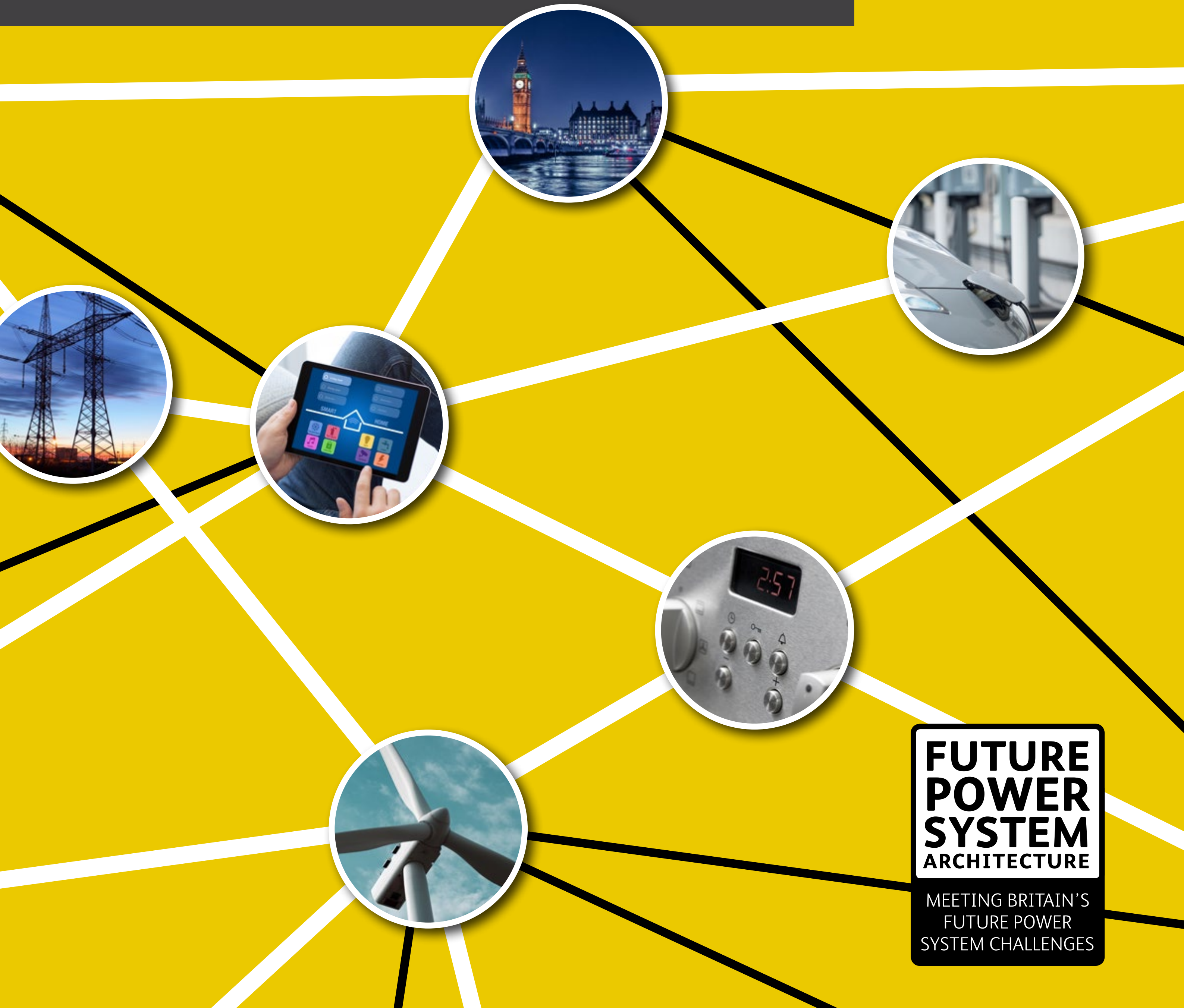
The Institution of Engineering and Technology

Energy Systems Catapult

Future Power System Architecture Project 2

Work Package 2 Final Report - Functional Analysis

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



FUTURE POWER SYSTEM ARCHITECTURE

MEETING BRITAIN'S FUTURE POWER SYSTEM CHALLENGES

The Institution of Engineering and Technology

Catapult Energy Systems

Future Power System Architecture Project 2

Final Report

Work Package 2: Functional Analysis

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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Table of Contents

1. Executive Summary

This report presents the outcomes of Work Package (WP2) of the FPSA2 project. This work has been undertaken by TNEI Services (TNEI), Element Energy and Kuungana Advisory.

The GB power system architecture i.e. the underlying structure of the power system and how its components and participants interact, must undergo transformative change towards 2030 to accommodate advanced technologies, new business models, major policy changes and various other challenges presented in the effort to meet the objectives of the energy trilemma: decarbonisation, security of supply and affordability. This has led to a whole system approach being required such that the changes to the physical network, market structures, regulatory and commercial codes and customer behaviour can be addressed in an integrated manner.

The FPSA programme has been commissioned to anticipate new developments and assess their significance with a view to understand the requirements of the future power system and how these can be met. FPSA1, the first stage of the project, identified *thirty-five* new or significantly modified functions required to meet the 2030 power system objectives. It has been the aim of FPSA2, the second stage of the project, to develop a greater understanding of the functions and explore the various requirements and challenges to delivering them.

Within FPSA2, WP2 has been specifically tasked to test the validity of these functions and ensure they encompass what are understood to be the full requirements of the GB power system in 2030. In so doing, the principal outcomes of WP2 can be summarised as:

- A full list of *thirty-five* new or enhanced power system functions which have been reviewed, validated and refined where necessary to clarify the specific scope or intention of the function.
- Initial identification of the 'needs' of each function in consideration of how they can be delivered, encompassing process needs, e.g. rules or policies to govern how the system is planned and built, infrastructure needs, e.g. network assets, and needs for other functions, e.g. the dependence on the delivery of another function for implementation.
- Grouping of the functions according to the role they will perform in the power system allowing cross-cutting needs to be identified and delivery options across these common themes to be explored and proposed.
- Development of three test case functions whereby their needs and interdependencies have been mapped out in detail. These test cases have been developed in detail across WP2, WP3 and WP4.
- Proposal of areas for further RD&D (Research, Development & Demonstration) and Innovation which could address some of the immediate challenges the functions are facing.

2. Introduction

The Future Power System Architecture (FPSA) programme started in 2015 and was commissioned by the former Department of Energy and Climate Change (DECC), whose portfolio is now part of the Department for Business, Energy and Industrial Strategy (BEIS). The project sought to address the challenges facing the GB power system as it undergoes major change by 2030. The first stage of the programme, FPSA1, identified *thirty-five* new or significantly extended power system functions that will be required to embrace these changes, which include connection and operation of advanced technologies, new business models, greater customer engagement and supporting market structures.

The second stage of the programme, FPSA2, commenced at the end of 2016. The purpose of FPSA2 is to deepen the analysis of requirements considered in FPSA1, understand barriers to implementation, and to consider innovative frameworks for delivering new functionality. This work takes a whole-system approach that places the needs of present and future stakeholders at the forefront. It also addresses the implementation challenges for the *thirty-five* FPSA1 functions, recognising the need for greater process agility and responsiveness in the future. The findings from FPSA1 called on the power industry and government to focus urgently on delivering new capabilities to transform GB's power system architecture by 2030, making it fit to respond to the challenges presented by the energy trilemma: decarbonisation, security of supply and affordability.

The objectives for FPSA2 were to deliver:

- A comprehensive exploration of the current and future needs of both existing and emerging stakeholders.
- A review of the *thirty-five* FPSA1 functions to identify possible gaps or new insights into required functionality.
- An assessment of the feasibility of delivering the functions under the current power sector structure.
- Identification of possible early RD&D and Innovation actions to support the ambitions of future FPSA work streams.
- A methodology for assessing the probability and consequence of late or non-delivery of the functions.

- A methodology for determining the relative impact of the identified barriers to functions under the current structure, and hence the priorities for establishing *Enabling Frameworks* to address those barriers.
- The identification of a number of *Enabling Frameworks* for development under FPSA3 to deliver the functions.
- Full documentation of both the methodology and outputs from FPSA2 to provide the necessary audit trail and overall process assurance.
- A clear explanation of the complex messages delivered to relevant audiences throughout FPSA2.

The tasks for FPSA2 were split into a number of Work Packages to enable project activity to be co-ordinated and managed effectively. The main tasks associated with each Work Package are summarised in the table opposite.

This report provides the outcomes of the work conducted in Work Package 2 (WP2) of the FPSA2 project.

2.1 WP2 Purpose and Context

The principal outcome of the first stage of FPSA (FPSA1) was the identification of *thirty-five* new or significantly modified functions that are required to meet the objectives of the power system in 2030. In this vein, the purpose of WP2 in the overall context of FPSA2 has been to test the validity of these functions and ensure they encompass what are understood to be the full requirements of the GB power system in 2030.

Through this process has come a deeper understanding of the functions, which has driven the development of these from objectives into more tangible concepts, with WP2 providing initial practical options, shaped by the needs, for how these functions can be delivered in practice.

Identification of RD&D and Innovation opportunities has been another key output from WP2. These have been identified through consideration of the required timescales for delivery (urgency), as identified in the 'Evolutionary Pathways' of FPSA1, and the challenges the functions face for implementation (barriers), as identified in WP3 of FPSA2.

Figure 2-1: Tasks within each FPSA2 Work Package

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

WP	Description of Interaction Requirement	Contribution from WP	Contribution to WP	
1A	To validate the *thirty-five* functions across a range of existing stakeholders and highlight areas of concern for missing functionality.	Validation of functions and identified needs, including for the three test cases.	Refined functions	Questions for stakeholders and participation in specific focused interviews relating to the three test cases to support validation.
1B	To understand whether the *thirty-five* functions will meet the perceived needs of future stakeholders.	Validation of functions through mapping of future stakeholder needs to functions and drivers.		Consultation on future stakeholder needs and ensuring these are encompassed in the functions and drivers.
3	To correlate the function needs with their barriers and challenges.	Barriers and urgency of functions to identify RD&D and Innovation options.		Function needs to better understand the various barriers to implementation.
4	To provide function needs to facilitate the development of suitable *Enabling Frameworks*.	Guidance on the required outputs from WP2 regarding the function needs.		Provision of detailed function needs for the three test cases.
5	To facilitate synthesis of the work in WP2 with the overall FPSA2 project.	Direction and steer on WP2 outputs and narrative.		WP2 outputs and narrative.
6	To provide outputs from WP2 suitable for widespread dissemination.			Function groupings for dissemination.

2.2 WP2 interactions with other Work Packages

A vital aspect of the WP2 methodology has been the interaction with other Work Packages in the wider FPSA2 team. This has supported and validated the work being done in WP2 and also provided insights into the functions and their needs to better shape the analysis and enablement activity being undertaken in the different Work Packages. The table above describes the various interactions with the other Work Packages and highlights the bilateral contributions throughout the project.

2.3 Report structure

The work undertaken by WP2 comprises three distinct elements:

1. Function review methodology and refined list of functions for FPSA2.
2. Development of function groups, needs and delivery options.
3. Recommendation of RD&D and Innovation as proposed next steps.

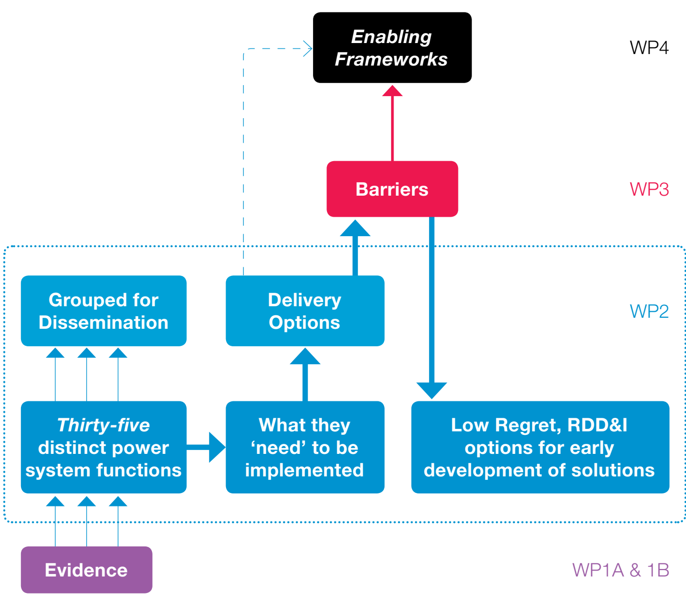
The report is therefore structured in the following way:

- Section 3 outlines the **methodology** used to review the FPSA1 functions and provides the refined list of functions for FPSA2 that have been progressed through the other Work Packages.
- Section 4 describes **function development** through WP2, encompassing function grouping and the rationale behind these, function needs categories and how these map to the needs of the overall power system.
- Section 5 provides a detailed description of each function and its associated needs and proposes delivery options for each function group.
- Section 6 provides **recommendations on RD&D and Innovation** projects as next steps for the FPSA project.

2.3.1 WP2 narrative

The WP2 narrative in the context of the overall FPSA2 project is illustrated in Figure 2-2.

Figure 2-2: WP2 Narrative



3. Function Review Scope and Methodology

This section describes the methodology employed to perform a review of the FPSA1 functions.

3.1 Scope of the functions

The *thirty-five* functions of FPSA are considered to be new or enhanced functions that the power system of 2030 will require. These *thirty-five* functions do not account for the primary functionality that is intrinsic to the power system and will be preserved through the whole system transformation that is envisioned, i.e.:

- Generation of electrical power.
- Transportation of power.
- End use of power.
- Storage of power.

In accordance with the overall energy trilemma objectives, it is the expectation that the intrinsic functionality will continue to be executed safely, securely and sustainably.

The *Enabling Frameworks* being recommended by WP4 are also being built to ensure the functions can evolve safely, securely and sustainably with integral enablement of other pre-requisites (Section 3.1.1) as appropriate. The WP4 report provides a more comprehensive overview of how these characteristics are influencing the development of the *Enabling Frameworks*.

3.1.1 Pre-requisites and not-in-scope functionality

The work carried out in WP1A has explored the scope of a number of requirements and obstacles that are either **pre-requisites** or that are **not in the scope** of the *thirty-five* functions, yet they will be important for the success of the future power system.

An example of a pre-requisite is an appropriate skills base of engineering, business, market and commercial knowledge to operate, build, manage and maintain the future power system. An example of a key requirement that is not considered to be in the scope of the functions is innovation; there is an implicit expectation that the power sector will continue to innovate, whereby the transformation envisaged for the power system will require not only more innovation, but innovation at a higher pace. Please refer to the WP1A report for more examples of pre-requisites and not-in-scope requirements.

3.2 Function requirements, drivers and timescales

The core information associated with the functions from FPSA1 consists of:

- **Requirements** – the underlying need that the power system has for new or enhanced functionality.
- **Drivers** – the seven major themes of change behind the major transformation that the power system will undergo.
- **Timescales** – the four timescales within which power system activity is undertaken.

Each of these was considered in the review conducted by WP2 as detailed in the following sections.

3.3 Review methodology

The process of reviewing the *thirty-five* FPSA functions comprised three principal stages:

1. Function Scoring.
2. Function Amendment.
3. Approval.

3.3.1 Function scoring

A scoring methodology was derived to test the robustness of the approach used in FPSA1 to identify the functions. In line with systems engineering principles, the first step involved the assessment of each of the functions where they are scored against five criteria, described opposite.

As a scoring tool, Red-Amber-Green (RAG) score was assigned to each criterion for each function, where:

- **Red** = Function does not clearly meet criteria.
- **Amber** = Function meets some aspects of the criteria.
- **Green** = Function clearly meets criteria.

Criterion	Rationale
Are the function boundaries clearly defined?	To ensure that a function is implementable, there must be a clearly defined scope of what the function is to be capable of, and how it should perform.
Is the function requirement justified?	Evidence is required to justify the requirement and subsequent function. Supporting evidence was provided by the stakeholder engagement activity carried out in WP1A and WP1B in addition to a review of relevant documentation.
Is there a clear link between function and requirement?	The function definition should reflect clearly the corresponding requirement to ensure successful implementation of an appropriate solution.
Is there a clear link between function and driver?	A clear link to the driver is preferable. However it is recognised that one function may map to several drivers depending on its scope. Therefore, a link to the driver, although useful, is not critical to the relevance of a function. Throughout the development of FPSA2, different options for grouping the functions have been developed.
Is the function represented appropriately across all timescales?	Representation across the appropriate timescales is important to reflect the unique requirements of similar functionality in different circumstances.

3.3.2 Function amendment

Where a score of Red or Amber was assigned, the function was flagged for further investigation and this was carried out depending on the criterion in question. Remedial action was taken as necessary and encompassed the clarification of scope, timeframe representation and/or intention of functions through refined wording.

3.3.3 Approval

All proposed amendments were subject to review, challenge and debate prior to approval by the FPSA2 Steering Group.

3.4 Evidence base and approach to missing functionality

As part of the review process, due consideration was afforded to the possibility of missing or insufficient functionality. In large part, this has been the focus of the stakeholder engagement activities performed by WP1A and WP1B whereby:

- WP1A considered the evolving requirements of existing stakeholders.
- WP1B considered the perceived requirements of new and emerging power system stakeholders e.g. those involved in electrified transport.

Extensive work has been done by these Work Packages, in collaboration with WP2, to understand whether these requirements will be met by the *thirty-five* functions identified in FPSA1. Although the work conducted by WP1A and WP1B was not an exhaustive exercise that gathered specific stakeholder evidence and support for all of the functions, it was broad-ranging (across the supply chain) and no significant gaps were identified through the interviews and participation in surveys. The sections below give examples of the supporting evidence gathered from these Work Packages.

3.4.1 Example evidence from WP1A

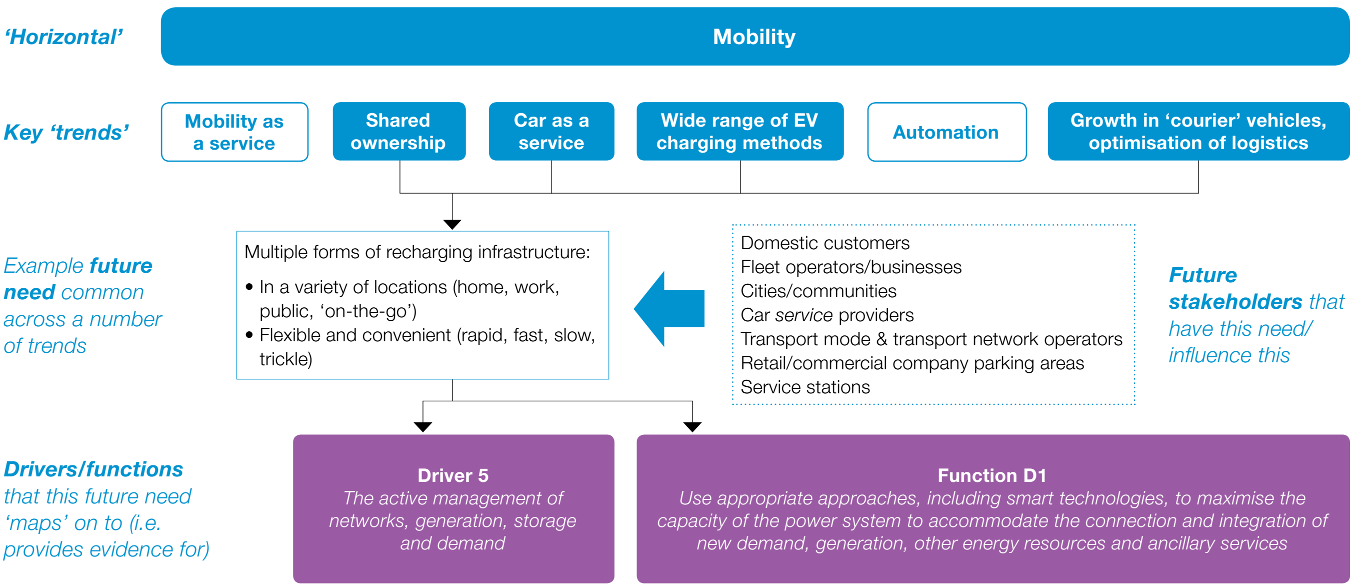
As is described in Section 4.5.1 later, three test case functions were selected for detailed development through FPSA2. A focus for WP2 was therefore to gather support and evidence for these particular functions. Across several focused discussions with network operators, an evidence base was built to support the identification of the requirements for planning Black Start, considering enhanced capabilities from new participants. The following new considerations for function G3 were offered by the stakeholders, and this helped to develop the detailed function needs and potential delivery options and RD&D and Innovation options which are discussed in later sections:

- Specific investment in communications infrastructure suitable for Black Start.
- Cyber security provisions will need to ensure Black Start assets are resilient.
- New processes required for SO/DSO interaction which will include Black Start provision/ procurement of services.
- Black Start capability will not be provided uniformly from all DSOs, this will depend on connected assets and level of customer engagement.

3.4.2 Example evidence from WP1B

To consider whether the requirements of future stakeholders would be met by the *thirty-five* functions, a mapping exercise was undertaken for the three 'horizontals' explored in WP1B. The transport horizontal identified a number of clear mappings between future stakeholder needs and the functions and drivers. Figure 3-1 below, illustrates how the requirement for new charging infrastructure across the transport horizontal maps to function D1: Use appropriate approaches, including smart technologies, to maximise the capacity of the power system to accommodate the connection and integration of new demand, generation, other energy resources and ancillary services.

Figure 3-1: Transport Horizontal Future Needs Mapping



Please refer to the WP1A and WP1B reports for detailed accounts of support, evidence and justification for the functions.

3.4.3 Consultation of literature

Within WP2, a range of external literature was consulted, including but not limited to, National Grid's System Operability Framework[1], the World Economic Forum's Digital Transformation of the Electricity Industry[2], to determine if additional functionality is required to meet previously unknown requirements. In addition, WP2 checked the outcomes of FPSA1 for missing drivers and requirements as a test for whether there was any missing functionality.

3.5 Refined functions for FPSA2

The final list of functions, incorporating amendments, is given in Table 3-1 below. This uses new function numbers (as introduced in Section 4.1).

Based on this review, no new functions have been proposed and few major changes have been proposed to existing function definitions. Minor changes have been proposed throughout in order to help clarify the intention of the functions, based on debate and discussion within the FPSA2 project. Two more significant changes have been proposed which cut across multiple functions:

- The definitions of five functions which describe collaborations and co-ordination within the sector have been extended in order to allow for a wide range of possible interactions, including interactions between the GB power system and other connected energy vectors, between the GB power system and internationally interconnected power systems, and between multiple operators within the GB power system (such as the SO, DSOs, and autonomous parties like smart cities).
- The phrase 'dispatchable energy resources' has been broadened to 'energy resources'.

Table 3-1: Refined Functions for FPSA2

Original Function Definition		Refined Function Definition	
0.1	Enable the power sector to respond readily to change, and ensure the timely introduction and implementation of new functions.	F1	Enable the power sector to manage necessary changes across the sector when faced with new developments or changes to its objectives and operating environment.
1.1	Provide a mechanism to ensure the portfolio of generation, EU Interconnectors, other dispatchable energy resources and ancillary services delivers carbon, security of supply, and affordability policy objectives.	A1	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.
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	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.
2.2	Monitor the impact of customer needs on system operability and propose solutions as necessary.	F3	Monitor the impact of customer behavioural changes on system operability and propose solutions to resulting operability issues as necessary.
2.3	Plan for the timely restoration of supplies following a pro-longed local failure (Cold Start).	G1	Plan for the timely restoration of supplies following a pro-longed local failure (Cold Start).
2.4	Provide the ability to move between different modes of overall operation in the event or threat of a system emergency.	G2	Provide the ability to move between different modes of overall operation in the event or threat of a system emergency.
2.5	Identify and protect, on an ongoing basis, against cyber security threats to operability of the power system originating from inside and outside the power sector. Detect and respond to cyber security incidents.	F4	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.

[1] http://www2.nationalgrid.com/UK/Industry-information/Future-of-Energy/System-Operability-Framework/
[2] http://reports.weforum.org/digital-transformation/electricity-generating-value-through-digital-transformation/

Original Function Definition		Refined Function Definition	
2.6	Plan for the timely restoration of supplies following a national failure (Black Start).	G3	Plan for the timely restoration of supplies following a total or partial shutdown (Black Start).
3.1	Assess the impact of gas and other energy vectors when forecasting the volumes of demand, generation and other dispatchable energy resources and ancillary services on the power system.	B1	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.
3.2	Forecast all demand, generation and other dispatchable energy resources and ancillary services within the power system.	C1	Forecast all demand, generation, other energy resources and ancillary services across all voltage levels within the power system.
3.3	Ensure that monitoring is in place to support the use of active system management.	E1	Ensure that monitoring is in place to support the use of active system management.
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 and other dispatchable energy resources and ancillary services.	D1	Use appropriate approaches, including smart technologies, to maximise the capacity of the power system to accommodate the connection and integration of new demand, generation, other energy resources and ancillary services.
5.1	Provide mechanisms by which planning can be co-ordinated between all appropriate parties to drive optimisation, with assigned responsibility for security of supply.	B2	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.
5.2	Review the power sector's developing operational characteristics to validate the assumptions made during the investment planning process.	E2	Review the power sector's developing operational characteristics to validate the assumptions made during the investment planning process.
6.1	Collate and distribute information throughout the power sector on the availability and performance of the generation and other dispatchable energy resources and ancillary services, and any associated operational restrictions.	C2	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.
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	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.
8.1	Forecast and model all generation and other dispatchable energy resources and ancillary services with operational, cost, and security implications for the power sector.	C4	Forecast and model all generation and other energy resources and ancillary services with operational, cost, and security implications for the power sector.
8.2	Enable the dispatch of generation and other dispatchable 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.	E3	Provide the capability to observe energy resources across the whole system and mechanisms for intervention.
9.1	Provide an operational planning process that engages with all affected stakeholders.	B3	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.
9.2	Identify by modelling and simulation constraints arising from credible events/faults, and plan remedial action.	E4	Identify by modelling and simulation constraints arising from credible events/faults, and plan remedial action.
10.1	Identify available generation and other dispatchable energy resources and ancillary services and associated operational restrictions in real-time.	C5	Identify available generation, other energy resources and ancillary services and associated operational restrictions in real-time.
11.1	Monitor the effectiveness of, and execute as required, remedial action for the delivery of demand control, generation constraint and other actions in response to all events/faults.	E5	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.
11.2	Co-ordinate demand, generation and other dispatchable 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	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.

Original Function Definition		Refined Function Definition	
12.1	Provide monitoring and control of those parts of the system under active management, including network assets, demand, generation and other dispatchable energy resources and ancillary services.	E7	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.
13.1	Enable the delivery of demand control, generation constraint and other actions in response to all extreme events.	B4	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.
14.1	Provide automated and secure management of demand, generation and other offered energy resources and ancillary services, including Smart Appliances, HEMS and BEMS.	E8	Provide automated and secure management of demand, generation, other offered energy resources and ancillary services, including Smart Appliances, HEMS and BEMS.
14.2	Collate and distribute information throughout the power sector on the performance of demand, generation and other dispatchable energy resources and ancillary services in order to enable settlement.	C6	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.
15.1	Provide aligned financial incentives across the power sector, e.g. innovative or flexible tariffs.	H1	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.
15.2	Enable settlement for all existing customer profile classes to support flexible tariffs, e.g. half-hourly using smart or advanced meters.	H2	Enable settlement for all existing customer profile classes to support flexible tariffs, e.g. half-hourly using smart or advanced meters.
15.3	Co-ordinate the roles and value propositions of all significant stakeholders across the power sector.	H3	Implement and co-ordinate a framework where the roles and value propositions of all significant stakeholders across the power sector can be managed.
15.4	Collaborate with other energy sectors to optimise across multiple sites and vectors.	B5	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.
15.5	Provide a mechanism for peer-to-peer trading with appropriate charging for use of the power system.	H4	Provide market mechanisms e.g. peer-to-peer trading, to allow all customers to access the value realised by their actions.
16.1	Provide a market process that facilitates active engagement of customers, e.g. aggregators, smart city schemes.	H5	Provide a market structure that enables customers to have choices within the power system.
16.2	Provide a full range of customer choices including individual, community and smart city services.	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.
16.3	Monitor and settle the delivery of contracted demand, generation and other dispatchable energy resources and ancillary services.	C7	Monitor and settle the delivery of contracted demand, generation, other energy resources and ancillary services.

4. Function Development

4.1 Function groups

The *thirty-five* functions have been categorised into eight groups based on the role they will perform in the power system. These roles are described in Table 4-1 opposite. The functions were given a unique number identifier in FPSA1; however a new numbering scheme has been employed in FPSA2 to correspond to this new grouping approach. Table 3-1 in the previous section highlights the mapping of updated function numbering.

These eight groups extend across the investment planning, operational planning, real-time and balancing, and markets and settlement timescales as shown in Table 4-2. Please note the numbering style from FPSA1 is included in the diagram for reference. Each of these groups is described in more detail below.

Table 4-1: Function Grouping

Function Grouping	
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 timescale.
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 markets to support customer aspirations and new functionality.

Table 4-2: New Function Grouping

	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**			

Table 4-2: New Function Grouping (Continued)

Group	Timescale	Ref	Function	New ID
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

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	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.

Group A

Design a competitive framework to deliver the energy trilemma

This group consists solely of function A1 which is responsible for the provision of means to model various energy system portfolios against GB trilemma policies and promote those that best fulfil the objectives.

Group B

Manage the interface with connected energy systems

This group consists of five functions which span the four timescales and are concerned with cross-border, cross-vector and intra-power system interactions. The functions account for 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 as appropriate across the four timescales. Forecasting functionality will provide this in the Investment Planning timescale, and form part of the required observability in Operational Planning timescales, alongside availability, performance and outage information. Information on real-time availability of assets is acquired for balancing, and dissemination of real-time performance informs settlements.

Group D

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

This group consists solely of function D1 and 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 operator interventions e.g. execution of remedial action during events or co-ordination of resource for optimisation, such that they can be executed as and when necessary. A primary enabler for operator interventions is adequate monitoring and control capability and two functions are dedicated to ensuring this is in place. Understanding credible events/faults is also important for operators to facilitate their execution of remedial action and so there is functionality to model these events and also to plan and learn from remedial actions as they are carried out.

Group F

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

Four functions make up this group which is focused in the Investment Planning timescale and involves 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 however there are also elements of this within the other individual functions.

Group G

Provide capabilities for use in emergencies

Three functions take account of power system operation in emergency situations and planning the actions and capabilities that will be required during these periods. Planning the restoration of supplies following prolonged local failure (Cold Start), partial or total shutdown (Black Start) are focal points of this group while function G2 necessitates provision emergency procedures either to avoid loss of supplies or to facilitate restoration.

Group H

Develop market to support customer aspirations and new functionality

This group covers six functions centred in the Markets and Settlement timescale and are primarily stakeholder-oriented. The functions account for 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, while not distorting competition.

4.2 FPSA2 function needs

A function's needs are the elements which need to be in place in order for that function to be implemented. In WP4 of FPSA2, a clear definition of each function's needs has been identified as one of the key inputs into the *Enabling Frameworks*. Within the context of the *Enabling Frameworks*, clear articulation of the needs of a function and the barriers preventing it from being implemented allow for enabling actions to be identified. However, it is important to note that not all of a function's needs would need to be delivered or facilitated through an *Enabling Framework*.

An initial assessment of function needs has been performed within WP2 of FPSA2. This has:

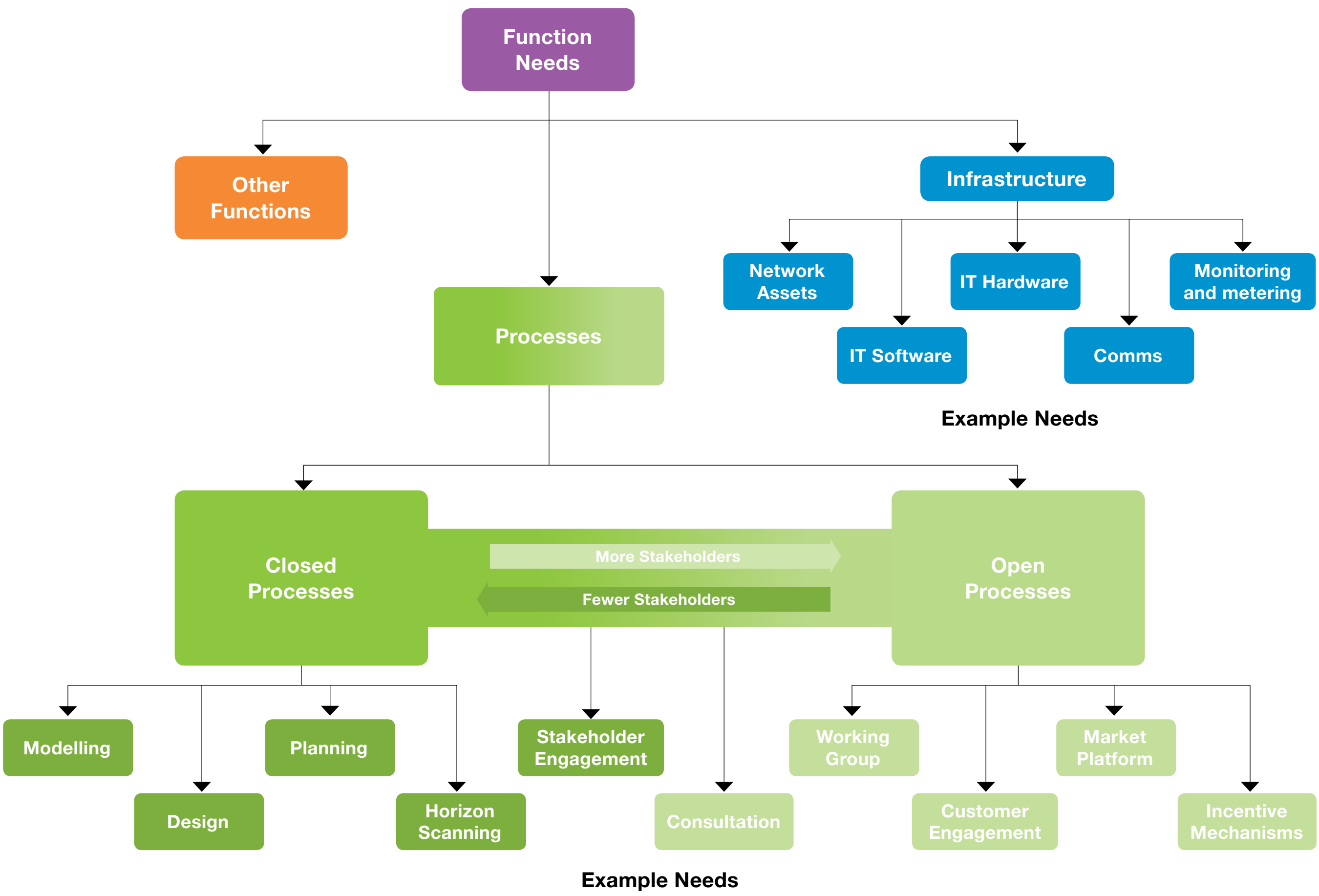
- Helped to provide a clearer understanding of the meaning of each function.
- Supported the identification of function delivery options and RD&D and Innovation actions.
- Illustrated the complicated interactions between the *thirty-five* functions in the FPSA project.
- Supported the analysis of barriers in WP3 (based on the assumption that a function's barriers will ultimately affect the delivery of one or more of that function's needs).
- Informed the 'testing' of *Enabling Frameworks* in WP4.

Identification of function needs has been an iterative process and it is expected that this process will continue as *Enabling Frameworks* are further developed. Three 'categories' of need have been identified within FPSA2:

1. Infrastructure.
2. Processes.
3. Other functions.

All of the function needs identified so far fit within these three categories, or are a combination of these categories: Each of these categories of need is discussed below and shown in Figure 4-1.

Figure 4-1: Function Needs



4.2.1 Process needs

Process needs encompass a wide variety of rules, processes, policies etc. that govern how the power system is planned, built, operated and managed and how stakeholders within the system co-ordinate their activities. These processes determine the 'Institutional Infrastructure' or 'Soft Infrastructure' of the power system, and are central to the way in which individual organisations are run and how multiple organisations interact. These processes may depend on underlying physical infrastructure.

A distinction has been noted between closed and open processes:

- Fully closed processes happen within a single organisation (they are 'intra-organisational').
- Fully open processes are open to the involvement of all potential stakeholders (they are 'inter-organisational').
- Many other processes sit on a spectrum between these two extremes. For example, a process which involves close collaboration between only two organisations is relatively closed but still involves multiple organisations. On the other hand, there could be a process which takes input from a large number of pre-selected stakeholders – this is a 'inter-organisational' process, and is relatively open although still closed to some.

Examples of process needs could include:

- Quantitative analysis.
- Planning.
- Stakeholder engagement.
- Working groups.
- Incentive mechanisms.

Figure 4-1 shows how these needs and others might fit on the spectrum between open and closed processes.

4.2.2 Infrastructure needs

Infrastructure needs describe the physical infrastructure which forms the power system. Examples of infrastructure include:

- Network assets, like transformers, overhead lines etc.
- IT software and hardware.
- Communication infrastructure (e.g. fibre optic cabling).
- Monitoring and metering infrastructure.

4.2.3 Process and infrastructure needs

Some needs will have both process and infrastructure elements. For example, the requirement for enhanced modelling capability is a central theme of the FPSA project, and many functions do have a need for modelling capability. This need has both process and infrastructure elements: software is required in order to undertake the analysis, and a process will be defined which determines how that software is used and how results are interpreted. Where appropriate, the need for modelling capability has been identified separately to processes and infrastructure as an example of this sort of interaction.

4.2.4 Other functions

Throughout FPSA2, it has become clear that there are many strong interdependencies between the *thirty-five* functions. Specifically within WP2, it has been identified that one function might have a need for the implementation of another function. For example, a function which collates and distributes data will have a need for infrastructure to facilitate the initial collection of that data.

Within FPSA2, an initial view of function interactions has been provided. This has been developed in greater detail for the three test cases (G4, H5 and H6). However, the complexity of the interactions between functions has precluded a rigorous analysis of interactions being undertaken for all of the functions.

4.3 FPSA2 function needs

Based on this categorisation, the needs of the *thirty-five* FPSA2 functions have been explored by WP2, with explicit identification of:

- **Process needs,** including both open and closed processes.
- **Infrastructure needs,** specifically physical infrastructure.
- **Modelling capability,** as an example of a need which has process and infrastructure elements.

In addition, we have provided an initial view on possible **Function Interactions**.

4.4 Opportunities for further development

Further exploration of function needs would assist with the continued development of *Enabling Frameworks* in WP4. The following tasks may be worth considering:

- More granular categorisation of different types of function needs.
- A more thorough investigation of function interactions.
- Identification of function needs which describe new function capability and those which describe existing capability which needs to be enhanced.

As well as feeding into WP4, this would inform the development of a critical path for function implementation which would build on the 'Evolutionary Pathways' explored in FPSA1. This would also allow for a more thorough investigation of those needs which span multiple functions and might allow for grouping of functions to be proposed based on common needs[3]. This more granular development of the functions has been carried out within FPSA2 for three test case functions to explore and test the *Enabling Frameworks* that WP4 are developing.

4.4.1 Function test cases

There are three functions that have been worked through in detail across the FPSA2 project:

- **Function G3:** Plan for the timely restoration of supplies following a total or partial shutdown (Black Start).
- **Function H5:** Provide a market structure that enables customers to have choices within the power system.
- **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.

These three functions were selected and have been developed through WP2, WP3 and WP4 to illustrate the initial stages of identifying needs and barriers and enablement options as part of the overall process of bringing the functions from concept through to delivery.

WP2 has assessed the validity of the functions, outlined their needs in detail, and explored interdependencies with other functions across the different timescales. WP3 has performed an impact analysis on these requirements through assessment of the barriers to implementation while also highlighting the consequences of failure to implement them, both on the implementation of other functions and on the overall power system. Based on this analysis, WP4 has considered the function needs in relation to the design of *Enabling Frameworks* which will address specific and common barriers to each one. Where evident, WP2 has proposed RD&D and Innovation actions.

With regards to the test cases, this report outlines the work carried out by WP2 on the development of these three functions and their needs (Sections 5.7 and 5.8), and proposed RD&D and Innovation options (Sections 6.2.2, 6.2.4 and 6.2.8). Please refer to the WP3 and WP4 reports for details on further development of the test cases through these Work Packages.

[3] This was explored within FPSA2.

5. Detailed Discussion of Functions

This section describes each of the functions as they are categorised into the eight groups, and elaborates on their needs. Some examples of function interactions are provided to illustrate interdependencies that will be characteristic of delivering the new and enhanced capabilities across the power system. In practice these interdependencies will be very complex and so the examples provided are not exhaustive lists, however they highlight some of the important interactions that will have to be considered.

It is important to note at this stage that the *thirty-five* functions proposed in FPSA1, and developed through FPSA2, must be implemented to meet the challenges faced by the power system in 2030. There is a definite justification as to why each of these functions needs to be implemented but no presumptions have been made as to what organisation will actually come to implement them. In the following sections, suggested delivery options point to different organisations but the list of delivery options is not exhaustive and these are provided only as examples.

5.1 Design a competitive framework to deliver the energy trilemma

A1 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.

FPSA1 Requirement: *To be able to select and deliver the desired future generation portfolio and predict the green house gas emissions for future generation portfolios.*

This function is needed as a planning measure to forecast the emissions, costs and security levels of the proposed system (government, network, generation fleet and portfolio of service contracts) and to create the frameworks and mechanisms to ensure investment in the most appropriate assets. This is similar to mechanisms such as the Capacity Market and the Contract for Difference which have been implemented in order to promote certain policy objectives, based on modelling and projection. This function could even be extended further to cover other types of mechanisms which will promote the fulfilment of policy objectives e.g. those mechanisms such as the 'Losses Discretionary Reward' which seek to minimise network losses.

Final decisions on the composition of the generation portfolio are expected to still be made in the market – the intent of this function is to provide a wider understanding of how different portfolios perform against objectives and to give the sector an opportunity to influence this.

The definition of this function has been refined since the completion of FPSA1. The original definition was: "*Provide a mechanism to ensure the portfolio of generation, EU Interconnectors, other dispatchable energy resources and ancillary services delivers carbon, security of supply, and affordability policy objectives*".

This was refined to clarify that the scope of this function is only to model and influence energy policy; it is not suggesting that generation portfolios should be subject to central planning. The refined definition reflects the fact that, ultimately, the power system cannot 'ensure' that policy objectives are delivered. Instead, the power system can (collaboratively) determine the characteristics of a portfolio that might meet objectives (e.g. in terms of whole system cost, intermittency and carbon intensity) and then adopt mechanisms that support that.

Function Needs

The following needs have been identified for this function:

Process: *To promote those generation portfolios which will deliver policy objectives.*
Infrastructure: *To measure the performance of portfolios of generation against policy objectives.*

Function Interactions

This function will take account of outputs from functions:

- H3, which co-ordinates the value framework of the power sector.
- C6, which provides historical data about the power system.

This function will also feed into functions:

- H1 and H5, which determine the structure of the market and financial incentives.

These needs could be delivered through policy mechanisms and market interventions similar to the Capacity Market, the Contract for Difference, the Electricity Balancing Significant Code Review (large scale participants) and Feed-in Tariffs (FiT) (smaller scale), or non-market mechanisms such as the decision not to grant planning for unabated coal stations. However, future policy mechanisms may need to be considered more holistically to consider how they interact with each other and how they interact with the wider market. There will probably be a greater need to consider the whole energy system in future mechanisms – e.g. interactions between the transmission and distribution network, with actions that take place 'beyond-the-meter', and with other energy vectors. This will require more sophisticated modelling approaches which can accurately forecast portfolio performance at a whole-system level.

5.1.1 Delivery options for Group A

Design a competitive framework to deliver the energy trilemma

This function group aims to have an appropriate future national plant portfolio in place to meet the demands of the energy trilemma. The needs of this function group could be delivered through policy mechanisms and market interventions similar to the Capacity Market and the Contract for Difference, or non-market mechanisms. However, future policy mechanisms may need to be considered more holistically to consider how they interact with each other and how they interact with the wider market.

Scenarios could be developed to generate a range of possible portfolios (e.g. FES) and more sophisticated modelling is required which can accurately forecast the performance of such portfolios. There will probably be a greater need to consider the whole energy system in future mechanisms – including interactions between TSO and DSO, interactions between the power system and other energy vectors and also consumer behavioural impacts.

5.2 Manage the interface with connected energy systems

B1 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.

FPSA1 Requirement: *To have the capability to consider potential cross-vector impacts on electricity demand across physical and virtual networks.*

This function is needed to properly and effectively consider relevant dependent energy infrastructures in planning the power system so as to avoid over-investment and stranded capacity in the power sector.

The definition of this function has been refined since the completion of FPSA1. The original definition was: "*Assess the impact of gas and other energy vectors when forecasting the volumes of demand, generation and other dispatchable energy resources and ancillary services on the power system.*"

This was refined to reflect the fact that operational interactions between interconnected countries could also affect forecasting, as well as operational interactions within the power system itself (e.g. between the SO and DSOs or with autonomous parties like smart cities).

Function Needs

The following needs have been identified for this function:

Process: *To account for other energy sectors, interconnected systems and parties with operational responsibilities.*

Modelling: *Capability to account for the impact operational interactions in planning and forecasting of demand and generation.*

Function Interactions

This function will depend on input from function:

- B2, which promotes co-ordination of planning activity between parties.

B2 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.

FPSA1 Requirement: *To have the capability to co-ordinate planning across all engaged organisations.*

This function is needed to better co-ordinate planning across relevant parties and so improve accuracy of forecasting and whole system optimisation of planned investments and developments of the GB system. This requires having the capability to co-ordinate planning across all engaged stakeholder organisations in timeframes sufficient to allow effective investment planning.

The definition of this function has been refined since the completion of FPSA1. The original definition was: "*Provide mechanisms by which planning can be co-ordinated between all appropriate parties to drive optimisation, with assigned responsibility for security of supply.*"

This was refined to provide more detail on how the existing functionality within the power sector needs to be enhanced, as power system planning already involves co-ordination across many organisations. The refined wording accounts for the fact that future planning activities might require closer co-ordination in cross-border, cross-vector and intra-power system operational interactions. This includes co-ordination between distribution and transmission planning, with internationally connected networks, with 'autonomous' users such as smart cities, or with the operators of other vector networks such as gas or heat. It does not specify which party or parties would be responsible for planning or co-ordination.

Function Needs

The following needs have been identified for this function:

Process: *To engage with operators of connected and autonomous system as well as other energy vectors and interconnected systems.*
Process: *To co-ordinate planning activities between engaged parties to drive optimisation.*
Modelling: *To consider whole system interactions when undertaking network planning.*

Function Interactions

This function will take input from other functions including:

- B1, C1 and C6, which provide forecasts and historic data.
- F2, F3 and F4, which identify future changes and threats to the system.
- E2, which reviews planning assumptions.

This function could be delivered through changes to how co-ordination between parties currently works and through enhancements to modelling capability. This could involve a process similar to the network options appraisal, but which considers the whole system. This is echoed by Ofgem and BEIS whereby, in their call for evidence for a smart, flexible energy system, they suggest the development of formalised frameworks by DSOs, TOs and the SO to ensure network planning process takes into account the requirements of the whole system and needs of stakeholders.

B3 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.

FPSA1 Requirement: *To have visibility of planning processes across all relevant parties.*

This function is needed to share plans appropriately across system operation participants and stakeholders in support of co-ordinated operation of the system in real time.

The definition of this function has been refined since the completion of FPSA1. The original definition was: “*Provide an operational planning process that engages with all affected stakeholders.*”

This was refined to more specifically identify the types of system operational interactions which might need to be considered in operational planning processes, including cross-border, cross-vector and intra-power system interactions.

Function Needs

The following need has been identified for this function:

Process: *To design an engaging operation planning process which takes into account different levels of engagement.*

Function Interactions

This function will benefit from input from functions:

- B2, which undertakes multi-vector planning activity across the investment timeframe.
- B4, which provides feedback on real-time cross-vector activities.
- H3, which co-ordinates the value framework of stakeholders in the power sector.

B4 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.

FPSA1 Requirement: *To be able to co-ordinate all involved parties to minimise the consequences of a system incident and restore the system in a timely manner.*

This function is needed to effectively manage the interface with connected networks in real-time.

> The definition of this function has been refined since the completion of FPSA1. The original definition was: "*Enable the delivery of demand control, generation constraint and other actions in response to all extreme events.*"
>
> This was refined to specify the types of system operational interactions which may be required in response to system incidents. This could include cross-border, cross-vector and intra-power interactions.

Function Needs

The following needs have been identified for this function:

Process: *To enable engagement with other energy vectors and interconnected systems on a real-time basis.*
Process: *To co-ordinate responses to system incidents from multiple stakeholders.*
Process: *To deliver actions in response to system incidents.*
Infrastructure: *IT hardware for the provision of monitoring and control.*
Infrastructure: *Communication infrastructure to support monitoring and control activity.*

Function Interactions

This function would require input from function:

- E5, which makes provisions for remedial action (including the use of demand control and generation constraint) for use in response to system incidents.

The function is also reliant on the delivery of functions:

- E1 and E7, which provide monitoring and control capability to support the use of active system management.

B5 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.

FPSA1 Requirement: *To be able to optimise use of energy across multiple sites and vectors, with suitable rewards for the contributions made.*

This function is needed as there is likely to be major interest in trading across vectors and between connected power systems and it is in the interests of the power sector to establish attractive and common processes for doing so.

> The definition of this function has been refined since the completion of FPSA1. The original definition was: "*Collaborate with other energy sectors to optimise across multiple sites and vectors.*"
>
> This was refined to emphasise the necessity of collaboration between cross-border, cross-vector and intra-power system entities to enable market operation across multiple sites and vectors.

Function Needs

The following needs have been identified for this function:

Process: *To engage and collaborate with companies in other energy sectors.*
Process: *For market operation across multiple energy sites and vectors.*

Function Interactions

This function will be enabled by the delivery of function:

- H5, which provides a market structure.

5.2.1 Delivery options for Group B

Manage the interface with connected energy systems

These functions could be delivered by deployment of monitoring and advanced control and communication hardware and development of modelling tools for multi-vector planning optimisation. Stakeholder engagement activities could be broadened across the power system and other sectors to ensure all energy vectors are properly represented. The DSO, for example, could be given the remit to enhance co-ordination of actions across multiple parties in its geographic region (including aggregators, community energy companies and smart city operators). Consideration of the changes to the existing market structure and regulatory framework to efficiently incorporate cross-vector interactions in all timescales may be required.

Trials could be performed for specific multi-vector interaction types, e.g. power2gas, hybrid heating systems. Learning should be captured on technical and commercial implications of operating multi-vector systems.

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

C1 Forecast all demand, generation, other energy resources and ancillary services across all voltage levels within the power system.

FPSA1 Requirement: *To have the capability to forecast generation and demand across public and private networks. (Virtual networks will be picked up via their physical connection points, as happens for large generating companies now).*

This function is needed as transmission and distribution network constraints will arise in unforeseen ways if forecasting models are unable to predict the impact of Low Carbon Technologies (LCT), reverse flows due to DG and demand shape impact of ToU tariffs and DSR.

> The definition of this function has been refined since the completion of FPSA1. The original definition was: "*Forecast all demand, generation and other dispatchable energy resources and ancillary services within the power system.*"
>
> This was refined to reflect the enhanced functionality which will be required in the future, as system level forecasting is already undertaken (e.g. in the Future Energy Scenarios). The enhanced functionally will require more granular data from the system to account for energy resources on all voltage levels and beyond the meter.

Function Needs

The following need has been identified for this function:

Modelling: *Capability to forecast within the power system over investment timescales.*

Function Interactions

This function will benefit from input from functions:

- C6, which provides historic data about the power system.
- B1, which accounts for operational interactions of the power system, including with other energy vectors and systems.

C2 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.

FPSA1 Requirement: *To enable efficient information exchange within the sector and with external parties to allow settlement.*

This function is needed to ensure that all relevant power sector stakeholders have current information of assets and services that can influence system operations and that will support operational decision making by multiple stakeholders.

Function Needs

The following needs have been identified for this function:

Process: *Collate and process availability and performance information.*
Process: *Distribute availability and performance information.*
Infrastructure: *Hardware to collect data on performance and availability.*
Infrastructure: *IT infrastructure to communicate/ distribute data on performance and availability throughout the power sector.*

Function Interactions

This function depends on outputs from function:

- C6, which provides historic data about the power system.

This function is also reliant on the delivery of function:

- E1, which provides monitoring infrastructure for data collection.

C3 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.

FPSA1 Requirement: *To maintain visibility of the planned availability of significant network assets, generation, demand side resources, storage capacity and ancillary services.*

This function is needed to ensure that all relevant power sector stakeholders have up-to-date knowledge of planned outages of assets that can influence system operations in order to support operational decision-making.

Function Needs

The following needs have been identified for this function:

Process: *To collect and process outage information.*
Process: *To co-ordinate between affected partied and identify and resolve clashes.*
Process: *To assign responsibility for security of supply based on outage information.*
Infrastructure: *Hardware to collect data on outages.*
Infrastructure: *IT infrastructure to communicate outage data.*

Function Interactions

This function is reliant on the delivery of function:

- E1, which provides monitoring infrastructure for data collection.

This function will also provide information for function:

- C4, which performs forecasting and modelling.

C4 Forecast and model all generation, other energy resources and ancillary services with operational, cost, and security implications for the power sector.

FPSA1 Requirement: *To have the capability to forecast generation, storage, demand, and other services within operational planning timescales, across all public and private networks. (Virtual networks will be picked up via their physical connection points, as happens for large generating companies now).*

This forecasting function is needed to ensure that all relevant power sector responsible licensees and stakeholders have necessary current and forecast future information of system status to ensure optimal operational decision-making and remedial action planning.

Function Needs

The following need has been identified for this function:

Modelling: *Forecasting capability to incorporate and model resource, cost and security information on all connected resources.*

Function Interactions

This function will require input from functions:

- C3, which collects outage information.
- C2, which provides information on the availability and performance of connected assets including operational restrictions.
- B3, which provides operational planning information from relevant stakeholders.
- C6, which provides post-operation performance information of connected assets.

C5 Identify available generation, other energy resources and ancillary services and associated operational restrictions in real-time.

FPSA1 Requirement: *To be able to confirm availability of physical assets and operational capability against operational plans.*

This function is needed to ensure that all relevant power sector stakeholders are integrated into real-time control and balancing and that system operational responsible parties have access to current information of the system assets available for operations in real-time and the flexibility these afford to whole system operation.

Function Needs

The following needs have been identified for this function:

Process: *To identify available assets from monitored data.*
Infrastructure: *Hardware for monitoring connected assets in real-time.*
Infrastructure: *Communications for real-time monitoring.*

Function Interactions

This function will require input from a number of other functions including:

- C3, which provides outage information.
- C4, which provides forecasting information.
- E3, which provides observability and controllability of connected assets.
- E4, which provides remedial action plans for credible system events.

This function will also be reliant on the delivery of function:

- E1, which ensures monitoring is in place to support the use of active system management.

C6 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.

FPSA1 Requirement: *To enable efficient information exchange within the sector and with external parties to allow settlement.*

This function is needed to address the sheer number of customer demand management actions that will likely become too high to manage through existing approaches, if the full benefit is to be achieved.

Function Needs

The following needs have been identified for this function:

Process: *To collate and process availability and performance information.*
Process: *To distribute availability and performance information.*
Infrastructure: *Hardware to collect data on performance of assets.*
Infrastructure: *IT infrastructure to communicate/distribute data on performance of assets throughout the power sector.*

Function Interactions

This function is closely related to function:

- C2, which collates and distributes information, and promotes co-ordination between parties.

This function will also be dependent on functions:

- E7, which provides monitoring and control infrastructure.
- H2, which enables settlement.

C7 Monitor and settle the delivery of contracted demand, generation, other energy resources and ancillary services.

FPSA1 Requirement: *To be able to confirm that contracted demand, generation and other dispatchable energy resources and ancillary services commitments are being met and take remedial action where they are not.*

This function is needed to provide an appropriate level of certainty that the required energy and system services will be delivered if system operator, network companies, suppliers, aggregators etc. are relying on demand management in lieu of capacity.

Function Needs

The following needs have been identified for this function:

Process: *To implement settlements.*
Infrastructure: *Hardware to enable settlement for demand, generation and ancillary services.*
Infrastructure: *IT infrastructure to transmit settlement signals.*

Function Interactions

This function is reliant on a number of other functions including:

- E7, which provides monitoring and control infrastructure.
- H2, which enables settlement.

5.3.1 Delivery options for Group C

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

In order to deliver this function group and thereby improve the view of the state of the system in each time scale, multiple types of delivery options are likely to be required.

Appropriate monitoring could be designed and trialled by first establishing what information would be required and by whom. Subsequently, sufficient meters could be installed which would increase the visibility of (automatically managed) distributed energy resources and inform the analysis of customer behaviour. Operational software could be developed to support this by enabling monitored data to be collated and analysed.

Commercial codes may have to be adapted to allow for the increased quantity of data exchange. Infrastructure (IT, communications, etc.) would also be required to provide information on the availability of resources and flexibility services to all parties, and enable planning processes to be developed which would allow engagement with all affected stakeholders.

Furthermore, newly monitored data could lead to enhanced modelling capability being developed which would improve the granularity of forecasting of generation and demand at transmission system and distribution system levels (including weather impacts). This could also enhance understanding of customer behaviour changes, and allow the construction of tools at distribution networks level that could be used for dispatch modelling (to access a range of flexibility services).

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

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

FPSA1 Requirement: *To develop the power system to accommodate developments in both generation and demand, using both network assets and active management of distribution systems.*

This function is needed as traditional reinforcement solutions will need to be augmented with techniques for managing national, regional and local peak system demands and/or DG/DER exports and temporary capacity shortfalls. This will include commercial instruments, active network management and plant rating enhancement techniques. This requires development of the power system to accommodate changes in both generation and demand, using both network assets and active management of distribution systems.

Function Needs

The following needs have been identified for this function:

Process: *To identify how to maximise the capacity of the power system.*
Process: *To manage existing assets in a way that maximises capacity and making best use of available capacity.*
Process: *To engage users in maximising capacity.*
Modelling: *Capability to assess technologies and asset management approaches.*
Infrastructure: *Network assets (including IT) to maximise the capacity of the power system.*
Infrastructure: *Communications to better utilise existing capacity.*

Function Interactions

This function will be reliant on the delivery of a number of other functions including:

- E1, E3 and E8, which provide greater monitoring and control capability of all parts of the system.

This function will also inform developments in functions:

- H1 and H5, which could introduce new incentives or commercial structures for maximising system capacity.

5.4.1 Delivery Options for Group D

Use smart grid and other technologies to accommodate new demand, generation and energy resources
There has been significant progress towards the delivery of the needs of this function group in recent years. Innovation funding streams like the Low Carbon Networks Fund, the Network Innovation Allowance and the Network Innovation Competition have promoted the use of innovative approaches. Some of these are starting to now be adopted into business-as-usual, for example, most DNOs now utilise active network management schemes on some areas of their networks. However, the power system will need to continue to innovate in order to test and implement new approaches to maximising system capacity, particularly commercial approaches which engage users. In particular, full delivery of these needs may depend on the transition from DNOs to a more dynamic DSO role.

5.5 Enable and execute necessary operator interventions

E1 Ensure that monitoring is in place to support the use of active system management.

FPSA1 Requirement: *To have access to sufficient increasingly granular data at lower distribution system voltages to determine trends as an input to load forecasting and identification of emerging local network constraints.*

This function is needed as distribution network designs based on traditional After Diversity Maximum Demand (ADMD) principles are likely to be inadequate to accommodate LCT demand or have unused/ stranded capacity. More granular monitoring of voltage and network flows will be required to support real time control and system balancing and this will need to be planned and implemented ahead of requirement so adding to the system planning challenge.

Function Needs
The following needs have been identified for this function:

Process: *To determine the requirements for additional monitoring capability.*
Infrastructure: *To monitor areas of the network.*
Infrastructure: *To integrate monitoring data with other systems and processes.*

Function Interactions
Many functions are reliant on the delivery of this function, including:

- B4, C2, C3, C5, D1, E3, E5, E6, E7, E8, G1 and H2, which require monitoring assets and infrastructure.

This function could also benefit from information from function:

- H2, which enables flexible settlement using smart or advanced meters which could potentially provide information on monitoring requirements.

E2 Review the power sector's developing operational characteristics to validate the assumptions made during the investment planning process.

FPSA1 Requirement: *To develop the power system to accommodate developments in both generation and demand, using both network assets and active management of distribution systems.*

This function is needed to ensure that any deficiencies with planned network and system interventions are identified and rectified. This requires review of investment plans when significant differences emerge between the data used in the planning process and current expectations and observed system behaviours.

Function Needs
The following needs have been identified for this function:

Process: *To review power system operational characteristics and compare against assumptions.*
Process: *To assess the impacts of changing operational characteristics on investment plan.*
Process: *To update investment plan as required.*

Function Interactions

This function will make use of information from other functions, including:

- B1, B2 and C1, which underpin the network planning process and the assumptions that are made about future forecasts.
- C6, which collates and distributes data throughout the power sector.

E3 Provide the capability to observe energy resources across the whole system and mechanisms for intervention.

FPSA1 Requirement: *To be able to dispatch power across GB for optimal reconciliation of national, regional and local needs. Involve operational stakeholders in operational planning.*

This function is needed to address the growth in distributed and variable energy profile assets and the need to optimise their operation and reconcile that with system operational requirements in order to meet overall policy objectives of security, sustainability and affordability.

> The definition of this function has been refined since the completion of FPSA1. The original definition was: *"Enable the dispatch of generation and other dispatchable 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."*
>
> This was refined as the original use of the word "dispatch" had connotations of central dispatch which is not the intention of this function.
>
> In addition, this function now sits under the "Investment Planning" timescale. This acknowledges that these capabilities would need to be designed into the system in the investment timeframe rather than in operational timescales.

Function Needs

The following needs have been identified for this function:

Process: *To ensure system assets are visible.*
Modelling: *Capability to perform optimal cost solutions while considering security of supply.*
Infrastructure: *Hardware to monitor all relevant network locations for observability.*
Infrastructure: *Hardware for controllability of connected assets.*
Infrastructure: *Communications for data retrieval and signal delivery to enact interventions.*

Function Interactions

This function is reliant on the delivery of functions:

- E1 and E7, which provide monitoring and control capability.

This function will also make use of information provided by function:

- C2, which provides information on the availability and performance of connected assets including operational restrictions.

E4 Identify by modelling and simulation constraints arising from credible events/faults, and plan remedial action.

FPSA1 Requirement: *To plan remedial actions for all credible scenarios and faults.*

This function is needed to ensure that operational timescale plans for emergency response are put in place.

Function Needs

The following needs have been identified for this function:

Process: *To assess modelling results and develop remedial action plans for credible events.*
Modelling: *Constraint modelling capability applicable across all voltage levels.*

Function Interactions

This function will inform functions:

- E5, which executes remedial actions as and when necessary.
- F2, which identifies threats to the operability of the power system.

E5 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.

FPSA1 Requirement: *To have the market mechanisms and smart capabilities to ensure an effective real-time response to system events or faults across the power system.*

This function is needed to implement active management of the whole power system with the anticipated additional degrees of operation and possible normal and corrective responses to real-time requirements.

The definition of this function has been refined since the completion of FPSA1. The original definition was: *"Monitor the effectiveness of, and execute as required, remedial action for the delivery of demand control, generation constraint and other actions in response to all events/faults."*

This was refined to clarify that the overall goal of this function relates to remedial action in response to events. Demand control and generation constraint are examples of how this could be delivered, as are market mechanisms and smart capabilities (which were originally set out as examples in the requirement).

Function Needs

The following needs have been identified for this function:

Process: *To provide remedial action as and when necessary in response to events and faults.*
Process: *To monitor the effectiveness of remedial actions that are planned to be implemented following an event or fault.*

Function Interactions

This function will be supported by functions:

- E1, which provides monitoring and control capability on the system.
- E3, which provides greater observability across all parts of the system.
- E4, which plans remedial actions based on modelling credible events/faults.

E6 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.

FPSA1 Requirement: *To be able to dispatch power across GB for optimal reconciliation of national, regional and local needs.*

This function is needed to co-ordinate otherwise unilateral action by individual parties, which would likely be detrimental to the optimal reconciliation of national, regional and local system needs and overall objectives of economy, security and sustainability.

Function Needs

The following needs have been identified for this function:

Process: *Identification of interventions to lower cost or deliver security.*
Infrastructure: *Hardware to enable co-ordination of connected assets.*
Infrastructure: *Communications to enable co-ordination in real-time.*

Function Interactions

This function is reliant on the delivery of function:

- E1, which provides monitoring and control capability on the system.

This function will also be supported by outputs from function:

- E3, which provides greater observability across all parts of the system.

This function will inform function:

- E5, which requires a real-time view of system operation to execute remedial action if necessary.

E7 Provide monitoring and control of those parts of the system under active management, including network assets, demand, generation, other energy resources and ancillary services.

FPSA1 Requirement: *To have effective monitoring and state estimation of generation and demand across the power system.*

This function is needed to provide effective monitoring and state estimation to enable the power system to be actively managed.

Function Needs

The following needs have been identified for this function:

Infrastructure: *Hardware for monitoring and control in areas of active system management.*
Infrastructure: *Communications to enable monitoring and control in areas of active system management.*

Function Interactions

This function is dependent on function:

- E1, which ensures the provision of monitoring in areas of active system management.

E8 Provide automated and secure management of demand, generation, other offered energy resources and ancillary services, including Smart Appliances, HEMS and BEMS.

FPSA1 Requirement: *To have the capability to introduce secure M2M automation without compromising the explicit or hidden interests of customers.*

This function is needed to address the number of customer demand management actions being too high to manage manually, if full benefit is to be achieved.

Function Needs

The following needs have been identified for this function:

Process: *To ensure secure and automated management of demand and generation.*
Infrastructure: *Communications and control infrastructure to enable secure and automated management of demand and generation.*
Infrastructure: *IT infrastructure to enable secure and automated management of demand and generation.*

Function Interactions

This function is reliant on the delivery of functions:

- E1 and E7, which provide monitoring and control capability on the system.

5.5.1 Delivery options for Group E

Enable and execute necessary operator interventions

To deliver this function group, additional information of the energy system with higher granularity at all voltage levels is required. This is likely to be achieved through the installation of increased monitoring, communication and control infrastructure. Greater visibility would also improve active system management and operator intervention (e.g. through market mechanisms or smart capabilities) in case of credible events. The development of an efficient mechanism (e.g. based on Big Data) to analyse all monitored data and draw out important information, particularly on dynamically changing networks, would be an effective tool to consider the vast increase in volumes of data. The extracted information could be used to review the operational characteristics of the system to validate assumptions that were made during investment.

The demand and generation within the power system would benefit from greater co-ordination and possible automatic management in order to deliver security of the grid, improve network efficiency, maximise the use of low carbon generation and avoid unilateral action taken by individual parties which would likely be detrimental to optimisation of the system as a whole. It would have to be ensured that automatic management does not compromise the interests of customers, and data confidentiality is taken into account. Governance and regulatory changes might be required in order to define roles responsibilities of all engaging parties with respect to customer safety and privacy.

Advanced modelling (of the system as a whole) is required to understand constraints arising from credible events and ensure appropriate remedial actions will be taken. This could include state estimation tools that can predict wider network characteristics. The effectiveness of these remedial actions would be monitored to make sure they are executed as required. This also enables post-fault reporting from smart devices, which could be combined with the post-fault reporting on network performance.

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

F1 Enable the power sector to manage necessary changes across the sector when faced with new developments or changes to its objectives and operating environment.

FPSA1 Requirement: *To continuously monitor its objectives and operating environment, and manage necessary changes across the sector.*

This function is needed because the rate and extent of change within the power sector and its operating environment is driving the need for a more responsive and flexible system in order to harness opportunities and manage threats as they arise. These require the power sector to continuously monitor its objectives and operating environment, and manage necessary changes across the sector. This might include introduction of additional functions, beyond those identified by FPSA1.

> The definition of this function has been refined since the completion of FPSA1. The original definition was: *"Enable the power sector to respond readily to change, and ensure the timely introduction and implementation of new functions."*
>
> This was refined in order to ensure that the scope of this function was clear: broader sector-wide change management in response to changing market conditions, changing policy objectives, changing technology deployments etc. This was largely achieved by more closely linking the definition of the function with its requirement.
>
> The reference to "introduction and implementation of new functions" was removed, as future change management could also require variation of existing functions, or implementation of changes that cut across many functions (e.g. broader legislative change).

Function Needs

The following needs have been identified for this function:

Process: *To identify, evaluate, and implement change.*
Process: *To record knowledge and learning about the system's operating environment.*
Process: *To engage stakeholders in management of changes.*

Function Interactions

It is anticipated that this function will interact with all of the other functions identified in FPSA1, and potentially with others that have not yet been identified. This function will be critical to the implementation of many functions and will record knowledge and learning acquired from parties and functionality across the sector.

Delivering these needs is central to the development of FPSA2, particularly WP4 and the development of *Enabling Frameworks*. Please refer to the WP4 report for more information.

F2 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.

FPSA1 Requirement: *To identify and manage threats to system operability.*

This function is needed to pre-empt and assess future threats and challenges to enable the GBSO, DNOs and any other operators and stakeholders to take the necessary action in a timely manner.

Function Needs

The following needs have been identified for this function:

Process: *To engage the whole sector in threat identification.*
Process: *To record learning from threat assessments.*
Process: *To plan counter-measures to perceived threats.*
Modelling: *Capability to model threats across the whole system.*
Modelling: *Capability to model activity beyond the meter.*

Function Interactions

This function will work in conjunction with functions:

- F3 and F4, which identify specific changes and threats to the power system.

This function will also require input from function:

- C2, which provides data about connected assets throughout the power system.

These needs could be delivered through an extension to the current System Operability Framework (SOF) to look at the whole system, including beyond the meter issues. This could be produced through collaboration between the SO, TOs and DNOs, perhaps with oversight from parties such as BEIS or the ENA.

F3 Monitor the impact of customer behavioural changes on system operability and propose solutions to resulting operability issues as necessary.

FPSA1 Requirement: *To ensure the operability of the system whilst minimising the constraints placed upon user flexibility.*

This function is required because the power sector needs to co-ordinate and harmonise interventions by market participants in order to exploit synergies and avoid conflicts that could threaten whole system operability (including security, efficiency and sustainability drivers). This function is strongly linked to function F2 – it specifically considers the need to consider customers when identifying threats. However, whereas function F2 is required to counter threats, function F3 only has to propose solutions.

The definition of this function has been refined since the completion of FPSA1. The original definition was: *"Monitor the impact of customer needs on system operability and propose solutions as necessary."*

This was refined to clarify that the intention of the function is not to alter customers' needs but rather to propose solutions to operability issues caused by changing customer behaviour, thereby allowing the system to accommodate changes in customer needs.

Function Needs

The following needs have been identified for this function:

Process: *To identify operability issues resulting from customer behavioural changes.*
Process: *To propose solutions to operability issues.*
Modelling: *Capability to model system impact of customer behavioural changes.*

Function Interactions

This function is dependent on functions:

- C2 and C6, which provides data about customers and system performance.
- E8, which facilitates interaction between the system and consumers.

This function will also feed into function:

- F1, which will be required in order to implement proposed solutions.

These needs could be delivered through a process similar to the SOF but which places a greater emphasis on the needs and behaviour of consumers and is more forward-looking. This might be similar to the role which WP1B has played within FPSA2. This would be underpinned by detailed modelling of customer behaviour and the impacts which this has on the system.

F4 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.

FPSA1 Requirement: *To protect from, detect, and respond to incidents which impact the confidentiality, integrity, and availability of critical control and commercial functions, including the data required for those functions i.e. the cyber security of critical control and commercial functions.*

This function is needed to identify the needs and develop a plan to provide much higher levels of detection, protection and response to cyber security threats and incidents.

The definition of this function has been refined since the completion of FPSA1. The original definition was: *"Identify and protect, on an ongoing basis, against cyber security threats to operability of the power system originating from inside and outside the power sector. Detect and respond to cyber security incidents."*

This was refined to reflect that the power system does already have some cyber security capabilities but that the emergence of new and unforeseen threats is critical. This refinement also reflects that implementation of this function will extend into Operational Planning and Real-Time and Balancing timescales, with some automated capability being designed into systems in the investment planning timescales.

Function Needs

The following needs have been identified for this function:

Process: *To continually assess cyber security threats, including from new potential sources of threats, and put measures in place to respond to these.*
Infrastructure: *To identify cyber security threats.*
Infrastructure: *To enable effective detection and response to cyber security incidents.*

Function Interactions

This function will work in conjunction with functions:

- F2 and F3, which identify other threats to system operability.

This function will also provide key information to functions:

- B4, E5, G1, G2 and G3, which govern how the system will respond to various emergency actions.

The function must also consider function:

- E8, which enables provision of smart appliances, HEMS and BEMS, which could be at risk of cyber-attack.

These needs could be delivered by, for example, adoption within the power sector of cyber security functionality and technologies that has been implemented in other sectors. Existing control infrastructure could be audited to identify cyber security weaknesses and contingency measures could be put in place (such as secure communications for ancillary service provision or consideration of cyber security risks in network planning).

5.6.1 Delivery options for Group F

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

Delivering this function group requires comprehensive understanding of the changing landscape of the power sector through horizon scanning. Identifying and defining needs to enable the required changes is central to the development of FPSA2, particularly WP4 and the development of *Enabling Frameworks*.

Refined modelling may be required that incorporates data from beyond the meter to understand new threats to operability. To deal with those threats, an extension to the current System Operability Framework could be constructed to look at the whole system (including beyond the meter issues). This could be produced through collaboration between the SO, TOs and DNOs, perhaps with oversight from an organisation such as BEIS.

More regulatory flexibility might be required for NOs and SOs to allow them to appropriately respond to threats.

In order to also account for threats as a result of customer behaviour changes, a similar process to the SOF, but which places a greater emphasis on the needs and behaviour of consumers and is more forward-looking, could be developed. Forecasting and modelling the system impact of customer behaviour changes, based on smart meter data, could enhance efficient investment.

Appropriate identification of, and protection against, cyber security threats could be delivered by, for example, adoption within the power sector of cyber security functionality and technologies that have been implemented in other sectors. Existing control infrastructure could be audited to identify cyber security weaknesses and contingency measures could be put in place (such as secure communications for ancillary service provision or consideration of cyber security risks in network planning).

5.7 Provide capabilities for use in emergencies

G1 Plan for the timely restoration of supplies following a pro-longed local failure (Cold Start).

FPSA1 Requirement: *To have a Cold Start capability under all credible future generation portfolio and demand scenarios.*

This function is needed as temporary cold pick-up demand, exacerbated by latent demand and loss of diversity following a prolonged interruption, may exceed network ratings leading to thermal overloading and potentially voltage excursions.

Function Needs

The following needs have been identified for this function:

Process: *To plan Cold Start.*
Process: *To engage with Cold Start service providers.*
Process: *To develop technical criteria for Cold Start service providers.*
Modelling: *Capability to model Cold Start scenarios.*
Infrastructure: *Secure communications, control, and IT infrastructure for controllable demand that will operate after many hours of local supply failure.*

Function Interactions

This function is dependent on a number of other functions, including:

- E1, E3 and E7, which provide greater observability, monitoring and controllability of networks and connected resources.

This function will also benefit from information from functions:

- F2 and F3, which identify changes in operability and threats to the system.

There are a range of options for how these needs could be delivered. This could involve a DSO being granted temporary control of customers' smart meters so that their demand could be directly managed, or alternatively this control could be delivered by aggregators as a commercial service to the DSO. Alternatively, this could be achieved through the use of distributed energy resources such as storage and non-intermittent embedded generation to offset low diversity demand pick-up.

G2 Provide the ability to move between different modes of overall operation in the event or threat of a system emergency.

FPSA1 Requirement: *To have emergency procedures that can be used to avoid the loss of supplies and speed their restoration.*

This function is needed to prevent loss of supplies and restore the system following a major outage/ Black Start in a timely manner utilising actions from a significantly greater and wider set of system participating parties. This requires planning the emergency procedures to be used to either avoid the loss of supplies or speed restoration resulting from credible and non-credible events.

Function Needs

The following needs have been identified for this function:

Process: *To plan for movement between different modes of operation in response to threats or an emergency and engage the parties who would be involved.*
Modelling: *Capability to model contingency situations across the whole system.*
Infrastructure: *To facilitate movement between operation modes.*

Function Interactions

This function will require information from functions:

- F2, F3 and F4, which identify changes in, and threats to, power system operability.

This function will also be reliant on functions:

- E1 and E7, which provide monitoring across the system.
- B4 and E6, which monitor and enable emergency actions in real-time.

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

Requirement: *To have a Black Start capability under all credible future generation portfolio and demand scenarios.*

This function is needed to counter threats effectively, including planning for Black Start capability, which is essential for security of supply purposes. The current means of providing Black Start will need to be reviewed. It is expected that the load factor of thermal stations will fall and so ensuring that a critical number of them are kept warm will have increasing financial and environmental costs. The co-ordination of self-dispatching generation and virtual communities will be complex. There is also likely to be an increasing reliance on VSC connected DC interconnectors and these present new system electrical characteristics but also create new opportunities in the stable operation of the system. This requires securing Black Start capability under all credible future generation portfolio and demand scenarios.

The definition of this function has been refined since the completion of FPSA1. The original definition was: *"Plan for the timely restoration of supplies following a national failure (Black Start)."*

This was refined to more closely align this function with the Grid Code definition of a Black Start, which is "the procedure necessary for a recovery from a Total Shutdown or Partial Shutdown". This reflects the fact that Black Start capability may also be required in instances where certain parts of the network have failed completely while other areas remain intact.

This function was used by WP4 to test their development of the *Enabling Frameworks*. Therefore, the needs of this function and interactions with other functions have been developed in more detail, as well as potential delivery options.

Function Needs

The following needs have been identified for this function. Note that there are many prominent and important interdependencies between these needs.

Process: *Planning a Black Start:* *There will need to be an overarching process in place which governs the end-to-end process for planning Black Start. This will cover each of the steps that the SO will go through, from identification of a requirement for new capabilities or service providers, to adoption into internal policies, technical codes or standards as required. To an extent, this process will provide overall governance for the other needs e.g. it will define when the SO needs to engage with service providers, who is responsible for developing technical criteria, how modelling is incorporated into the planning etc. The need for new 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 undertaken in function A1 may identify a need for new capability – alternatively, this function may define the requirements of that modelling (e.g. in terms of Black Start capability to provide security objectives). This process will also inform future network planning requirements (B2).*

Process: ***Engaging with Black Start service providers:*** *There will need to be a process in place which procures Black Start services from providers. This will cover every stage, from initial market engagement through to remuneration of providers. Auctions or bilateral negotiations would probably also form part of this process. The overall structure of the market (H5), the nature of financial incentives (H1) and the framework of value propositions (H3) may feed into this function, as they may set boundaries on how services can be procurement.*

Process: ***Developing technical criteria for Black Start service providers:*** *A process will need to be in place to set out the technical criteria which Black Start providers need to fulfil. These criteria will depend on the plan that is in place, but also on wider threats to power system operation (F2) and specific threats such as cyber security (F4). This will determine how the emergency capabilities of service providers are monitored in real-time (E5).*

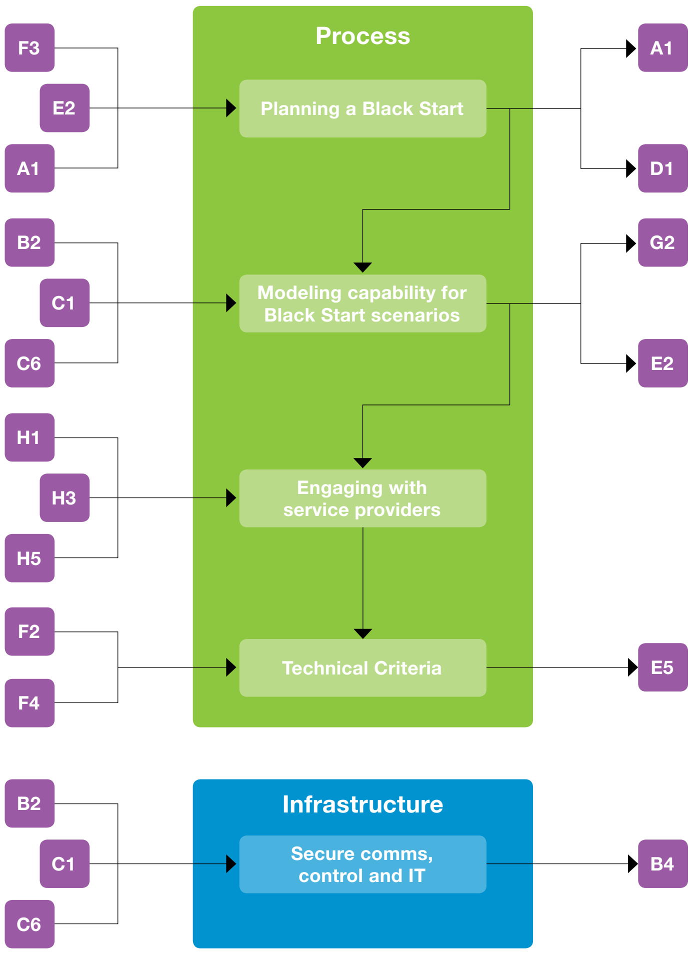
Process: ***Develop a plan for linking up the individual Black Start providers to form "power islands".*** *Once individual providers have started up supplying pockets of load, it will be necessary to interconnect these to form larger power islands that can then be used to energise non-Black Start sources of energy and progressively re-connecting load.*

Modelling: ***Black Start scenarios:*** *Modelling capability will be required which can assess the viability of different Black Start plans in order to support evaluation. This might include second-by-second modelling of dynamic power system phenomena (e.g. in an Electromagnetic Transient simulation package) or a whole system optimisation model to determine the relative costs and benefits of different plans (e.g. in a whole system market model). The modelling will be informed by network planning (B2), forecasting (C1) and historic data (C6) and will in turn be incorporated into wider emergency planning (G2) and investment plan reviews (E2).*

Infrastructure: ***Secure communications, control, and IT infrastructure for controllable energy resources:*** *As part of the Black Start plan, communications, control and IT infrastructure will be required which is secure in the event of a total or partial system failure. This will depend on the further development of the system (D1), and the deployment of monitoring and other associated infrastructure (E1, E3) and will ultimately be required in the event of a Black Start (B4).*

This is not an exhaustive list of interactions. It is likely that as this function is developed, more will be identified. In addition, there will be secondary interactions (e.g. the functions which this function depends on will similarly depend on other functions). However, this demonstrates the complexity of the interdependencies between FPSA functions. The needs, and the interactions, are illustrated in Figure 5-1 below.

Figure 5-1: Function G3 Needs and Function Interactions



New parties, such as interconnectors, are likely to deliver Black Start services in the future. It is also possible that future Black Start provision will be initiated and/or supported by aggregation of multiple service providers and through direct control of smart appliances, HEMS and BEMS during Black Start events. This could even include the use of renewable energy sources to support re-energisation by helping to manage voltage and frequency. There are a wide range of different approaches for how Black Start is delivered, and these could all have different requirements and be delivered by different parties.

5.7.1 Delivery options for Group G

Provide capabilities for use in emergencies
In order to deliver this function group, sufficient infrastructure and procedures need to be in place to enable communication and allow a managed response. Following a local failure (Cold Start), a DSO could, for example, be granted temporary control of customers' smart meters so that their demand could be directly managed, or alternatively this control could be delivered by aggregators as a commercial service to the DSO. This could also be achieved through the use of distributed energy resources such as storage and non-intermittent embedded generation to offset low diversity demand pick-up.

For major outages or Black Starts, minimum system requirements could be defined for 'emergency mode', which may include various grades of emergency. Emergency procedures could be planned to either avoid loss of supplies or speed up restoration. These procedures will require contracts with multiple participants, including e.g. generators and aggregators to manage the transition to emergency modes. Advanced modelling that includes greater contributions from DERs and large-scale variable generation could be used to simulate Black Start processes under a range of generation and demand scenarios and restoration methodologies. Based on these simulations the appropriate controls (e.g. ancillary services) and infrastructure could be installed to enable a response in case of a Black Start.

To ensure operable communication during a major outage, hardware could be installed at each Black Start provider site including adequate redundancy (e.g. a separate power supply). Infrastructure should be made available for DSOs to connect and interface with SO.

5.8 Develop market to support customer aspirations and new functionality

H1 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.

FPSA1 Requirement: *To have the means to align financial incentives across generation/demand and transmission/distribution by using innovative or flexible tariffs.*

This function is needed so that customers, both demand and generation, have controlled exposure to the variable prices on the system and so have appropriate incentive to modify their production and consumption behaviours.

The definition of this function has been refined since the completion of FPSA1. The original definition was: *"Provide aligned financial incentives across the power sector, e.g. innovative or flexible tariffs."*

This was refined as the function did not address "the means" to provide incentives, as stated in the requirement. The new wording reflects that these incentives will largely come from signals to users (e.g. price signals and market signals) which support competition. It also reflects that the impact on customers will need to be considered.

Function Needs
The following needs have been identified for this function:

Process: *To design tariff structures for a range of users.*
Process: *To implement tariff structures.*
Modelling: *Capability to assess different tariffs for different users.*

Function Interactions

This function will be complemented by functions:

- H2, which provides market mechanisms for customers.
- H4, which enables customer settlements.

This function will also inform functions:

- H5, which provides a market structure.
- H6, which enables customers to choose from a range of market options.

H2 Enable settlement for all existing customer profile classes to support flexible tariffs, e.g. half-hourly using smart or advanced meters.

FPSA1 Requirement: *To have the capability to recognise, record and reward customer responses to cost incentives.*

This function is needed to align the financial incentives for customers with an enlarged portfolio of different types of energy sources and the mechanisms and systems to support this.

Function Needs

The following needs have been identified for this function:

Process: *To implement settlements.*
Infrastructure: *Hardware to enable settlement for all customer profile classes.*
Infrastructure: *IT infrastructure to transmit settlement signals.*

Function Interactions

This function is reliant on the delivery of function:

- E7, which provides monitoring and control infrastructure.

This function will facilitate the delivery of function:

- C7, which monitors and settles the delivery of contracted resources.

H3 Implement and co-ordinate a framework where the roles and value propositions of all significant stakeholders across the power sector can be managed.

FPSA1 Requirement: *To have co-ordinated commercial arrangements reflecting the value delivered by energy retailers, aggregators and community energy managers.*

This function is needed to co-ordinate the otherwise unilateral and unco-ordinated commercial/market driven actions by parties that could compromise whole system optimisation.

> The definition of this function has been refined since the completion of FPSA1. The original definition was: *"Co-ordinate the roles and value propositions of all significant stakeholders across the power sector."*
>
> This was refined to ensure that the function aligns with a decentralised market structure, which might involve a number of parties working together to manage their roles and value propositions. Therefore, the intent of this function is instead to provide a framework in which this can be achieved.

Function Needs

The following needs have been identified for this function:

Process: *To enable engagement with stakeholders.*
Process: *To co-ordinate and manage commercial arrangements of multiple stakeholders.*
Process: *To design and implement a framework for stakeholder engagement.*

Function Interactions

This function will complement function:

- H1, which provides aligned financial incentives.

H4 Provide domestic-scale market mechanisms e.g. peer-to-peer trading, to allow customers to unlock the value realised by their actions.

FPSA1 Requirement: *To enable market trading between domestic customers, communities, smart cities etc. to unlock the value realised by their actions and trade with their chosen parties.*

This function is needed to address the anticipated significant interest in peer-to-peer trading so it is in the interests of the power sector to establish attractive and common processes for doing so.

The definition of this function has been refined since the completion of FPSA1. The original definition was: *"Provide a mechanism for peer-to-peer trading with appropriate charging for use of the power system."*

This was refined to reflect that peer-to-peer trading may be just one of many potential options for customers to realise the value of their actions. The new wording also aligns the function more closely with its requirement.

Function Needs

The following needs have been identified for this function:

Process: *To engage domestic customers.*
Process: *To offer domestic scale market mechanisms.*

Function Interactions

This function will complement functions:

- H1, which provides aligned financial services.
- H2, which enables customer settlements.

H5 Provide a market structure that enables customers to have choices within the power system.

Requirement: *Promote the active engagement of customers by enablement of different market options through which they can participate e.g. smart cities, community energy schemes.*

This function would provide the necessary technical integration of active customers, aggregators, community/municipal energy managers etc. into overall system operation through appropriate interfaces and information infrastructure. This function is needed to prevent unnecessary investment in network and generation capacity through failure to fully leverage the demand management capability of customers.

The definition of this function has been refined since the completion of FPSA1. The original definition was: *"Provide a market process that facilitates active engagement of customers, e.g. aggregators, smart city schemes."*

This was refined throughout the development of FPSA2 as the interactions between H5 and H6 were explored, as discussed below.

This function was used by WP4 to test their development of the *Enabling Frameworks*. Therefore, the needs of this function and interactions with other functions have been developed in more detail, as well as potential delivery options. Through this testing, the definitions and intentions of function H5 and H6 were explored in great detail. This is illustrated in Figure 5-2: H5 covers the overall market structure, and H6 the development of market options that align with this structure.

Figure 5-2: Function H5 and H6 Relationship

The new functionality envisaged within FPSA is that new parties will emerge with commercial propositions which fundamentally change the way in which consumers interact with the power system. In general, these market options and commercial propositions will involve consumers being more actively engaged (e.g. through the use of automated DSR or dynamic tariffs). H6 is the function which describes the development of these market options. However, the overall structure of the electricity markets needs to be setup in a way which facilitates these market options. This is the goal of H5.

These two functions could be described together as:

"Provide a market structure that allows service providers *to* ***propose market options that enables customers to have choices*** *within the power system."*

The orange highlighted text describes the role of H5 and the green highlighted text describes the role of H6. The new function definitions for H5 and H6 were developed in order to better reflect this intention.

Function Needs

The following needs have been identified for this function. Note that there are many prominent and important interdependencies between these needs.

Process: *Development and evaluation of market design options:* *There will need to be an overarching process in place which governs the end-to-end optioneering, evaluation and administration of new market structures. 'Building blocks' for market structures will need to be identified, with wider policy objectives (A1) and operability threats (F2) in mind, as well as the overall framework of value propositions (H3). In addition, market structures will need to be suitable for market options that are being developed (H6), multi-vector interactions (B5) and other types of domestic scale market interaction (H4). This will allow for options for market structures to be developed. Market options will then need to be evaluated and ultimately implemented.*

Modelling: *Capability to evaluate proposed market changes:* *Modelling capability will be required to support the evaluation of market development options. This will need to be able to assess the costs and benefits across the whole system. This modelling will utilise data about energy resources (C6) and forecasts (C1).*

Process: *Mechanisms for implementation of new market structures:* *Once a preferred market design is identified, this will need to be implemented and administered, which will depend on function F1.*

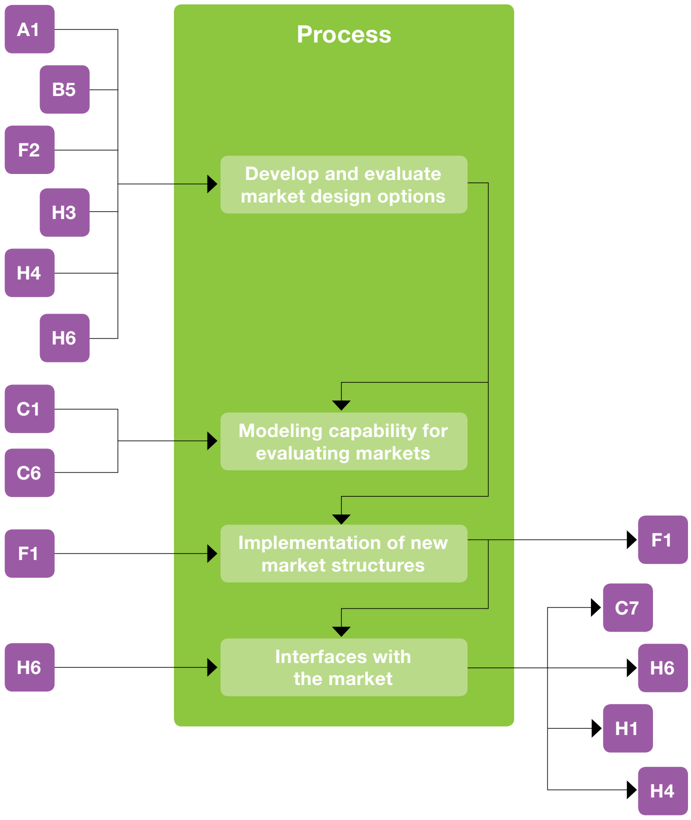
Process: *Mechanisms which allow users and service providers to interface with the market:* *Mechanisms will need to be in place to allow users and service providers to interact with the market. This might include centralised platforms where users can submit data about volumes of trades in the wholesale energy market or auction platforms for procurement of ancillary services. This might in turn imply a need for further IT infrastructure.*

For many customers, market interactions will be achieved through the market options developed in function H6. The options in H6 will therefore need to be compatible with the market mechanisms developed in H5 – for example, currently, market exchanges must interface with centralised balancing mechanisms systems and processes. This process will ultimately affect the design of settlement arrangements (C7), tariff structures (H1), and domestic scale market mechanisms (H4).

This is not an exhaustive list of interactions. It is likely that as this function is developed, more will be identified. In addition, there will be secondary interactions (e.g. the functions which this function depends on will similarly depend on other functions). However, this demonstrates the complexity of the interdependencies between FPSA functions. The needs, and the interactions, are illustrated in Figure 5-3 opposite.

Delivery of this function is likely to be complicated, and will probably be an iterative process due to the many pre-requisite functions identified. Research on market structures, supported by analysis of existing arrangements as well as horizon scanning and international review, will need to be undertaken in order to set out an objective for a future market structure. This review could be co-ordinated and governed by BEIS and Ofgem, incorporating views from stakeholders across the industry. This will need to be supported by enhanced modelling capability to evaluate the performance of different market structures across the whole system.

Figure 5-3: Function H5 Needs and Function Interactions



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

Requirement: *To afford customers the choice of a full range of market options in regards to how they interact with the power system e.g. individual, smart city.*

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.

The definition of this function has been refined since the completion of FPSA1. The original definition was: "Provide a full range of customer choices including individual, community and smart city services."

This was refined throughout the development of FPSA2 as the interactions between H5 and H6 were explored.

This function was used by WP4 to test their development of the *Enabling Frameworks*. Therefore, the needs of this function and interactions with other functions have been developed in more detail, as well as potential delivery options.

The definition of this function, and its interactions with H5, are described in the previous sub-section.

Function Needs

The following needs have been identified for this function:

Process: *Processes for developing new market options:* *Suppliers and energy service providers will need to have processes in place to manage the development of new market options. As an initial step, these providers will need to identify changing customer needs and gaps where new market options could meet these needs. This overlaps to a degree with function F3, which is about assessing how changing behaviour impacts on the system.*

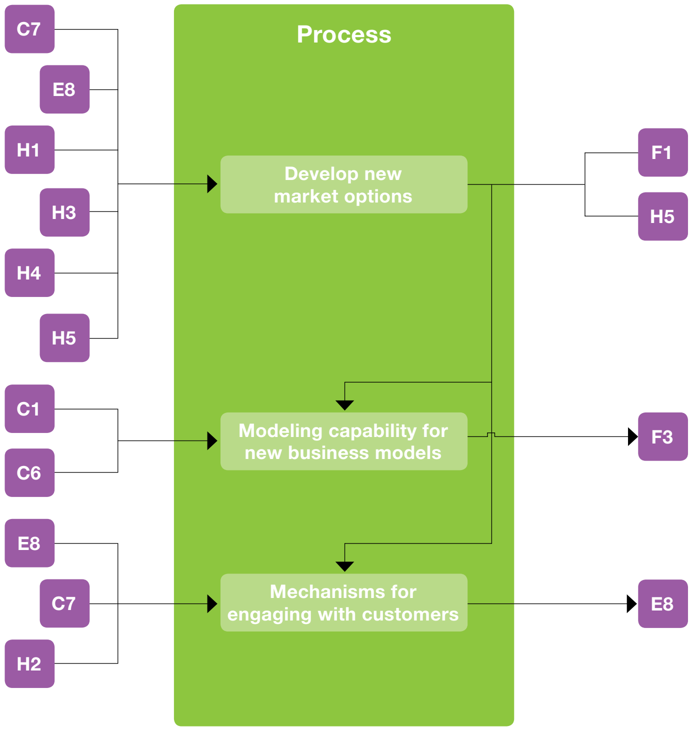
However, H6 is more focused on how these needs can be met, rather than the impacts on the system. The design of the market options will ultimately determine the way in which consumers' needs drives behavioural changes.

Commercial models will need to be developed in detail, and these will need to be supported by business cases to demonstrate that they are viable. These commercial models will need to fit within the existing market structure (H5), settlement processes (C7), the framework of value propositions (H3), financial incentives (H1) and domestic scale market mechanisms (H4). Business models might depend on automation of distributed energy resources (E8). The development of new market options will also feed into defining the requirements for the market structure (H5), and implementation of any changes may depend on function F1.

Modelling: *Capability to determine the viability of new business models:* *Suppliers and service providers will need to have the capability to analytically assess the viability of new business models. This will require modelling capability which can account for how customers behave in response to market options, and will utilise data about the performance of energy resources (C1) and forecasts about the future (C6). This modelling could depend on, or inform, the assessment of how customer needs affects system operation (F3).*

Process: *Mechanisms for engaging with customers:* *Mechanisms will need to be in place to support suppliers and service providers engaging with their customers in a number of ways. This might include educational campaigns to raise awareness of options, marketing to promote business models, and the systems and technologies which consumers use to interact with the service providers. This will require monitoring and settlement of consumers (C7 and H2), and may depend on further infrastructure, including, potentially, web-based applications, smart meters, and or smart appliances (E8), which facilitates this engagement. This might in turn shape the development of market options which include the use of smart appliances (E8).*

Figure 5-4: Function G3 Needs and Function Interactions



There are potentially a number of innovative business models which might be used in the delivery of this function. This might be defined based on how the business model is technically implemented (e.g. via peer-to-peer or blockchain technologies) or based on the coverage of the options (e.g. options based on specific smart cities or community energy schemes). The development of these market options will largely be led by energy suppliers and service providers themselves, but there are likely to be many pre-requisites which will have to be enabled by the wider industry. Many market options will probably depend on the roll out of smart energy infrastructure for consumers (including smart meters and smart appliances).

Consumers' needs will need to be evaluated (e.g. through surveys) and this may depend on programmes of engagement and education. There may need to be a mechanism for service providers to trial market options, which might be enabled by Ofgem's new 'regulatory sandbox'.

5.8.1 Delivery options for Group H

Develop market to support customer aspirations and new functionality

In order to deliver this function group sufficient visibility of customers is required. Smart meters roll out, together with any additional network monitoring, control and communications infrastructure, could achieve this and also support the new functionality of the energy system. With the monitoring and control in place, trials of novel customer propositions, such as smart city services and community energy schemes, could be performed. To enable the opportunities of such schemes and the advanced monitoring and control infrastructure in place to support them to be fully exploited, trials could encompass development of open data platforms, providing opportunities for non-traditional energy sector players to innovate and develop new services. Proper mechanisms could be in place to implement settlements for all commercial propositions and between all relevant parties.

Consumer surveys would help to identify what customers want from future commercial arrangements, as well as surveys of potential service providers, to understand the range of new services that might operate. Trials of new commercial propositions could test the impact of financial incentives and ensure that new propositions do not have any unintended consequences that could be detrimental to system operability.

Based on the outcome of such trials new market designs may need to be developed to accommodate the introduction of new commercial propositions. Market modelling is likely to be required to assess the impact of new market designs on stakeholders across the power sector (and potential cross-vector impacts).

6. Next Steps: RD&D and Innovation Recommendations

6.1 Approach to identifying next steps

Areas for further Research, Development, Demonstration and Innovation have been identified based on the Evolutionary Pathways of FPSA1, the function needs and delivery options identified within WP2 and the quantitative assessment of barriers undertaken in WP3. Based on this, possible RD&D and Innovation actions have been set out which the sector should address in parallel with the ongoing development of *Enabling Frameworks*.

RD&D and Innovation actions should satisfy as many of the following criteria as possible:

- **Importance:** The success of the RD&D and Innovation action should result in a significant step forward.
- **Urgency:** RD&D and Innovation should tackle an existing/emerging problem where there is time pressure to achieve a solution.
- **Holistic:** RD&D and Innovation should not restrict future choice by locking us into a particular set of arrangements.
- **Achievable:** RD&D and Innovation should not depend on the solution of another, more difficult, problem before yielding value.

Two categories of potential RD&D and Innovation actions have been identified, each of which is discussed below. In addition, the barriers identified in WP3 are discussed at a high level in order to give an indication of what sort of activities RD&D and Innovation may need to address.

6.1.1 Actions based on Evolutionary Pathways

FPSA1's Evolutionary Pathways showed four possible ways in which the power sector might implement the *thirty-five* functions. Across these four Evolutionary Pathways, there were nineteen functions which were either required immediately or very soon. Of these nineteen functions, the ten with the highest difficulty (as determined in WP3) are A1, C1, D1, E8, F1, F3, G1, G3, H5 and H6. Specific RD&D and Innovation actions have been identified that would support the delivery of these functions. The actions identified in this manner satisfy many of the criteria identified above:

- The **importance** of the actions is illustrated both by the difficulty of implementing the functions, and the consequences associated with failure to deliver these functions.
- The **urgency** of the actions is demonstrated by the immediate or urgent sequencing of the associated function within one or more Evolutionary Pathways.

When describing possible actions in more detail, care has been taken to ensure that they are also **holistic** and **achievable**.

6.1.2 Actions based on future functionality and common FPSA themes

In addition to the urgently required function, further possible RD&D and Innovation actions have been identified based on some of the common themes within FPSA and on difficult functions which are required later in the Evolutionary Pathways. These themes, which broadly describe some of the ways in which the future power system will differ to the existing system, are:

- Enhanced modelling capability, which relates to many functions in many groups.
- More granular monitoring and metering, which relates to many functions, particular in Group C.
- IT, communications, control, and cyber security, which relates to many functions in Group E and F4.
- Data, which relates to many functions in group C, particularly C7.
- New business models, which relates to most of the functions in group H.
- Greater interaction between energy vectors, which relates to most of the functions in group B.

Although some of this enhanced functionality may not be required until later on (based on Evolutionary Pathways), the scale of the required change is so significant that there is some **urgency** associated with beginning research on these topics as soon as possible. As with the other actions, **importance** is demonstrated both by the difficulty of implementing the related functions, and the consequences associated with failure to deliver them. Care has been taken to ensure that resulting RD&D and Innovation actions are holistic and achievable.

6.1.3 Actions based on primary research

The work carried out in the stakeholder-focused Work Packages, WP1A and WP1B, have highlighted some areas where RD&D and Innovation actions could be productive in understanding some of the customer impacts on the future power system.

6.1.4 Barriers

Extensive work has been carried out in WP3 to identify the barriers and challenges that face the delivery of the functions. The most pervasive barriers give a general indication of the sorts of actions which could be taken to try and facilitate the delivery of the FPSA functions. The most pervasive barriers are discussed below (see WP3 report for a more comprehensive description of the barriers), with some discussion of what actions this might suggest. In general, these barriers support the need for further RD&D and Innovation, continued development of new approaches to governance, and the need to consider new parties in all ongoing work.

- **Industry governance:** Actions which streamline the industry governance process are likely to facilitate function implementation. This supports FPSA2's overarching goal of developing *Enabling Frameworks*.
- **Technical challenges and commercial barriers:** Industry should continue to explore ways to address technical and commercial barriers across all functions. This suggests that it is important that industry continues to support innovation across the sector. Commercial innovation in particular has been discussed below under several RD&D and Innovation actions.
- **Regulatory framework:** For many functions, the existing framework of regulation may impact on function implementation. This has been a common theme in relation to energy storage in recent years – regulatory barriers. RD&D and Innovation which explores regulatory interactions and barriers is therefore likely to be very valuable. This could involve supporting or testing innovations within Ofgem's new 'Regulatory sandbox'[4].

6.2 Actions based on Evolutionary Pathways

This section describes potential actions which the power sector could pursue next. These actions

[4]https://www.ofgem.gov.uk/publications-and-updates/regulatory-sandbox-calling-expressions-interest

should facilitate implementation of those functions which (i) have significant barriers to overcome and (ii) are required immediately across one or more of the four Evolutionary Pathways developed in FPSA1.

6.2.1 Mechanisms to encourage participation in change processes

Function F1 (manage changes across the sector) is, broadly, the 'enabling' function and much of the development of the *Enabling Frameworks* will address the needs of this function.

> One aspect of the *Enabling Frameworks* design which could require **RD&D and Innovation** in particular is the development and demonstration of a mechanism which will encourage participation of a wider group of stakeholders in change processes and allow for this to be progressed quickly and efficiently.
>
> WP4 is developing thinking on this as part of their initial development of the *Enabling Frameworks*. They have described an online portal, similar to the cloud-based software solution 'Slack'[5], where stakeholders could discuss the change process and share all knowledge and documentation.
>
> Further RD&D and Innovation on how such a portal could be designed and implemented should be undertaken prior to the implementation of *Enabling Frameworks*. For example, once the functional requirements of such a portal have been developed in more detail, a funding call could give providers an opportunity to demonstrate solutions. For the purposes of the trial, this could be adopted as part of the change process for a code modification proposal.

6.2.2 Market designs and policy mechanisms for promoting policy objectives

One of the needs of function A1 (model portfolios against objectives) is a mechanism which can be used to plan for the delivery of portfolios of generation and demand that fulfil certain policy objectives. A (limited) case in point is the Capacity Market, which has been used to promote affordability and security policy objectives in the GB energy market. Decarbonisation and affordability objectives have been progressed through the contract for difference mechanism in GB and this is supported by the EU Emissions Trading Scheme at a European level.

In addition, the design of the electricity market itself (as governed by function H5 (market structure)) could also be a 'mechanism' through which energy policy objectives can be promoted, as could the structure of financial incentives (function H1 (aligned financial incentives)). For example, the treatment of imbalance pricing within BETTA was recently modified through the Electricity Significant Balancing Code Review in order to help promote security of supply. The fundamentals of the GB electricity system were implemented in the early 2000's with the transition from the electricity pool to the New Electricity Trading Arrangements (NETA). Since then, changes in the system have been accommodated through modifications to these market arrangements, with significant reforms that include the inclusion of Scotland (BETTA), the introduction of the Capacity Market and the Contract for Difference (Electricity Market Reform), and the recent CMA investigation. In addition, policy objectives have also been promoted through other mechanisms outside of the wholesale electricity market. For example, the Losses Discretionary Reward is a mechanism which ultimately aims to make the distribution networks more efficient, thus reducing cost and environmental impacts[6].

The future power system, however, may undergo such significant change that the existing market structure and supporting policy mechanisms are not appropriate. The existing GB wholesale market essentially values units of energy. However, as the nature of the system changes, and specifically as most forms of generation have zero or near-zero short run marginal costs, the intrinsic value of other system characteristics may become increasingly important, including capacity (MW), ramp rates (MW/s), response durations (h), and reactive power (MVAr). This might be better supported in an entirely new market structure, rather than through

[5] www.slack.com
[6] Although this is outside of the scope of this function as it is not explicitly concerned with the generation portfolio.

incremental reforms to the 'energy only' market. Alternatively, greater integration of different energy vectors could require greater integration of markets for electricity, gas, and heat.

There is scope to undertake further **RD&D and Innovation** on market design policy and market mechanisms which might be required in the future system and which might help promote policy objectives (particularly those that might simultaneously enable all three aspects of the energy trilemma). Future mechanisms should be considered holistically from a whole systems perspective in light of anticipated future developments in distributed energy resources, multi-vector integration and changes 'beyond the meter'.

Initial research could be undertaken to determine what the options might be for a future market design which:

- Accounts for developments such as multi-vector integration, the emergence of new service providers, greater flexibility, and further growth in distributed energy resources.
- Holistically promotes policy objectives, in terms of the trilemma, or any future set of energy policy objectives.

This should include consideration of issues such as regulation, distributional impacts, incentives etc. In parallel (and perhaps on an ongoing, iterative basis) the existing market and supporting incentives and policy mechanisms should be reviewed with this future system in mind, so that issues can be identified early and recommendations can be made on incremental actions.

Related RD&D and Innovation projects:

- *Hook Norton Low Carbon Community Smart Grid - Western Power Distribution - LCN Fund Tier 1*
- *Community Energy Action - Western Power Distribution - LCN Fund Tier 1*
- *Sunshine Tariff - Western Power Distribution - Network Innovation Allowance*

6.2.3 Monitoring impact of customer behaviour on network

Function F3 (customer behavioural changes) is a high difficulty function that is required immediately under the Evolutionary Pathways that focus on customers and communities. With the rapidly changing energy system, and the corresponding increase in customer propositions, it is vital to understand changing customer behaviour and its impact on the network. Increased engagement of customers provides opportunities to improve utilisation of existing assets, reduce losses and defer investment, but it could also result in threats to system operability.

RD&D and Innovation projects should be undertaken to improve understanding of consumer behaviour with respect to electricity use and in particular how consumers interact with new technologies and commercial propositions. This is likely to require increased monitoring 'beyond the meter', e.g. monitoring of individual loads within trial properties. This will provide valuable data to underpin assessment of how future customer behaviour will impact on the network. The focus of work on understanding consumer behaviour could include:

- To what extent are customers flexible in their demand and generation profiles?
- What levels of incentives are required to capture this flexibility?
- How do consumers view the system and how does this influence their reaction to automated control of demands?
- Can customers be segmented?
- What are the implications for future customer behaviour and how much is this reliant on them recognising they play a part in the operation of the whole system?

This is not an exhaustive list. Having proper monitoring of customer behaviour and the lower voltage network in place will contribute to efficient design of the network, improved forecasting of future demand and generation, understanding of future commercial propositions and implications for market design.

Related RD&D and Innovation projects:

- Hook Norton Low Carbon Community Smart Grid - Western Power Distribution - LCN Fund Tier 1
- Community Energy Action - Western Power Distribution - LCN Fund Tier 1
- Customer-Led Network Revolution - Northern Powergrid - LCN Fund Tier 2

6.2.4 Aggregation of Black Start and Cold Start

Function G1 (Cold Start) and G3 (Black Start) are high difficulty functions that are required immediately under several of the Evolutionary Pathways. These functions are considered together as there are many similarities between them.

Black Start could, in the future, be provided centrally by new providers, although Cold Start cannot be provided centrally. However, there is a significant possibility that future Black Start provision could be initiated and/or supported by aggregation of multiple service providers. Aggregation of these services is not currently well understood and TRL of renewable generation for Black Start is not sufficiently high, therefore further work is required. Future Black Start and Cold Start processes might also require a DNO (or future DSO) to have the ability to directly manage demand, particularly heat pump and EV demand[7]. Cold Start may also involve contributions of local generation in order to offset local demand.

Specific **RD&D and Innovation** actions which could support the implementation of both of these functions have been identified based on the function needs.

- **Technological capability:** National Grid has highlighted that new providers of Black Start are required in the future. The capability of alternative technologies has been assessed at a high level as part of National Grid's Black Start Alternative Approaches project. DNV GL and Mott MacDonald both highlighted that a number of 'unconventional' providers could have a role to play during Black Start processes including energy storage (which could initiate the Black Start itself) and intermittent renewables such as wind and solar (which could support an islanded network during the Black Start). These different technologies should be assessed in more detail to determine what the requirements of each technology are for future Black and Cold Start scenarios.
- **Appraisal of approaches:** DNV GL considered a range of alternative approaches that could be used for Black Start, and recommended a move towards a 'spine' or 'top-down' approach. More detailed research should be undertaken on these different approaches with involvement across the power sector including DNOs, generators, and equipment manufacturers.
- **Central management of demand:** Management of demand during a Black or Cold Start may be required, particularly if there is low diversity heat pump and electric vehicle demand. A trial could be undertaken to demonstrate how a DNO or future DSO could manage demand during these events, for example, through direct control over smart meter infrastructure.
- **Secure control, communications and IT**: It is likely that greater aggregation of services will necessarily involve a large amount of control, communications and IT infrastructure in order to co-ordinate and manage the Black Start and Cold Start response. All of this infrastructure will need to be secure in the event of a prolonged blackout. Approaches to ensuring this security will need to be researched further to ensure this does not prevent the adoption of new approaches and technologies.

Related RD&D and Innovation projects:

- Primary SCADA Communications IP Upgrade – UK Power Networks – Innovation Funding Incentive
- Black Start Alternative Approaches – DNV GL for National Grid Electricity Transmission plc
- Black Start Alternative Approaches – Mott MacDonald for National Grid Electricity Transmission plc

[7]Customers giving operational control to another party could in the future be a commercial service.

6.2.5 Forecasting modelling and scenarios

Function C1 (forecasting) is a high difficulty function that is required immediately under several of the Evolutionary Pathways. Improved forecasting is a necessity as there are many uncertainties regarding the future energy system and customer needs that will impact on future demand, generation and the requirement for ancillary services.

Currently there is a lack of consistent scenarios used for investment planning between main actors in the power system, despite some efforts to create standard tools (e.g. the TRANSFORM model). Also, demand and generation in the power sector have many interdependencies with other sectors and energy vectors which may not be fully captured in current forecasting.

In order to better inform investment planning, **RD&D and Innovation** work should focus on the development of a set of scenarios for demand, generation and ancillary services that industry agrees on. A wide range of future pathways for the energy system should be accounted for by the scenarios, and they should include 'beyond the meter' impacts and wider factors. The scenarios will provide a consistent set of assumptions for use across the power sector at an appropriate resolution (temporal and spatial) for planning purposes. The scenarios could be developed in conjunction with other vectors, in particular gas, such that greater consistency in the way multi-vector interactions are captured propagate through the wider energy sector.

Building on these scenarios, updateable, whole system energy forecasting tools could be developed. These models should properly reflect activity in other sectors (endogenously where possible) and include improved representation of factors such as e.g. consumer behaviour, policy impacts, climate change and so on.

Previous related RD&D and Innovation projects:

- Future Network Modelling Functions - Electricity North West Limited - Network Innovation Allowance
- Improving Demand Forecasting - Northern Powergrid - Network Innovation Allowance
- Smart Analytics - Scottish and Southern Electricity Networks - Innovation Funding Incentive
- Met Office Energy Phase 2 Climate Change Mod. - Northern Powergrid - Innovation Funding Incentive

6.2.6 Maximising power system capacity

Function D1 (maximise capacity using appropriate approaches) is a high difficulty function that is required earlier under several of the Evolutionary Pathways. Broadly speaking, this function is about implementing technical and commercial smart grid solutions which facilitate the connection and integration of distributed energy resources and new users.

Significant progress has been made in recent years towards technological innovations which maximise capacity, and many of these are approaching business as usual adoption. New types of network assets like power electronics and automatic voltage regulators have been trialled, and new operating practices such as active network management and dynamic thermal rating are starting to become more common. For example, EA Technology's summary of the Low Carbon Networks Fund Learning[8] lists the learning generation from LCNF projects with learning generated relating to:

- System solutions for voltage and network management.
- Network simulation and modelling.
- Technological solutions.
- Processes changes.
- Development of new commercial arrangements.

Network and technological solutions which maximise power system capacity have been trialled extensively through the LCNF, and continue to be explored in the NIC. We expect that technical and technological RD&D and Innovation will continue, for example, BEIS recently initiated a funding competition for the demonstration of energy storage technologies. However, there is scope to undertake further RD&D and Innovation in other areas, particularly commercial arrangements and asset management approaches, as will be discussed in the following sub-sections.

[8]https://www.ofgem.gov.uk/system/files/docs/2016/04/summary_of_low_carbon_networks_fund_learning_1.0.pdf

Commercial Arrangements[9]

Development of new commercial arrangements within the LCNF has included new contractual arrangements for flexible connections and active network management, and Time of Use tariff trials to encourage DSR. However, innovative commercial approaches to maximising power system capacity have not been explored to the same extent as technical solutions. To an extent, this is reflected by the commercial barriers identified to this function in WP3.

In their recent call for evidence, Ofgem and BEIS noted that "there is significant scope for... system requirements to be addressed through market-based approaches", with particular emphasis on network planning requirements and co-ordination of the efficient local and whole system use of resources. Ofgem and BEIS set out future models for joint transmission/distribution network planning and system operation and suggest that further work should be undertaken in this area. These strongly relate to the transition of DNOs to DSOs.

DNOs are starting to consider the potential for market-based approaches[10] for addressing future requirements, and the DSO transition is likely to be a central theme in 2017 NIC submissions. The ENA has also started to consider whole system interaction in detail through its TSO-DSO Project[11], where it will consider requirements, models and potentially even trials.

All of this work will be hugely informative and important. There will probably be a need for additional **RD&D and Innovation** to support the implementation of market-based approaches, however, the scope of these activities will, to an extent, depend on where there are 'gaps' in the existing work.

Further activities might therefore include:

- Monitoring and synthesis of learning about DSOs and market-based approaches that is generated by existing and ongoing projects and identification of gaps.
- Promoting commercialisation of feasible models e.g. by supporting widespread trials across multiple distribution networks.
- Greater integration of market models with power system models.
- Promoting collaboration[12] between network companies and with third parties (particularly service providers) when scoping future research projects.
- Early stage research on novel commercial approaches which are not yet ready to be explored within the NIA or the NIC.
- Providing further research into the 'beyond the meter' impact, interactions and effectiveness of market-based approaches e.g. through engagement with new service providers.

This should be considered in more detail when: (i) there is more certainty on the scope of the ENA's TSO-DSO project, (ii) the content of the 2017 NIC submissions is clearer, and (iii) Ofgem and BEIS have published the responses and their decisions following the Smart, Flexible Energy System call for evidence.

Related RD&D and Innovation projects:

- Activating Community Engagement (ACE) – Northern Powergrid – Network Innovation Allowance
- Capacity to Customers – Electricity North West Limited – LCN Fund Tier 2

Asset management approaches

Innovation in asset management within the LCNF has largely been focused on development of monitoring strategies and dynamic thermal rating. There could be scope to explore asset management innovation through RD&D and Innovation.

For example, Ofgem and GB's network companies have recently implemented common methodologies for monitoring and reporting on the status of their network assets, including aspects such as the condition, reliability, loading, age, risk, criticality, etc. For transmission, this is the Network Output

[9]This is discussed here in the context of function D1, however, there are significant overlaps with numerous functions, particularly those in the "Markets and Settlement" timeframe.
[10]https://www.ofgem.gov.uk/publications-and-updates/electricity-nic-submission-national-grid-electricity-transmission-transmission-distribution-interface-tdi-2-0
[11]http://www.energynetworks.org/electricity/futures/tso-dso-project/overview/
[12]Greater co-ordination in innovation activities is likely to be central to the future of the NIC.

Measures[13] (NOM) methodology and for distribution the Network Asset Indices (NAI) methodology[14]. There is a large amount of data that goes into producing these outputs. For example, under the NAI, the health index is calculated based on information from the asset register, location, duty, age, etc. This would be based on existing information about the asset base, condition monitoring information and inspections. In turn, data will be produced on probability of failure, consequence of failure, etc. Currently, this information is used largely for regulatory reporting and prioritisation of asset replacement programmes.

There is potential for **RD&D and Innovation** in both the data sources that feed into these asset management processes, and also in the way in which the resulting information is used. For example, innovative condition monitoring techniques could produce new and different information about network assets. Social media could be mined in order to provide information about network faults, which could reduce the need for visual inspections of assets[15]. New methods could even be used to help network companies manage existing data about their networks. For example, TNEI recently helped a DNO to reconcile the electrical information in its power systems analysis models with the asset information in its Geographic Information Systems database.

In turn, data could potentially even be used in more innovative ways. A future distribution company could take a much more dynamic role in managing outage risks[16], through active management of distributed energy resources and new commercial agreements with customers such as interruptible contracts. Asset management information, e.g. the probability and consequence of asset failure, could therefore be considered in the operation of the network, either by control room engineers or within automated control systems.

This could be supported by, for example, a funding call for ideas on condition monitoring, asset management, and the use of new sources of data. This could be similar to the Losses Discretionary Reward, which has provided funding to the DNOs for promoting innovative ways to understand and manage losses.

Related RD&D and Innovation projects:

- Orkney Active Power Network (Phase 3) Electrical State Estimation – Scottish and Southern Electricity Networks – Innovation Funding Incentive
- Smart Data – Northern Powergrid – Innovation Funding Incentive

6.2.7 Mechanism for automated and secure management of demand and generation

Function E8 (automated management of resources) is a high difficulty function that is required immediately under several of the Evolutionary Pathways.

The Government is committed to rolling out 53 million smart meters by the end of 2020, which will greatly improve the insight domestic consumers have on their energy usage. Smart meter roll out is a significant step in increasing accessibility of demand side flexibility, through smart tariffs and automated load control. Consumer driven uptake of home automation technologies, such as consumer hubs and smart thermostats will further increase the availability of connected devices for potential demand management activities. Consumer education and awareness will be important to ensure the potential of these devices to provide services to the electricity sector can be fully exploited.

The increasing amount of smart appliances and electric vehicles allow a wider range of consumers to participate in flexibility offers and the impact of DSR could be much larger if customers would agree on automated management of these smart appliances, or the charging of their electric vehicle. Studies have shown that smart tariffs with automation can

[13]https://www.ofgem.gov.uk/publications-and-updates/decision-direct-modifications-electricity-transmission-network-output-measures-methodology
[14]https://www.ofgem.gov.uk/publications-and-updates/decision-dno-common-network-asset-indices-methodology
[15]https://www.oxfordcc.co.uk/projects/emergent/
[16]For example, in the review of P2/6, NERA suggested that a future DNO could be exposed to clearer signals on the value of reliability, and options for different required levels of redundancy have been discussed.

deliver peak energy demand reductions that are between 60-200% greater than smart tariffs without automated control[17]. However, there are some risks associated with smart appliances, such as: (i) without appropriate commercial frameworks, consumers may derive little value from smart appliances and therefore not be incentivised to invest; (ii) there is a risk of consumers becoming locked into a specific technology if the smart devices are not interoperable; and (iii) some consumers are concerned about the data privacy and security of smart appliances and home automation devices.

To ensure secure and holistic implementation of automated management of demand and generation, and optimise the effectiveness of DSR, **RD&D and Innovation** work is required to make sure all smart appliances should meet specific standards relating to interoperability, data privacy, grid security and energy consumption.

Furthermore, customers should be properly informed of the opportunities and risks of automated management of their smart appliances. Multiple societal **RD&D and Innovation** projects could take place:

- For (web-based) commercial propositions, user tests could be performed to determine which customer interface is most convenient and insightful, and stimulates the use of DSR the most.
- An online platform could be developed on which all information concerning the use of smart appliances and automated management is gathered, and made available to the public.
- Coaches could be embedded within communities to enhance behaviour change of customers.

Related RD&D and Innovation projects:

- Low Energy Automated Networks (LEAN) - Scottish and Southern Electricity Networks - LCN Fund Tier 2
- High Performance Computing Technologies for Smart Distributed Network Operation (HiPerDNO) - UK Power Networks - Innovation Funding Incentive
- Smart Meter Enablement - Scottish Power Energy Networks - Innovation Funding Incentive
- ENA/ENFG Smart Grid Studies - Northern Powergrid - Innovation Funding Incentive
- Wide Area Data Gathering - Electricity North West Limited - Innovation Funding Incentive
- Low Carbon London - UK Power Networks - LCN Fund Tier 2
- Orkney Active Network Management - Scottish and Southern Electricity Networks - Innovation Funding Incentive

6.2.8 Enable new market options

Function H6 (customer choices) is a high difficulty function that is required early under the evolutionary pathways that focus on customers and communities.

Commercial propositions that reflect customers' needs will be important to gain more widespread engagement. Providing customers with choice will be important, although it is also important that these choices are properly communicated and can be understood by customers. Appropriate market structures will need to be in place to support these commercial propositions.

A comprehensive transition to a smart network enables many new options, e.g. individual, city, community and independent schemes, but careful consideration will be required to ensure there are no market or regulatory barriers that block implementation of these innovative propositions. Furthermore, the increase of localised flexibility and control, as well as the increased deployment of distributed generation will necessitate processes to be developed that ensure co-ordination, avoid conflicts and enable optimisation of the system as a whole. New industry standards will be required to tackle issues of cyber security and privacy issues related to the vast increase in customer data.

As the propositions are new and unexplored, the customer response to them is also uncertain and therefore it is important to enhance modelling of customer behaviour change and to perform trial projects to gather empirical data on customer responses.

[17] Frontier Economics, "Future potential for DSR in GB", October 2015. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/467024/rpt-frontier-DECC_DSR_phase_2_report-rev3-PDF-021015.pdf

In order to be able to provide such propositions, early significant investment in infrastructure is required, and **RD&D and Innovation** projects should take place to:

- Trial smart city and community schemes to better understand the data and communications required to offer a full range of market options.
- Identify through these trials the technical codes and standards required (especially by the new parties). To make sure regulation is in place that enables sufficient sharing of data of such trials, Ofgem's Regulatory Sandbox could prove to be a valuable tool that allows innovators to trial innovative business propositions.
- Design surveys or engage in discussions with new parties to understand the way they would like to interact with customers and the types of data flows such interaction would require.
- Model the impact of independently managed smart systems on the system as a whole to ensure system operability.
- Increase the understanding of consumer needs by consumer surveys to understand what the consumers want from future commercial propositions or to understand reaction to particular options. Understanding of the consumer needs will help to identify what new system functionality (data, communication) and commercial models need to be developed.
- Identify and respond to market barriers. Consultations/surveys should be performed for all relevant market participants in order to understand the commercial models they want to implement, but are unable to. New arrangements that allow such models could be trialled locally to ensure all market barriers are resolved. All stakeholders should be continuously consulted on industry changes that are carried out to remove the barriers, so innovation can take place quickly.

In all trials it should be encouraged to use open standards for data access in order to enable third-party development of customer propositions.

Related RD&D and Innovation projects:

- Autonomous Regional Active Network Management System (AURA NMS) - UK Power Networks - Innovation Funding Incentive
- DECC Smart Capital Grant Comms Hub - Scottish and Southern Electricity Networks - Innovation Funding Incentive
- Hook Norton Low Carbon Community Smart Grid - Western Power Distribution - LCN Fund Tier 1

6.3 Actions based on Future Functionality and Common FPSA Themes

This section describes potential actions which have been identified based on (i) difficult functions which are required later in most of the evolutionary pathways from FPSA1 and (ii) common themes and needs which affect and are relevant to many of the FPSA functions and delivery options.

6.3.1 Modelling capability

Quantitative analysis capability (e.g. modelling capability) is likely to be central to the implementation of many of the new and enhanced functions. Several of the high difficulty functions which are required immediately under one or more evolutionary pathways have some needs associated with modelling. This includes A1 (model portfolios against objectives), F3 (customer behavioural changes), G1 (Cold Start), G3 (Black Start), C1 (forecasting), D1 (maximise capacity), H5 (market structure) and H6 (customer choices).

This modelling is likely to cover a wide range of requirements, from dynamic power systems models to market models to whole system energy models. Modelling new approaches to Black Start, for example, could be particularly challenging: this would probably require some high granular dynamic power systems modelling which considers short-term voltage and frequency fluctuations. At the same time, this would need to be a large model that covers the whole of the GB energy system.

The IET considered the need for enhanced modelling capability in the power system as part of its 2015 report for the Council of Science and Technology. Specific gaps that the IET highlighted include modelling capabilities to address:

- Power systems models that span both transmission/distribution networks and active consumers.
- Markets and commercial externalities (including new market mechanisms).
- New ranges of data.
- Interoperability issues between different system and equipment models.
- Interactions with new third parties (including new network services and service providers).

The IET noted generally that more leadership and greater cross-sector co-ordination would be required and development of skills would have to be supported.

All of these gaps align with aspects of the FPSA project's new and enhanced functionality and could be addressed through further **RD&D and Innovation**. This includes the need to model the whole systems power system and potentially interactions with other vectors and sectors, modelling of new markets and service providers, and the use of new types of data. We believe that future stages of FPSA provide an excellent opportunity for the Energy Systems Catapult to continue the work initiated by the CST by developing modelling requirements in more detail and supporting the development and demonstration of new modelling techniques. In the first instance, this could involve a funding call for innovative modelling solutions from industry that address the areas identified within the FPSA project and the original IET report such as more integrated modelling, rather than disparate tools.

6.3.2 Monitoring and metering

There are several functions which relate to monitoring, metering and settlement that have comparatively low difficulty scores yet are required early under some of the evolutionary pathways. These functions include:

- Investing in monitoring infrastructure (E1).
- Using this in real time to check the effectiveness of remedial actions (E5).
- Using this in real time to monitor areas of the network under active management (E7).
- Enablement of 'flexible' settlement (e.g. through smart meter installation) (H2).
- Implementation of settlement (C7).

Monitoring technologies and strategies have been studied within previous innovation projects. For example, Flexible Networks included an extensive study on the use of monitored data. The smart meter roll out is currently in progress, although there have been some delays and criticisms[18]. Several code modifications have been raised which support the transition to half-hourly settlement[19].

Although these functions are *comparatively* less difficult, there are still significant barriers to implementation. In addition, these functions are pre-requisites for many of the functions identified within the FPSA project relating to the use of data, active management and control of the network, and new business models. Therefore, taking actions to help facilitate the implementation of some or all of these functions is urgent and therefore low regret actions should be taken.

It would be worth carrying out further **RD&D and Innovation** and potentially engagement with industry to gain a better understanding of what is currently impeding the network companies and suppliers from deploying advanced monitoring and metering technology. There is discussion in the WP3 report about concerns around managing data, the expense of new infrastructure at LV and how this is likely to impact on deployment of monitoring technology. One of the key concerns for implementing smart meters appears to be the extent of the required changes in infrastructure and the necessary rate of deployment to meet the 2020 target. In addition, there are ongoing concerns about standardisation of interfacing technologies with communication networks[20], and an updated business case last year showed increased costs and reduced benefit.

Beyond general research and development into barriers, specific actions to support this might include:

[18] http://www.computerweekly.com/news/450403114/Smart-meter-benefits-millions-of-pounds-less-than-thought-admits-BEIS
[19] https://www.ofgem.gov.uk/publications-and-updates/half-hourly-settlement-update-march-2017
[20] https://www.spenergynetworks.co.uk/userfiles/file/FITNESS_Document.pdf

- Further appraisal of innovative network monitoring technologies, engagement with equipment suppliers, and research into how to maximise visibility of lower voltage assets at minimum cost.

6.3.3 IT, communications, control and cyber security

Many of the functions are related to the notion of a more 'digital' power system, with enhancement and greater use of IT technology, communications infrastructure and control systems. This has big implications for network security, as it introduces the threat of cyber security incidents into power systems planning and operation.

The future power system envisaged in the FPSA project will contain more intelligent devices (including generation and other distributed energy resources) connected to the power system which operate on the distribution network or beyond-the-meter. Therefore, controllability of these assets implies a significant enhancement of control and communication capability between these decentralised assets and centralised control rooms, with greater flows of information in general on the system.

If the safe operation of the power system relies on this controllability, then this introduces a new source of risk to security of the energy supply, both due to physical threats (e.g. hardware failures) as well as cyber threats. Many existing control systems within devices were designed with availability and controllability in mind which may mean that assets are vulnerable to cyber attacks or do not encrypt information flows[21]. The long life span of network assets mean that updates which resolve vulnerabilities may be slow to address.

Within FPSA1, those functions which imply widespread 'digitisation' of the power system, including E3[22] (observe whole system) and F4[23] (cyber security), were expected to be required relatively late in each of the evolutionary pathways.

However, there are some immediate functions which relate to this theme, such as E8[24] (automated management of resources), which may also be challenging to implement. This suggests that RD&D and Innovation (perhaps early stage research) on these topics should be undertaken now.

As a first action, detailed research and/or a focused call for evidence should be undertaken to gain a detailed understanding of the possible future IT, communications and control requirements of the power system. This could build on the work undertaken within WP1B of FPSA2, and involve specific engagement with, for example, RD&D and Innovation teams within equipment manufacturers, experts within the IT sector, and innovation teams within the traditional power system participants. This would help to generate learning across the power systems sector on how a 'digital grid' might look in practice, provide timescales and a roadmap for when change might be required, and highlight specific barriers and mitigations.

Depending on the outcomes of this research, follow on actions are likely to include:

- Detailed consideration of the way in which the security of IT, communications and control infrastructure affects the overall security of the power system. This might involve further appraisals of existing network planning standards such as the NETS SQSS and P2 to explore how IT failures are accounted for. Currently, these standards give consideration to the required redundancy of network assets. For example, a requirement for N-1 redundancy means that it should be possible to safely operate the power system following the loss of any single circuit or transformer. Future planning standards may have to extend redundancy requirements to include redundancy for the loss of hardware or software components.

[21] https://cybersecurity.theiet.org/users/20921-jon-longstaff/posts/13611-cyber-security-in-the-energy-industry
[22] "Enable the dispatch of generation and other dispatchable 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."
[23] "Identify and protect, on an ongoing basis, against cyber security threats to operability of the power system originating from inside and outside the power sector. Detect and respond to cyber security incidents."
[24] "Provide automated and secure management of demand, generation and other offered energy resources and ancillary services, including Smart Appliances, HEMS and BEMS"

- An appraisal of systems and technologies for providing communications and control within the power sector, with the potential for funding support and trials. Deployment of further communications in the power sector does not necessarily require more installation of fibre optic cables, radio links, or even internet connectivity. For example, last year, National Grid demonstrated a system where control instructions were sent to devices through minute signals embedded within system frequency modulations[25].
- Further detailed consideration of cyber security risks and potential mitigations within the power sector. National Grid has recently initiated a collaboration with the Electric Power Research Institute (EPRI) to study cyber security, with the project due to come to a close relatively soon[26]. This project aims to raise the TRL of cyber security from 3 to 4. The results of this study may inform the detail of further research tasks. A cyber security White Paper from the MIT Energy Initiative[27] suggests that the issues which need to be addressed include cloud security, machine-to-machine information sharing, cyber security technologies, regulation and implementation of best practices, and international approaches. Research should be undertaken on how to identify existing vulnerabilities within the network, particularly those where patches already exist. This could, for example, be embedded with existing asset management and inspection processes.
- Although not RD&D or Innovation, steps should be taken to ensure that there is not a digital skills gap within the power sector. The changes discussed here are likely to require different types of qualification and domain knowledge which may not exist in the sector today. Training requirements should be considered as part of an overall digital strategy.
- Introducing an automatic 'fall back mode of operation' when there is a loss of communications. For example, non-urgent loads could be made frequency sensitive to provide a more linear version of low frequency load disconnection or individual smart meters could limit the householder's maximum load in event of a loss of communications.

6.3.4 Data

There are many functions within the FPSA programme that relate to collation, distribution and utilisation of data. This covers data applications in investment planning (B2) and operational planning (C2 and C3) timescales, as well as markets and settlement (C6 and C7). Function C6 in particular has been deemed to be a difficult function in the WP3 assessment.

Deployment of advanced metering and monitoring technologies as described above will introduce new technical data about the power system, which is likely to have new applications. In addition, this technical data may be combined with information about consumers from other sources such as social media or information obtained from suppliers about their customers in the market. This may lead to the introduction of Big Data into the power system. Data was discussed in the context of asset management in Section 6.2.6.

In a 2011 report[28], McKinsey set out five sources of value that big-data can introduce:

- "Big data can unlock significant value by making information transparent and usable at much higher frequency".
- "As organizations create and store more transactional data in digital form, they can collect more accurate and detailed performance information... and therefore expose variability and boost performance".
- "Big data allows ever-narrower segmentation of customers and therefore much more precisely tailored products or services".
- "Sophisticated analytics can substantially improve decision-making".
- "Big data can be used to improve the development of the next generation of products and services".

[25]http://www.smarternetworks.org/NIA_PEA_PDF/NIA_NGET0119_CL_4713.pdf
[26]http://www.smarternetworks.org/NIA_PEA_PDF/NIA_NGET0190_2613.pdf
[27]https://energy.mit.edu/wp-content/uploads/2016/12/CybersecurityWhitePaper_MITUtilityofFuture_-2016-12-05_Draffin.pdf
[28]http://www.mckinsey.com/business-functions/digital-mckinsey/our-insights/big-data-the-next-frontier-for-innovation

Companies are already starting to explore opportunities for big data in the power sector. For example, AutoGrid is a start-up in the USA, spun out of a university research project in 2011, which provides a technology which "enables energy providers to mine the Energy Internet's rich data lode to extract flexible capacity from distributed energy resources." The WEF has highlighted the potential role of Big Data in the power sector, and this has implications for privacy, security, standardisation etc. The WEF report highlights capturing, understanding and leveraging data as a "no-regret capability" that should be progressed.

There is scope to promote further **RD&D and Innovation** on the future opportunities and risks associated with 'big-data' in the power system and its applications in GB. Research could be undertaken to explore:

- Conduct a thorough review of new sources which could provide data to the power sector in the future.
- Engage with electricity market participants, including generators, suppliers, network companies and new participants, to understand how data is managed and used currently and to identify opportunities for big-data applications. This might be supported by a funding call.
- Risks relating to privacy should be explored, perhaps in parallel with any work undertaken on cyber security.
- The potential for encouraging or incentivising sharing of data between parties should be explored. This could require research into regulatory mechanisms for promoting the sharing of data.
- This could be supported by the development of an overarching big data strategy for the power sector, which could help to identify emerging threats and opportunities and prioritise next steps.

6.3.5 New business models

Another common theme across the FPSA programme is the emergence of new participants and service providers offering new commercial propositions to consumers. This might involve the emergence of entirely new parties – such as smart city service providers and local energy schemes. New systems and mechanisms which might support this have also been discussed. This is likely to involve smart meters and more granular settlement and new flexible incentives and tariffs, but it could also involve the use of blockchain technologies and peer-to-peer trading within the electricity market. This theme affects the majority of the markets and settlement functions within the FPSA programme.

Ofgem has already undertaken work on Non-Traditional Business Models[29], where it grouped those under three areas:

1. Local energy services.
2. Bundled services.
3. Customer participation.

The key issues raised in response to this work were:

- **Enabling diversity and innovation:** Respondents noted that the regulatory framework doesn't give flexibility to develop business models. Ofgem recently called for Expressions of Interest in a 'Regulatory Sandbox' where service providers can trial business models.
- **Consumer protection and service:** Respondents noted that these models could have positive and negative impacts on consumers, and these should be considered.

Opportunities for further RD&D and Innovation on new business models could include:

- Detailed research to understand the potential for business models that consumers might value in the future but which are not currently being proposed, particularly those that involve other energy vectors or sectors. This could be an extension of the work undertaken in WP1B of FPSA2. This might involve reviewing lessons learned from the emergence of new service led business models in other sectors.
- More research on the consumer requirements

[29]https://www.ofgem.gov.uk/sites/default/files/docs/2015/02/non-traditional_business_models_discussion_paper_0.pdf

of new business models. For example, this might include consideration of distributional impacts, or ways in which the sector can engage with customer segments that have traditionally not engaged with the power system e.g. through programmes of communication.

- Horizon scanning to identify the emergence of new technologies and systems that might support new business models which could then be trialled, for example within Ofgem's 'Regulatory Sandbox'.
- Research into how to capture the impacts of new business models within existing models, particularly forecasting and market modelling.

Detailed requirements for RD&D and Innovation may become clearer as the responses to Ofgem's expression of interest are published.

6.3.6 Multi-vector interactions

Multi-vector interactions encompass a wide range of potential energy system configurations that involve two or more supply vectors working together to provide a service, either directly to consumers or to help the system to operate more efficiently. The supply vectors include the electricity network, gas network, district heating, hydrogen as an energy vector and also the liquid fuels supply network. While there is a multiplicity of ways in which these vectors can be combined within the energy system, we find that many of the most beneficial interactions involve the power system and include services such as peak load shaving or fault management, balancing excess renewable generation, price arbitrage and improved system resilience.

Key multi-vector systems that have the potential to provide benefit to the system overall include:

- Hybrid heating systems (e.g. significant electrification with peak gas supply).
- Power-to-gas and power-to-heat.
- Advanced conversion technologies for waste treatment (by taking advantage of the flexibility of final outputs produced by these conversion technologies).

Each of the high potential multi-vector technologies identified above are at a nascent stage of commercialisation, hence there are a number of technical innovation opportunities. The power sector can contribute to the development of multi-vector systems by ensuring that the commercial and regulatory framework, as well as the industry codes, are in place to exploit the potential services such systems can provide.

- Multi-vector interactions are currently not exploited to any significant extent within the energy system, hence there are a number of **RD&D and Innovation** actions that can be undertaken to enable future deployment.
- Opportunities for trials of a range of multi-vector technologies to understand the potential benefits to the power system.
- Increase LV network telemetry in real-time, to provide improved LV network visibility and identify opportunities to optimise the benefits of multi-vector systems.
- Extended trials of electrolyser technology to identify the potential for service provision to the power system (e.g. ancillary services, balancing etc.) and understand the potential impact on the business case (compared to other routes for hydrogen production).
- Fully engage in the development of strategic direction and policy decisions around low carbon heat, e.g. assessment of the cost of heat electrification for clear comparison with other heat supply systems.
- Identify opportunities for collaboration with gas distribution network companies to develop a consistent set of assumptions regarding the future role of the gas networks to inform investment planning across electricity and gas networks.
- Consider the regulatory and market models required to take advantage of multi-vector opportunities, for example consider how benefits that accrue to the power sector due to multi-vector interactions can be distributed to ensure all stakeholders are adequately incentivised.

6.4 Actions based on Primary Research

The following sections highlight areas of development that could benefit from RD&D and Innovation that have been identified from the stakeholder engagement work carried out in WP1A and WP1B.

6.4.1 Customer protection

With the implementation of the new market structure by function H5 (market structure) comes the responsibility to ensure all – but especially vulnerable – customers remain protected and can take full advantage from newly introduced market options. Naturally this includes the privacy of confidential data (Section 6.3.4), protection from cyber threats (Section 6.3.3), and also the security of smart appliances of home automation devices. Governance and regulatory changes to define the roles and responsibilities of (new) parties will be required to maintain this protection within the new system.

The customer propositions introduced by function H6 (e.g. DSR, smart cities, etc.) require a high level of customer engagement, which might unintentionally cause unfair disadvantages for vulnerable customer types if they are unable to use, or uncomfortable with using new ways of interaction (e.g. through Apps or website interfaces). The first project to investigate how DNOs can engage with vulnerable customers, Energywise[30], is currently ongoing and will provide valuable information on how to improve accessibility to the entire range of market options for all customers.

Building on the knowledge gained in the Energywise project, a number of **RD&D and Innovation** actions can be undertaken to guarantee customer protection for all customer types:

- The design of engagement materials and communication channels that effectively support this vulnerable group of customers. These customer types are likely to require more traditional communication channels, and might even benefit from a more personal approach (e.g. energy coaching). If these customers are properly educated it is much more likely they will be able to fairly participate in DSR and ANM.
- Trials to improve understanding of the savings that can be achieved by these customer groups by improving their energy efficiency or participating in DSR. A large section of the vulnerable customers also struggle with fuel poverty, it is important to understand how new customer propositions can alleviate these problems. A proper understanding and communication to the customers of possible savings can help in incentivising them to engage.
- Surveys and trials to ensure smart meter technologies are customer friendly and age appropriate, to guarantee consumers are always protected and able to use their devices.

6.4.2 Consumer response to price

The new market structure will have high levels of active engagement with customers, which allows them (or their agents) more than ever before to respond to changes in prices. Since this will enable new, unexplored market options, an improved understanding of consumer behaviour is required.

In order to achieve this, it should be realised that there are many types of consumers, all of which will engage with, and respond to, the new market options in their own way. Domestic consumers for example might be incentivised by allowing them to compare their energy usage to similar households or by creating an online energy game that allows them to engage in DSR in an interactive way[31]. SMEs on the other hand may struggle to find the capacity to participate, so would require easily accessible automated management. Companies in the industrial and commercial sector may have greater ability to engage, but might find it hard to be flexible in their demand.

For each customer segment, there are multiple questions that need to be addressed:

- How flexible are they in their energy demand?
- What type of incentives are required to stimulate them?

[30] http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Energywise/
[31] http://www.smarternetworks.org/Project.aspx?ProjectID=1702#project-details

- Are they aware of, and do they understand all options that are available to them?
- Will they allow aggregators to manage their demands?
- Are the savings sufficient to make an aggregation business viable?

As the impact of consumer behaviour on the energy market will drastically increase in the new energy market structure, multiple **RD&D and Innovation** projects can be performed:

- Advanced segmented modelling of customer behaviour to understand consumer responses. Models should include both economic and social science aspects, as clearly the decision to participate in DSR or ANM is not purely a financial one.
- Surveys and discussion boards to determine what different types of consumers expect to gain from engagement with the new market structure, and in what way they wish to interact with the power system.
- Trials to explore the actual flexibility of demand and engagement of all consumer types. This could help in identifying barriers to participation or ineffective incentives.

Future Power System Architecture Project 2

Final Report

WP2: Functional Analysis

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

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