow new vendors to enter the market place.

The vendor perspective: what does this mean for me?

Vendors of all persuasions hardware, software, data, communications, applications, integrators, advisors (the list is extensive), have a huge role to play in the next decade in the power sector transformation. Often the challenge is just articulated as a technology opportunity for example, wind, solar, storage, etc., but the reality is the need for all of the supporting infrastructure and the coordination of these technologies, and others, to be at the heart of the transformation. If these new opportunities are to be delivered seamlessly, reliably and backed with top quality service, the wider power system must be equipped for the job - in other words, provided with the necessary new functions identified as key to a smart energy future.

Call to action:

For this future to become a reality, many parties have to step up and engage with change. This includes existing and new parties, it requires active participation of those who make policy and regulations, and it spans technical, commercial and governance challenges. Vendors are the engine room of this delivery, the ability for them to be able to easily engage, deliver and feel part of the whole-system solution will be imperative for the success of our future power system.

For more information and to get involved please visit: **es.catapult.org.uk/fpsa** and **www.theiet.org/fpsa**

Future Power System Architecture Project 2

Synthesis Report

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.

www.**theiet**.org/fpsa

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