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ROADMAP FOR FLEXIBILITY SERVICES TO 2030

A report to the Committee on Climate Change

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ROADMAP FOR FLEXIBILITY SERVICES TO 2030

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The Imperial College team conducted dedicated modelling of the UK's electricity system for this report. This team has led the development of novel advanced analysis approaches and methodologies that have been extensively used to inform industry, governments and regulatory bodies about the role and value of new technologies and systems in supporting cost effective evolution to smart low carbon future. The authors would like to express their gratitude to the Engineering and Physical Sciences Research Council for the support obtained through the Whole Systems Energy Modelling Consortium and Energy Storage for Low Carbon Grids programmes. This support enabled the fundamental research that led to the development of modelling frameworks used in this study.

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EXECUTIVE SUMMARY

The GB electricity system is expected to undergo a fundamental transformation over the next few decades in response to tightening energy sector decarbonisation targets. In its advice to Government on future carbon budgets, the Committee on Climate Change (CCC) has emphasised the importance of decarbonising the power sector and recommended that the aim should be to reduce the carbon intensity of power generation from current levels of around 350 gCO_2/kWh to around 100 gCO_2/kWh in 2030.

Delivering on such a target will require investment in a portfolio of low-carbon technologies and an increase in the provision of flexibility services to enable the cost effective integration of the new system. Growth in required flexibility will facilitate development and deployment of innovative technologies and emergence of new business models and service offerings.

While there are several possible configurations of demand and supply, in any future low-carbon electricity system we should anticipate:

- a much higher penetration of low-carbon generation with a significant increase in variable renewable sources including wind and solar and demand growth driven by electrification of segments of heat and transport sectors;
- growth in the capacity of distribution connected flexibility resource;
- an increased 'flexibility' requirement to ensure the system can efficiently maintain secure and stable operation in a lower carbon system;
- opportunities to deploy energy storage facilities at both transmission and distribution levels; and
- an expansion in the provision and use of demand-side response across all sectors of the economy.

System flexibility, by which we mean the ability to adjust generation or consumption in the presence of network constraints to maintain a secure system operation for reliable service to consumers, will be the key enabler of this transformation to a cost-effective low-carbon electricity system. There are several flexibility resource options available including highly flexible thermal generation, energy storage, demand side response and cross-border interconnection to other systems.

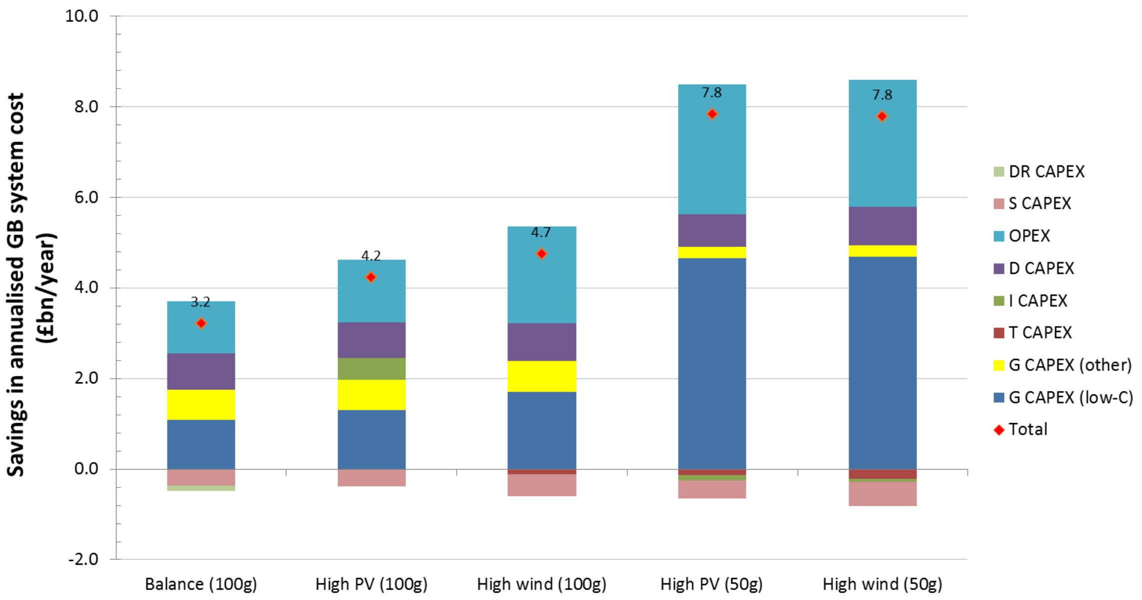
Scenario analysis undertaken by Imperial College as part of this study demonstrates that the system wide benefits of integrating new sources of flexibility relative to the use of conventional thermal generation based sources of flexibility, as shown in Figure 1, are potentially very significant – between £3.2bn and £4.7bn per year in a system meeting a carbon emissions target of 100gCO_2/kWh in 2030.

Key categories of system cost savings achievable by accessing the new sources of flexibility include:

- reduced investment in low-carbon generation (between 25% and 60% of the total savings depending on the scenario), as the available renewable resource and nuclear generation can be utilised more efficiently enabling the system to reach the carbon target with less low carbon generation capacity;
- reduced system operation cost (between 25% and 40% of the total savings), as various reserve services are provided by new, cheaper, flexibility sources rather than by conventional generation; and

- reduced requirement for distribution network reinforcement (between 10% and 20% of the total savings) and backup capacity.

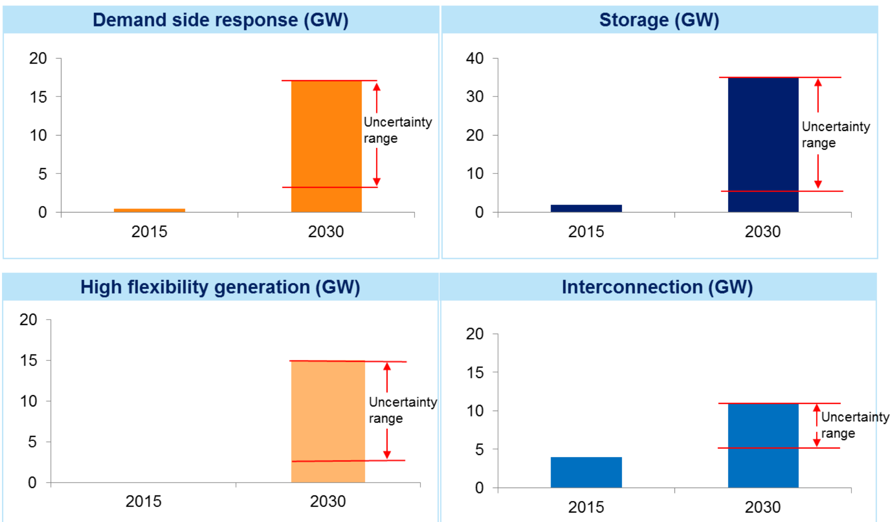
Figure 1 – Potential benefits of efficient integration of new system flexibility resource



Source: Imperial's modelling analysis of the CCC scenarios

However, due to uncertainties around future cost and technical performance of different options, the relative contribution of each flexibility technology may vary greatly, as shown in Figure 2, and it is therefore important that the future market and regulatory environment does not distort decisions but delivers clear signals on which participants can base their investment choices.

Figure 2 – Indication of uncertainty in the deployment of flexibility resource based on modelling analysis



Source: Imperial's modelling analysis of the CCC scenarios

From the analysis and stakeholder engagement undertaken as part of this study, we have identified four key requirements of a future GB electricity system.

- **Investment decisions should be made on the basis of the full system value offered by providers** – this means that the market design must effectively price and reward energy, capacity and flexibility.
- **Appropriate systems and interfaces should be in place to manage greater complexity in system operation and control** – this implies a shift in the resource of system control from the transmission to the distribution level and a capability of the system to deal with more interactions between distribution and transmission networks, and to promote and utilise more active demand management.
- **Ongoing support for innovation in technology, services and operating models** – it will be important that, as the institutional and market framework evolves, the drive for innovation across the value chain is not dampened.
- **Enhanced framework to achieve greater consumer participation** – in addition to establishing the technical infrastructure for demand-side response, legal and regulatory frameworks around consumer protection and data protection will be necessary to achieve widespread consumer acceptance.

Flexibility roadmap

To deliver these requirements, action will need to be taken to enhance the market and regulatory framework and in the course of this study we have developed a roadmap to facilitate low-carbon flexibility. The roadmap is intended to create a technology neutral investment environment supported by an innovation programme that facilitates uptake of the most efficient and cost effective flexibility technologies.

The roadmap, which was informed by a series of stakeholder workshops, defines specific enabling actions aimed at improving access for flexibility. For each action, we describe (a) the primary responsible party; (b) the timeframe over which action is required; and (c) the priority of the action.

Table 1 presents the recommended high priority actions included in the flexibility roadmap. Lower priority actions, together with a detailed description of the rationale for the proposed actions and a high-level overview of the relevant ongoing activities is provided in the main report (Chapter 3 to Chapter 6).

Table 1 – High priority actions of the flexibility roadmap

Action	Responsible	Time frame
Review characteristics of current procurement processes (e.g. threshold capacity level to participate, contract terms / obligations) and the procurement route (e.g. open market, auctioning or competitive tendering) that enable more efficient procurement of services without unduly restricting the provision of multiple services by flexibility providers.	Ofgem in conjunction with SO, TOs and DSOs	By 2020
Assess the materiality of distortions to investment decisions in the current network charging methodology (e.g. lack of locational charging, double-charging for stored electricity), and reform charging methodology where appropriate.	SO, DSOs, and Ofgem	By 2020

Action	Responsible	Time frame
Assess the materiality of distortions to investment decisions in the absence of non-network system integration charging (i.e. back up capacity and ancillary services) and implement charging where appropriate.	SO, DSOs, and Ofgem	By 2020
Publish annual projections (in each year) of longer-term future procurement requirements across all flexibility services including indication of the level of uncertainty involved and where possible location specific requirements, to provide greater visibility over future demand of flexibility services.	SO and DSOs	2020 onwards
Publish a strategy for developing the longer-term roles and responsibilities of system operators (including transitional arrangements) that incentivises system operators to access all flexibility resource by making investments and operational decisions that maximise total system benefits.	Ofgem in conjunction with industry	2018
Periodical review of existing system planning and operational standards for networks and generation, assessing whether they provide level-playing field to all technologies including active network management and non-build solutions (e.g. storage and DSR), and revise these standards as appropriate.	Industry codes governance and Ofgem	Initial review by 2019

A number of initiatives led variously by Government, Ofgem, National Grid and wider industry, are already underway which support our proposed actions. Some of the key initiatives include:

- BEIS and Ofgem's work on flexibility in 2016 (i.e. BEIS and Ofgem's position papers on flexibility) which led to their combined call for evidence for a smart, flexible energy system. It is a wide scope activity intended to collate stakeholder's views and evidence on system flexibility aspects such as; policy and regulatory barriers, price signals and consumers participation. It also presents alternative future models for system and network operator roles and responsibilities for stakeholder feedback.
- Power Responsive is a stakeholder-led programme, facilitated by National Grid, to stimulate increased participation in the different forms of flexible technology such as DSR and storage. National Grid is also working on rationalising the portfolio of the flexibility services it procures.
- The network companies have initiated a case to carry out a thorough review of Engineering Recommendation (ER P2) for the planning of distribution networks. Ofgem has supported this initiative as well as the public engagement process assessing the P2 review on the design of the electricity distribution networks and changes to SQSS (GRS 022) in relation to the integration of new technologies in the networks.

The combination of the ongoing work and the proposed roadmap actions will create a more robust and supportive environment for efficiently meeting the future flexibility requirements in the system.

Progress monitoring framework

In order to monitor progress in development of low-carbon flexibility, we have developed indicators that can be used by the CCC. The indicators and monitoring framework serve the following two main purposes:

- monitor whether the proposed actions are being implemented in line with the roadmap; and
- to assess the impact of actions – i.e. actual progress in the market around assimilating 'smart' flexible solutions.

Performance against specific actions

In relation to specific actions recommended in the roadmap we have, where appropriate, defined a time frame for completion of the action. Where actions are ongoing, this is noted separately.

Any delay in the completion of actions will need investigation to understand the reasons for such delay and its knock-on effect (if any) on other actions and wider achievement of decarbonisation objectives.

For the ongoing actions, a periodical monitoring will be required to check that progress is in line with the requirements and objectives set out in the roadmap.

Performance of the market in general

Performance in this area will be linked to the assessment of measureable impacts of actions on delivering enhanced and efficient volumes of flexibility in the GB system. However, the challenge with developing any quantitative metrics is that there is no precise target for particular forms of flexibility provision. This is driven by the uncertainties around costs and technical development of different types of flexibility sources as well as the long-term evolution of supply mix and market and regulatory frameworks.

In the above context and considering the practicality of collecting and processing information to determine an indicator, we propose that a broad measure of the deployment of additional capacity of flexible technologies should be used as the key indicator to measure the impact of roadmap action.

Based on the modelling analysis undertaken as part of this study for alternative future generation scenarios, we have assessed the required range of additional capacity of different flexible technologies to efficiently meet 2030 carbon intensity targets. Figure 3 shows these additional capacity requirements based on the modelling analysis undertaken as part of this study. The low and high levels for a given flexibility technology are based on its range of penetration across the four main future scenarios investigated in this study (see Section A.2 for scenario details) whereas the central level shows the mid-point of the range.

The central levels of additional capacity of flexible technologies are to be used to track progress on deployment of technologies in a given period. It is expected that a trade-off between various technologies will also take place. For example, lower deployment of additional storage may be compensated by higher uptake of another technology thus meeting the system's overall flexibility requirements.

However, a consistent low deployment of one or more technologies across several years could be seen as a flag for further investigation – e.g. to identify if there is a specific barrier that is hindering the deployment of the technology or affecting its competitiveness against other flexibility technologies.

Figure 3 – Potential levels of flexibility providing capacity (GW)

Flexible technology	By 2020			By 2025			By 2030		
	Low	Central	High	Low	Central	High	Low	Central	High
New flexible generation	1	3	5	2	6	10	3	9	15
Storage	0.8	2.9	5	3.2	11.6	20	5.6	20.3	35
DSR	2.1	6.3	10.5	2.76	8.28	13.8	3.42	10.26	17.1
Interconnection	3.4	3.4	3.4	4.45	5.825	7.2	5.5	8.25	11

Source: Imperial's modelling analysis

Considering the value and scalability of DSR we also propose that the following two indicators should be used to assess the progress for this particular flexibility resource:

- growth in number and size (i.e. total contracted volume, MW) of aggregators providing DSR-based flexibility in the market; and
- growth in the share of smart appliances as a percentage of total appliances sold each year.

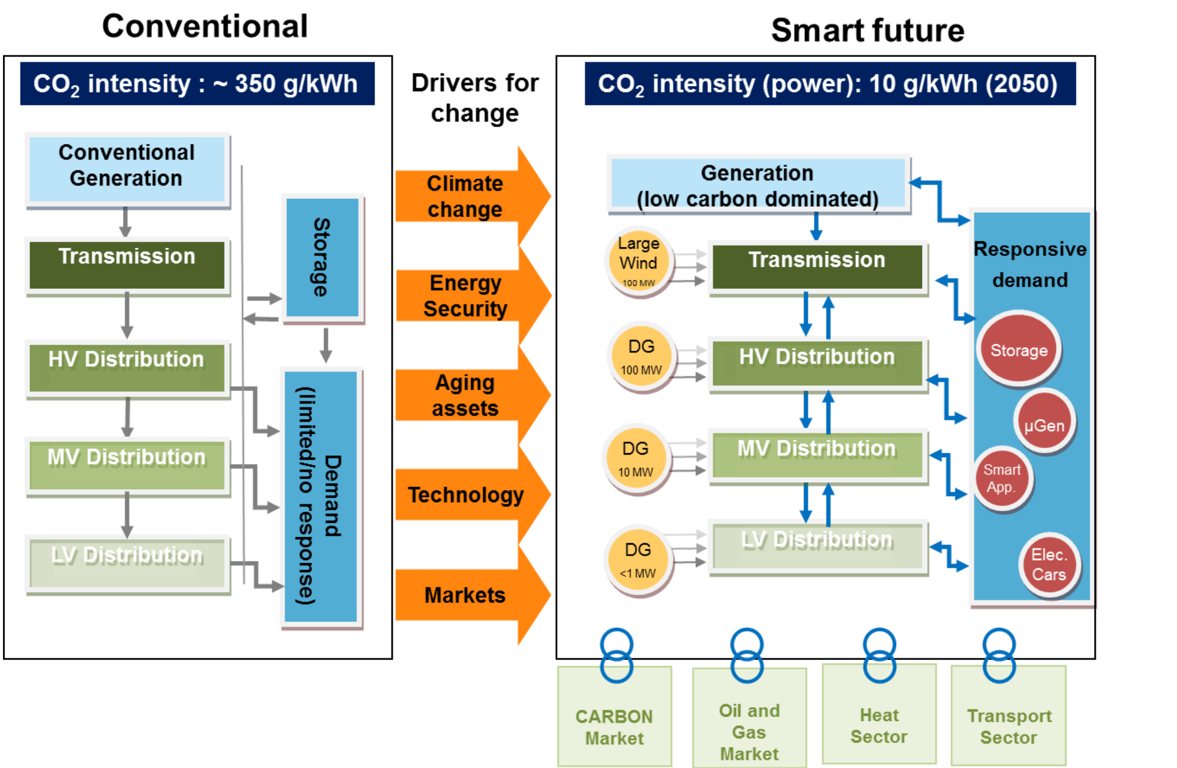
1. INTRODUCTION

The GB electricity system is expected to undergo a fundamental transformation over the next few decades in response to tightening energy sector decarbonisation targets, development and deployment of innovative technologies and emergence of new business models and service offerings. While there are several possible configurations of future demand and supply, we should anticipate:

- a much higher penetration of low-carbon generation with a significant increase in variable renewable sources including wind and solar;
- an increased 'flexibility' requirement to ensure the system can efficiently maintain secure and stable operation;
- growth in the capacity of distribution connected flexibility resource;
- opportunities to deploy energy storage facilities at both transmission and distribution levels; and
- an expansion in the provision and use of demand-side response across all sectors of the economy.

This paradigm shift in the GB electricity system is depicted in Figure 4 below.

Figure 4 – Potential evolution of power system in GB



Source: Imperial College

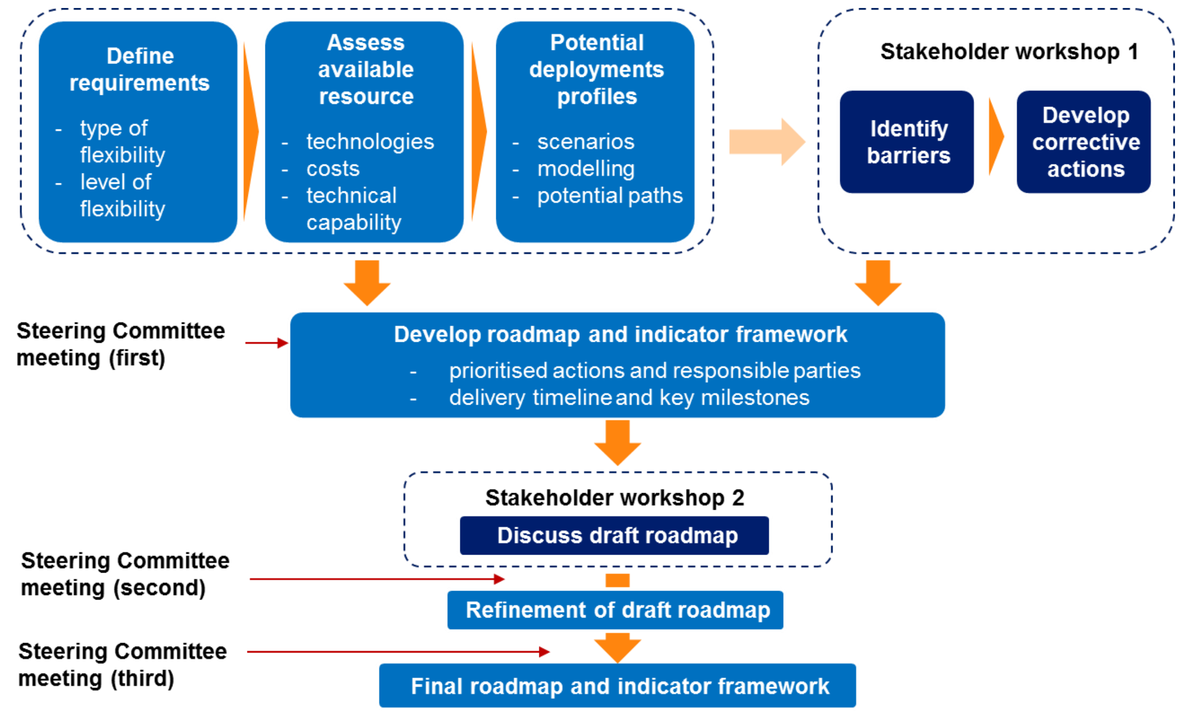
System flexibility will be the key enabler in delivering this transformation. It is important not only in the context of maintaining secure and efficient system operation but also for maximising the utilisation of the assets thus reducing the need for investment in new generation and network capacity. However, the volume of increased flexibility in the system is uncertain, and how and through which technologies these additional flexibility requirements will be served is also not clear.

The Committee on Climate Change, therefore, is looking to develop a roadmap for flexibility services out to 2030. The Committee have engaged Pöyry and Imperial College to develop the roadmap for the provision of flexibility services that would facilitate meeting the CO_2 emission reduction target of below 100gCO_2/kWh for the UK electricity sector by 2030.

1.1 Overall approach

In order to develop the roadmap we have applied the approach shown in Figure 5. Our approach includes research, review and analysis of the flexibility landscape (required flexibility services, flexibility providing technologies and relevant procurement processes), primarily focused on Great Britain and supplemented by knowledge and understanding of the same issues in other systems. Furthermore, a detailed quantitative assessment of the CCC scenarios[1] was also carried out by Imperial College to evaluate future flexibility requirements under alternative generation and demand projections of the GB electricity system.

Figure 5 – Roadmap development approach



1 Power sector scenarios for the fifth carbon budget, The Committee on Climate Change (UK), October 2015

In addition to Pöyry and Imperial's research and analysis, the project also benefitted from stakeholder input through two workshops:

- Stakeholder Workshop 1 was focused on identifying the barriers to deployment of different types of flexibility options and developing ideas on actions to address these barriers.
- Stakeholder Workshop 2 tested the draft flexibility roadmap with stakeholders by presenting the future flexibility requirements and discussing the actions for facilitating provision of enhanced flexibility out to 2030.

The list of participating organisations and their representatives in the first and second workshops are provided in Annex C and Annex D respectively.

The project work and findings were overseen by a Steering Committee comprising members from the Committee on Climate Change, BEIS and Ofgem. The project Steering Committee provided highly valuable feedback and guidance during three meetings at key milestones during the project.

While stakeholder and Steering Committee inputs have greatly contributed to the development of the roadmap, we (Pöyry and Imperial) have maintained our independent analysis in defining the actions necessary to enable an efficient provision of flexibility in the future GB electricity system.

We acknowledge that a number of enabling activities are already being progressed by Government, Ofgem, National Grid and the wider industry. Our proposed actions are intended to build upon or complement these ongoing activities and they are explicitly referred to in the relevant sections of the report.

1.2 System flexibility

In this report system flexibility is defined as the ability to adjust generation or consumption in the presence of network constraints to maintain a secure system operation for reliable service to consumers. It has the following two components:

- Operational flexibility – i.e. the use of resources, both energy and ancillary services, to ensure efficient and secure system operation; and
- System adequacy – i.e. maintaining the long-term capacity requirement of the system.

The two forms of flexibility are complementary to each – for example, the energy storage supports maintaining demand-supply balance during system operation and it can also reduce system's peak demand lowering the need for generation and network capacity in the long-term. Imperial's modelling based assessments presented in this report take account of the synergies and complementarities between the two forms of flexibility as well as across different flexibility providing technologies.

1.3 Flexibility providing technologies

In response to the flexibility challenge, novel flexible technologies that can make more efficient use of the existing infrastructure are emerging.

The analysis in this report focused on the following types of flexibility providing technologies.

- **Flexible generation:** advances in conventional generation technologies are allowing them to provide enhanced flexibility to the system. This is due to their ability to start more quickly, operate at lower levels of power output (minimum stable generation), and achieve faster changes in output (see Table 5 for technical parameters of flexible generation as applied in our modelling work).
- **Cross-border interconnection:** interconnectors to other systems enable large-scale sharing of energy, ancillary service and back-up resources.
- **Demand Side Response (DSR):** DSR schemes can re-distribute consumption and engage demand-side resources for system balancing to enhance system flexibility without compromising the service quality delivered to end customers. These schemes have a significant potential to provide different types of flexibility services across multiple time frames and system sectors, from providing primary frequency response to facilitating network congestion management.
- **Energy storage:** energy storage technologies have the ability to act as both demand and generation sources. They can contribute substantially to services such as system balancing, various ancillary services and network management.

In addition to the above mentioned flexibility providing technologies, there is significant potential for the power sector to access the flexibility embedded in other energy sectors particularly the heat and gas sectors. However, understanding the effectiveness and implications of exploiting this flexibility resource needs further research and analysis. This flexibility resource is discussed further in Section 5.1.3.

1.4 Flexibility services and technologies

In order to ensure that generation and demand are balanced at all times and in all locations, GB System Operator (i.e. National Grid) employs a range of measures (i.e. Flexibility Services) across various time horizons. These services are secured under various procurement mechanisms (e.g. markets, bilateral agreements, competitive tendering, etc.) and can be broadly broken down as follows:

- Capacity market: the aim of the Capacity Market (CM) is to deliver generation adequacy. Capacity contracts are allocated to providers through auctions intended to secure a capacity requirement in order to meet the reliability standard set by the UK government.
- Wholesale energy market: this market allows generators to sell their electricity to suppliers from several years ahead up until Gate Closure.[2]
- Balancing Market (energy): its purpose is to maintain demand and supply balance post Gate Closure as Generators and suppliers will most likely generate or consume more or less than they have sold or bought in the Wholesale market. The System Operator accepts offers and bids for electricity to enable it to balance the transmission system during the post Gate Closure period.
- Ancillary (Balancing) services: these are used by the System Operator to ensure that supply meets demand at all times and that the system frequency remains within statutory limits around the target level of 50Hz. Main balancing services are:
  - Short Term Operating Reserve (STOR) – to retain spare generation capacity (or demand reduction) on stand-by during certain hours of the day (typically during

[2] Gate Closure is the time by which all notifications must be given; currently it is set at 1 hour prior to the start of the traded period.

periods of rapid change in demand or generator loading) for dealing with actual demand being greater than forecast demand and/or plant unavailability.

- Fast Reserve – provides a rapid and reliable delivery of active power through an increased output from generation or a demand reduction, following receipt of an electronic despatch instruction from National Grid. This service operates in quicker timeframes than STOR.
- Frequency Response – is the automatic provision of increased/reduced generation or demand reduction/increase in response to a drop or increase in system frequency. It can be delivered through either Dynamic Response (a continuous service used to manage second by second changes on the system) or Static Response (a discrete service usually triggered by a defined frequency deviation).
- Enhanced Frequency Response – achieves 100% active power output at 1 second (or less) of registering a frequency deviation. This is a new service that is being developed to improve management of the system frequency pre-fault, i.e. to maintain the system frequency closer to 50Hz under normal operation.

In addition to the above mentioned main flexibility services, a range of other services are also used by the System Operator which are defined in Annex B.

A number of technologies are capable of providing the various types of flexibility services required in the system. Table 2 summarises technologies which are currently providing the key flexibility services in the GB electricity systems (see green dots) and those that are technically capable of providing the services based on their existing technical characteristics or with some technical improvements (see red dots). The lack of current service provision may be for several reasons including commercial constraints, market limitations or lack of incentives. For example, DSR can provide Enhanced Frequency Response (EFR) but no DSR aggregator was successful in securing a contract in the recent EFR auctions because bids were out of merit.

It is also worth noting that in some cases, although a technology is providing a given service, its market share for the service could be very small. For example, wind generation provided only 0.03% of total frequency response (FR) in 2015. It could potentially provide significant volumes of additional FR in the form of synthetic inertia if appropriate regulatory requirements or incentives were in place and this was considered efficient.

Therefore, there is a need for: (a) innovation support to improve technical characteristics of such technologies; and (b) improvements in existing flexibility markets, including procurement processes, in order to enable and facilitate access of such technologies in providing a wider range of flexibility services.

Table 2 – Flexibility services and technologies

Technology	Capacity market	Wholesale energy market	Balancing market (Energy)	Main balancing services			
				STOR	FAST reserve	Frequency response	Enhanced Frequency Response
Coal	🟢	🟢	🟢			🟢	
Nuclear	🟢	🟢	🔴			🔴	
Gas-CCGT	🟢	🟢	🟢	🟢	🔴	🟢	
Gas-OCGT	🟢	🟢	🟢	🟢	🔴	🟢	
CHP (Thermal / RES)	🟢	🟢	🟢	🟢	🔴	🟢	
Biomass	🟢	🟢	🟢	🔴	🔴	🟢	
Engines (gas / diesel)	🟢	🟢	🟢	🟢	🟢		
Wind (onshore / offshore)	🔴	🟢	🟢	🟢	🔴	🟢	
Solar - PV		🟢	🔴		🔴	🔴	
Solar - CSP	🔴	🔴	🔴	🔴	🔴	🔴	
Hydro (reservoir)	🟢	🟢	🟢	🟢	🔴	🟢	
Marine (wave, tidal, etc.)	🔴	🔴	🔴	🔴	🔴	🔴	
Hydro (pump storage)	🟢	🟢	🟢	🟢	🟢	🟢	
Storage (batteries)	🟢	🟢	🔴	🟢	🔴	🟢	🟢
Demand Side response	🟢	🔴	🟢	🟢	🟢	🟢	🔴

🟢 Technology is able to provide and is currently providing the relevant service

🔴 Technology that can potentially provide the service but is currently restricted due to economic or market limitations, or requires some technical improvements for providing the releavnt service

Blank cells indicate absence of any evidence or information to map technologies onto flexibility services

Source: Pöyry analysis

1.5 Structure of this report

The rest of this report is organised as follows:

- Chapter 2 provides the findings of the modelling analysis carried out as part of this study. It highlights the higher flexibility demands in the future system and identifies portfolios of technologies to meet this.
- Chapter 3 to Chapter 6 provide our analysis on each of the four identified components of an effective low-carbon flexibility system:
  - ensure efficient investment decisions in providing increased flexibility services;
  - develop capability to manage greater complexity in future smart electricity systems;
  - ensure innovation support; and
  - ensure effective consumer participation for exploiting demand flexibility potential.

  and the actions required to achieve them.
- Chapter 7 summarises the roadmap actions and describes the progress monitoring framework.

There are four annexes to the report.

- Annex A contains key modelling assumptions and methodology as applied by Imperial College in quantifying the need and benefits of system flexibility.

- Annex B provides an overview of the flexibility services currently procured by the system operator, and mapping of flexible technologies to various flexibility services in the future.
- Annex C and Annex D list the participants who joined the two stakeholder workshops.

1.6 Sources

Unless otherwise attributed the source for all tables, figures and charts presented in this report is Pöyry Management Consulting.

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2. MODELLING THE NEED FOR FLEXIBILITY

System flexibility will be the key enabler for an efficient transformation to the future smart electricity system. There is a general acknowledgement that a low-carbon power sector will need greater system flexibility to maintain stable and secure operation because of the nature of the generation technologies. However, the scale of growth and the mix of flexibility services required will depend on the way in which the decarbonisation of the power sector is achieved.

2.1 Modelling assessment of future flexibility requirements

As part of this study, a detailed modelling based assessment was carried out by Imperial College to investigate how flexibility requirements change in a system that meets the CO_2 emissions intensity target for the power sector (i.e. 100gCO_2/kWh by 2030 and 10gCO_2/kWh by 2050). The modelling investigated how flexibility needs changed across four alternative future scenarios of low-carbon generation.

- **Balanced scenario:** assumes balanced development across different low-carbon technologies (i.e. nuclear, CCS and renewables). The scenario is based on the extrapolation of the CCC power sector scenarios.[3]
- **High PV scenario:** assumes a large deployment of PV which significantly exceeds the development of other low-carbon technologies. This would be facilitated by a rapid decrease in the cost of solar cells, massive technology development in this area, and incentives given to the PV industry to stimulate significant growth.
- **High offshore wind scenario:** as the UK has one of the best wind sources in the world, this scenario reflects extensive exploitation of this large energy potential for decarbonisation of the UK electricity industry.
- **High nuclear and CCS scenario:** assumes that the future decarbonisation of the system will depend on the energy production primarily from nuclear and CCS.

The modelling provides a range of insights into the challenges of managing a low-carbon generation system and the potential benefits from access to a wider set of flexibility providers and technologies. In particular, it highlights that:

- regardless of the composition of the future energy mix, ***any low-carbon system will have a materially higher demand for system flexibility***;
- because of the different technical characteristics of the low-carbon generation technologies, the balance of ***additional flexibility services can be very different to today***;
- flexibility can be provided by a variety of new sources (including DSR, energy storage and additional interconnection) and ***deliver savings compared to relying on conventional sources of flexibility*** (e.g. conventional thermal plants like combined cycle gas turbines or open cycle gas turbines);
- ***savings can be made in investment and operating costs across the value chain*** if decisions are based on the full system value; and

[3] Power sector scenarios for the fifth carbon budget, The Committee on Climate Change (UK), October 2015

- the ***future flexibility portfolio is uncertain and will need to be responsive to a range of external factors*** including policy and market initiatives, technology costs and efficiency improvements.

These insights have helped inform the focus of actions in the flexibility roadmap. Importantly, they have demonstrated the need for any future market to encourage access from as wide a set of flexibility resource as possible, and not to be unduly restrictive given the various uncertainties around new technologies. In addition, they have emphasised the importance of continued support for innovation and clear, transparent signals of value for all flexibility services.

The remainder of this Chapter presents the key modelling insights in each area. An overview of the modelling methodology applied by Imperial College in this analysis and the key modelling assumptions are provided in Annex A.

2.2 Future flexibility requirements

Any future low-carbon power system will potentially have a large penetration of intermittent generation, or less flexible nuclear / CCS plants, or a combination of these low carbon sources. This generation setup drives the need for significant additional flexibility over shorter time scales (i.e. between few hours ahead to the real-time) necessary to maintain safe and efficient operation of the system as described in the following sections.

Figure 6 shows an illustrative[4] snapshot of the hourly net demand profile (i.e. system demand minus intermittent generation) in a single winter week in 2030. A key observation is that the net demand turns more volatile and often peakier with shorter duration of peak demand in the future than today. This leads to a need for a very steep ramping requirement – i.e. increase as well as decrease in generation or demand from dispatchable resources (demand or generation) in the system.

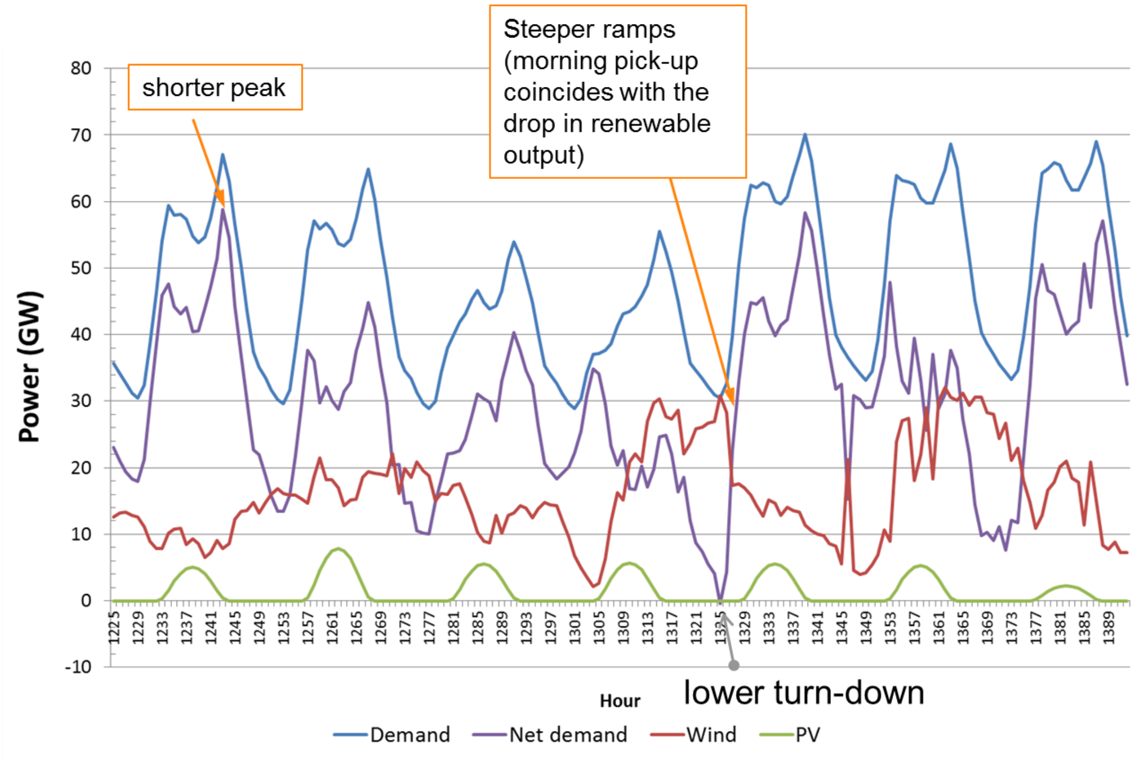
In this case, the steepest ramp requirement is found when the morning pick-up coincides with a large drop of renewable output. For safe operation of the system, a large number of dispatchable generators will need to be synchronised to be able to meet this ramping requirement in order to maintain demand-supply balance in the system.

Figure 6 also shows that the minimum net demand levels which occur during a low demand period coincide with high renewable output. The minimum net demand approaches zero indicating that the entire system demand is supplied by renewables during such periods. However, such conditions create a challenge in power system operation since renewables such as wind and solar PV do not contribute to the system inertia and are not the main providers of frequency response or regulation.

In order to mitigate the risk to safe operation of the system, a sufficient number of conventional plants need to be synchronised operating at least at the minimum stable generation level. This will lead to surplus generation in the system resulting in curtailment of renewable generation unless demand can be increased or energy is exported to other systems in order to accommodate the surplus energy.

4 The week is drawn from the modelled scenarios to demonstrate the potential volatility in net demand to be managed by the system operator through its range of flexibility services.

Figure 6 – An illustrative example indicating higher requirement for operational flexibility in the future (Balanced scenario)



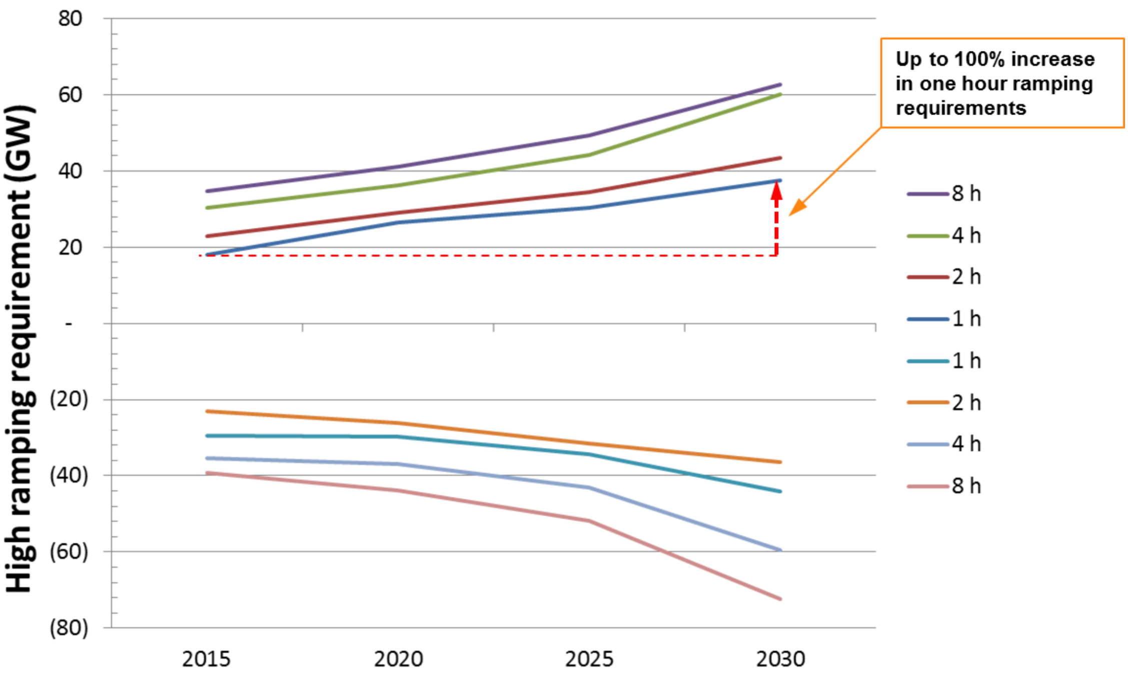
Source: Imperial's modelling analysis

2.2.1.1 Ramping requirements

Based on the modelling of scenarios analysed in this study, it is estimated that there will be an increase of up to 100% in the maximum ramping requirements over a one-hour time horizon in 2030 relative to the current situation. This is primarily driven by the increased renewable energy capacity. The maximum ramping up and ramping down requirements for different time scales (1 up to 8 hours) are shown in Figure 7.

In general, the ramping requirements increase over all time horizons (i.e. across 1-8 hours). This requires the system operator to plan a larger volume of ramping capability of the synchronised generators or other dispatchable demand/supply resource in the system within the respective time frame to meet the demand-supply balancing challenge. Meeting the increased ramping requirements by fossil based generation is expensive due to (a) efficiency losses as some plants will be required to run part-loaded; (b) increased number of start-ups; and c) increase in CO_2 emissions driven by efficiency losses. On the other hand, lack of adequate ramping capability in the system can jeopardise the safe operation of the system and potentially increases the need and cost of other (more expensive) flexibility services by several folds that are required over shorter term frames.

Figure 7 – Increase in ramping requirement (Balanced scenario)



Source: Imperial's modelling analysis

2.2.1.2 *Reserve requirements*

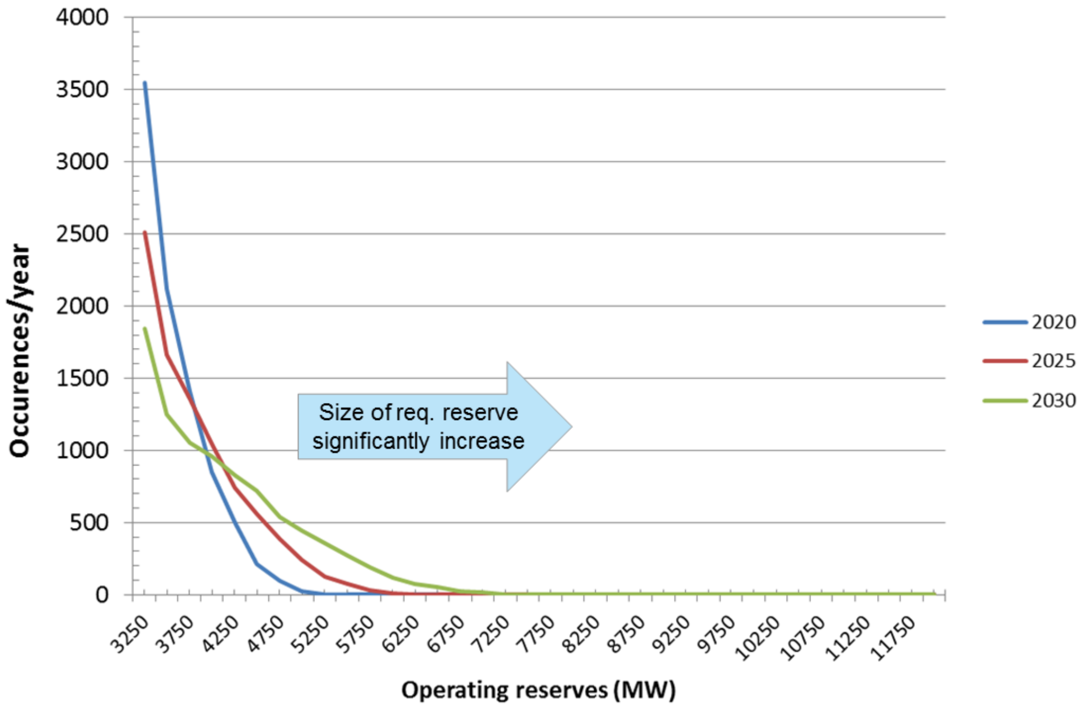
Operating reserve includes the provision of increased generation or demand reduction over a period of minutes to hours in response to an instruction from the system operator. Increased share of variable intermittent generation in the system also increases the uncertainty in demand and supply balance which increases the minimum operating reserves held by the SO to maintain sufficient system balancing capability. The amount of operating reserves depends on the level of uncertainty in supply and demand; so it is assessed dynamically and changed according the system conditions.

Figure 8 shows two implications of the low-carbon system:

a) a higher maximum requirement – e.g. the maximum reserve requirement across the year increase from 5.2 GW in 2020 to 7.3 GW in 2030; and

b) a more frequent need of higher reserve levels – e.g. the number of hours during which a reserve volume of 4.5GW will be required increase from about 300 in 2020 to 700 in 2030.

Figure 8 – Future GB operating reserves requirement (Balanced scenario)



Source: Imperial's modelling analysis

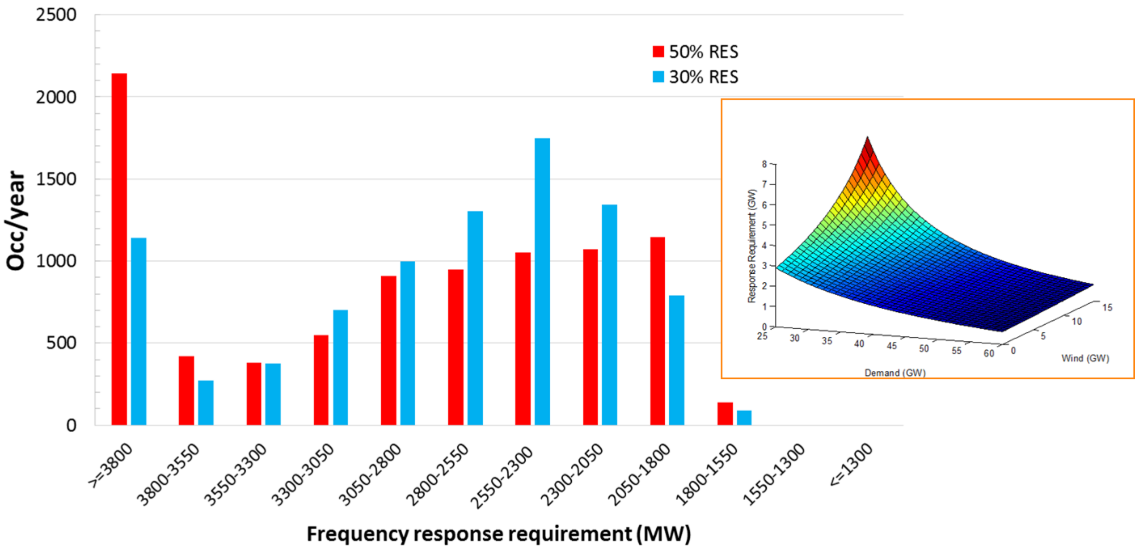
Today, the operating reserves mainly come from mid-merit (Combined Cycle Gas Turbine plants and Coal plants) and peaking plants (Open Cycle Gas Turbine). The available capacity of these technologies is expected to decrease in future in line with tighter decarbonisation targets and reduced economic viability. Therefore, the system will need to source alternative operating reserves.

2.2.1.3 Frequency response requirements

Frequency response (FR) refers to the automatic provision of increased generation or demand reduction in order to contain a drop in system frequency. Increased share of renewables (i.e. inverter based power generation) in the capacity mix reduces the system inertia which is provided by the stored kinetic energy of the rotating mass of the power generator's turbines. With this reduction in system inertia, any imbalance between supply and demand will change system frequency more rapidly making the system unstable. Therefore, a sufficient level of frequency response is needed to deal with sudden loss of supply to the system (e.g. as a result of a failure of a large generator / interconnector or rapid demand turn up) in order to keep the system frequency within its statutory limits.

Figure 9 (right box) shows the FR requirement as a function of net demand (demand minus wind output). It demonstrates that the FR requirement increases significantly when the net demand is low – e.g. when a low demand condition coincides with high output from intermittent renewables. On the other hand, the system will require less FR during high demand conditions coinciding with low output from intermittent generators considering there are many synchronised plants in the system. As the frequency of having low net demand is higher in future, it is expected that the requirement for frequency services by 2030 will also be higher as shown in the Figure 9 (left chart) for 50% renewables penetration.

Figure 9 – Impact of intermittent generation on frequency response requirements in the future system (illustrative)



Source: Imperial's modelling analysis

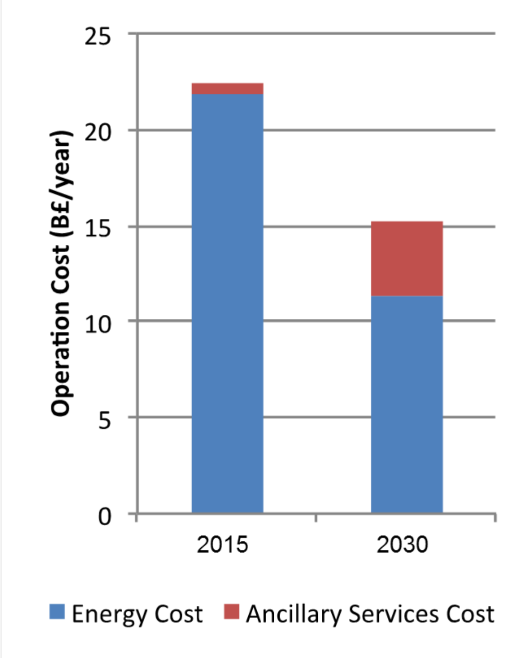
To date, the frequency response service can only be provided by synchronised conventional plants which need to operate part-loaded and produce at least at the minimum stable generation level (MSG). This reduces the ability of the system to absorb electricity production from renewables or other low-carbon technologies. Moreover, running at a suboptimal level of production (i.e. at MSG level) also reduces the fuel efficiency of the conventional generation and increases the emissions. This opens opportunities to alternative FR providing sources such as fast storage or DSR that can provide the required services potentially at lower cost and without increasing emissions.

2.2.1.4 Potential increase in the value of flexibility services

The large increase in flexibility requirements will result in a significant growth of the overall value of such services in the future GB system.

Figure 10 shows the potential change in system operation costs in order to efficiently meet the CO_2 reduction target of 100gCO_2/kWh in the power sector in 2030 relative to the 2015 system. Although the overall system operation costs are expected to reduce due to high penetration of low marginal cost low-carbon generation (wind, solar and nuclear), the cost of ancillary services costs will potentially increase by about 10 times relative to the 2015 levels.

Figure 10 – Change in overall value of ancillary services (illustrative)



Source: Imperial's modelling analysis

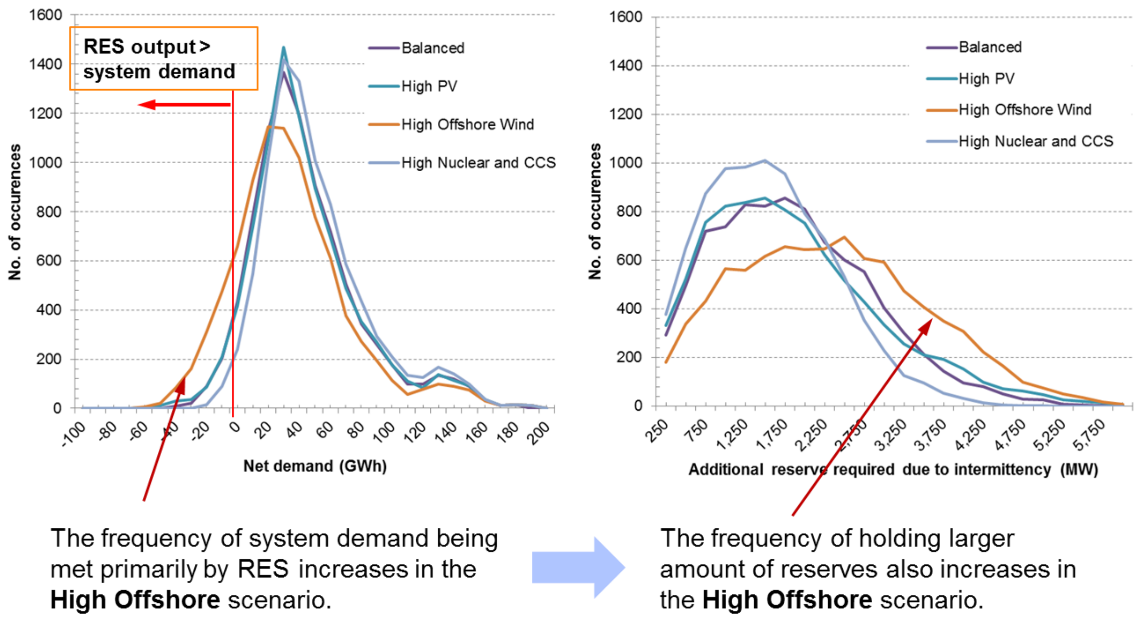
2.3 Impact of alternative generation mixes on flexibility requirements

The system flexibility requirements depend on many factors such as the characteristics of the generation system (capacity mix, locations, dynamic parameters, availability, output profiles of energy sources), demand characteristics (customer types, locations, profiles, peak demand) and network characteristics (e.g. AC vs. DC links to other systems).

Figure 11 (left chart) compares the frequency distribution of the net demand profiles of the four modelled scenarios. It can be observed that under the High Wind scenario there are more periods where the net demand is low or even negative (i.e. total wind output exceeds system demand).

Figure 11 (right chart) compares the frequency distribution of the operating reserve requirements across the scenarios, while all low-carbon options result in a rising (additional) demand for operating reserve, this is most strongly required in the case of High Wind scenario.

Figure 11 – Evolution of net demand and operating reserve requirements in the modelled scenarios by 2030



Source: Imperial modelling analysis of the CCC scenarios

2.4 Potential benefits of alternative system flexibility options

Across the modelled scenarios, there are several alternative options for delivering the necessary flexibility in a decarbonised energy system. To a greater or lesser extent, by exploiting new sources of flexibility, there is the potential to realise cost savings relative to a system that continues to rely on conventional generation to deliver flexibility. These savings are associated with:

- **Avoidance of energy curtailment from low-carbon generation sources:** a lack of operational flexibility limits the system's ability to accommodate output from intermittent renewable technologies, particularly during periods when low demand conditions coincide with high output from wind and solar sources. Presence of system flexibility sources such as energy storage facilities, demand side response or interconnectors can absorb/export surplus generation in the system thus avoiding energy curtailment and associated costs.
- **Efficient provision of operating reserve and response facilities:** the provision of operating reserve to the system by non-thermal flexibility technologies (i.e. Storage, DSR and interconnection) increases the ability of the system to absorb low-carbon electricity and reduces the need to maintain thermal plant at minimum stable generation with associated impacts on carbon emissions and operating costs due to efficiency losses.
- **Potential savings in generation capacity:** new service providers may reduce overall generation capacity on the system due to:
  - Reduced need for low-carbon capacity in the system: reductions in energy curtailment will result in increased utilisation hence lower capacity of low-carbon generation to meet the decarbonisation targets.
  - Peak reduction: electrification of heat and transport will disproportionally increase peak electricity demand however, system flexibility in the form of energy

storage or demand side response can reduce system peak by redistributing demand from high demand to low demand periods. This results in reducing the amount of required generation capacity in the system (particularly, the peaking plant capacity).

  - Reduced need for back-up capacity: energy storage, DSR and interconnection, can reduce the need for back-up generation capacity required to support the intermittent generation.

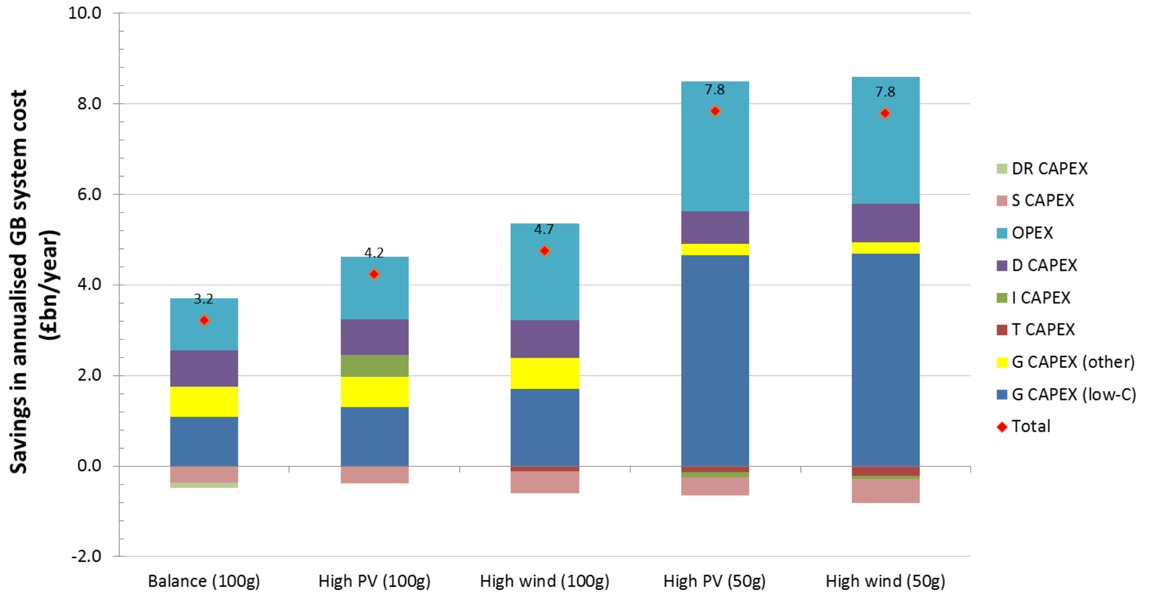
- **Deferral or avoidance of the network reinforcement/addition:** in addition to the network capacity savings driven by lower generation capacity requirements (as described above), additional network capacity savings are possible by deploying flexibility to manage network constraints and reassessing the need for network reinforcement in conjunction with innovative network planning and operation standards as discussed in Section 4.1.2.

The results of Imperial's modelling analysis demonstrate that alternative system flexibility solutions for meeting the CCC's 2030 carbon intensity target (100gCO_2/kWh) can save up to £4.7 bn/year. The savings are obtained from the reduction in system capacity requirement (low-carbon generation, conventional generation, transmission, interconnection, distribution assets) and lower operating cost (due to energy curtailment avoidance, CO_2 cost savings, and reduced fuel usage) as shown in Figure 12 for different scenarios.

The results also show that the savings due to increased system flexibility are higher in scenarios with large penetration of intermittent generation (High Wind or High PV scenarios). This is because the volume of additional system flexibility becomes more pronounced in such systems compared to a system that also contains non-intermittent low-carbon, nuclear and CCS, generation (e.g. the Balanced scenario). Presence of higher flexibility services, from energy storage and/or DSR, enables more efficient management of demand-supply balance by time shifting the surplus intermittent generation or demand. This avoids curtailment of solar and/or wind energy as well as reducing the need for their generation capacity resulting in higher savings in operational expenditure (Opex) and capital expenditure (capex) respectively.

Moreover, more ambitious carbon reduction target (50gCO_2/kWh) would see a further increase the value of flexibility (up to £7.8 bn/year) as the system would need to accommodate more low-carbon generation.

Figure 12 – System cost savings due to alternative flexibility provision across scenarios



Source: Imperial's modelling analysis of the CCC scenarios

2.5 Uncertainties related to the portfolio of flexibility services

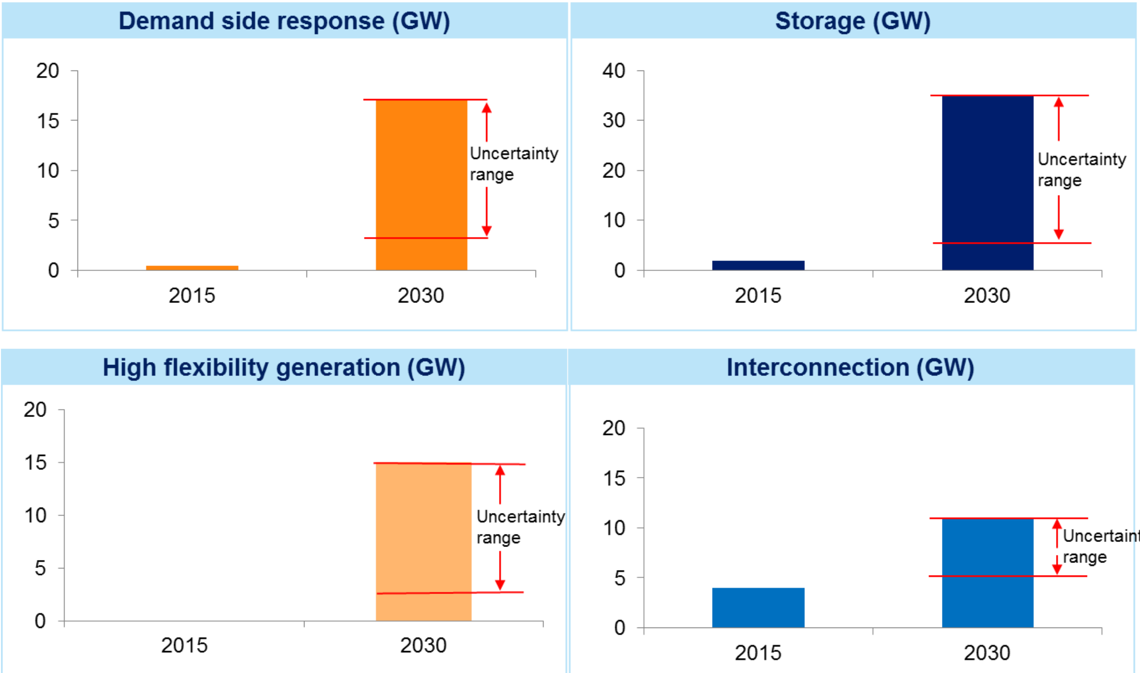
As mentioned earlier the required level of additional flexibility is dependent on the characteristics of the generation capacity mix in the system as multiple generation mixes can deliver the decarbonisation targets. For a given level of additional flexibility there are multiple other factors that will define the uptake of different flexibility resource in the future system, such as:

- relative costs, scalability, locational distribution, availability of the control infrastructure and technical performance of different types of flexibility sources;
- the adopted energy policies, market and regulatory framework; and
- the social (e.g. consumer acceptance) and cultural (e.g. maintaining status quo) aspects associated with effective participation of demand side flexibility.

There are uncertainties associated with the aforementioned factors introducing the uncertainty around the cost of demand side response and/or expected drop in cost of storage. Similarly, there is lack of clarity as well as diverging views on the level of consumer acceptance of DSR technologies.

Taking account of the technology cost and deployment rate uncertainties, Imperial College has analysed the range of possible penetration of different flexibility technologies in their modelling assessment. Figure 13 shows the modelling based potentials of different flexibility technologies such as DSR, storage, interconnection and flexible generation in 2030 across different scenarios to meet the 100gCO_2/kWh carbon intensity target.

Figure 13 – Indication of uncertainty in the deployment of different types of additional flexibility resource based on scenario modelling



Source: Imperial's modelling analysis of the CCC scenarios

Given the level of uncertainty over individual flexibility technologies that can be deployed to the system in future, it is important for the policy, market and regulatory framework should provide a technology neutral environment to facilitate the development and deployment of all flexibility technologies.

Earlier analysis by Imperial College[5] also supports the above argument that a 'balanced' strategy of deployment across different sources of flexibility is the 'least worst-regret' pathway for the UK energy system. Facilitating the 'balanced' deployment pathway, with some deployment of DSR, storage and flexible CCGT by 2020, and deployment of the current interconnector pipeline[6], is an effective way to avoid worst regret outcomes and technological lock-in.

2.6 Main requirements of the future electricity systems

Enabling the transformation to an efficient GB electricity system will not be without its own challenges. From the analysis and stakeholder engagement undertaken as part of this study, we have identified four key requirements of any future electricity system.

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5 An analysis of electricity system flexibility for Great Britain, D. Sanders, A. Hart, M. Ravishankar, G. Strbac, M. Aunedi, D. Pudjianto, and J. Brunert, Report by Carbon Trust and Imperial College London, November 2016, available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/568982/An_analysis_of_electricity_flexibility_for_Great_Britain.pdf

6 Electricity interconnectors. Ofgem, available at: https://www.ofgem.gov.uk/electricity/transmission-networks/electricityinterconnectors

- Investment decisions should be made on the basis of the full system value offered by providers – this means that the market design must effectively price and reward energy, capacity and flexibility.
- Appropriate systems and interfaces should be in place to manage greater complexity in the system – this implies a capability of the system to deal with more interactions between distribution and transmission networks and to promote and utilise more active demand management.
- Enhanced framework to achieve greater consumer participation – in addition to establishing the technical infrastructure for demand-side response, legal and regulatory frameworks around data protection and consumer protection will be necessary to achieve widespread consumer acceptance.
- Ongoing support for innovation in technology, services and operating models – it will be important that, as the institutional and market framework evolves, the drive for innovation across the value chain is not dampened.

In the following chapters, we outline in more detail the importance of each requirement, the current challenges to realising the objective and the specific actions that will help to realise the objective. A high-level overview of the ongoing activities relevant to the proposed actions, where information is available in the public domain, is also described.

3. ENSURING EFFICIENT FLEXIBILITY INVESTMENT DECISIONS

The shift to a low-carbon electricity system will require major investment, so it is important that the system makes adequate and timely investment in the most effective technologies and services. Investment decisions should be made taking account of the value to the system of the full range of services that the provider is offering. Since more flexibility will be required, the value of the flexibility offered by technologies should be a key consideration in any new investments, as should the costs they impose on system operation. If the value of flexibility is not transparently signalled in the market and available to all technologies, then the cost to consumers will be higher than it needs to be.

In theory, there are multiple potential revenue streams available to the market players (both demand and supply sources). These revenues reflect different 'products' or 'services' and are accessed from a variety of separate market platforms. The main forms of revenue relate to:

- capacity – i.e. provision of system security during system stress conditions through offers on the capacity market;
- wholesale energy provision – i.e. sale of electricity through standard wholesale markets;
- balancing – i.e. actions in the system balancing market;
- ancillary services – i.e. provision of specific services to the system operator such as frequency regulation services; and
- network support – i.e. provision of services to reduce the need for network reinforcement.

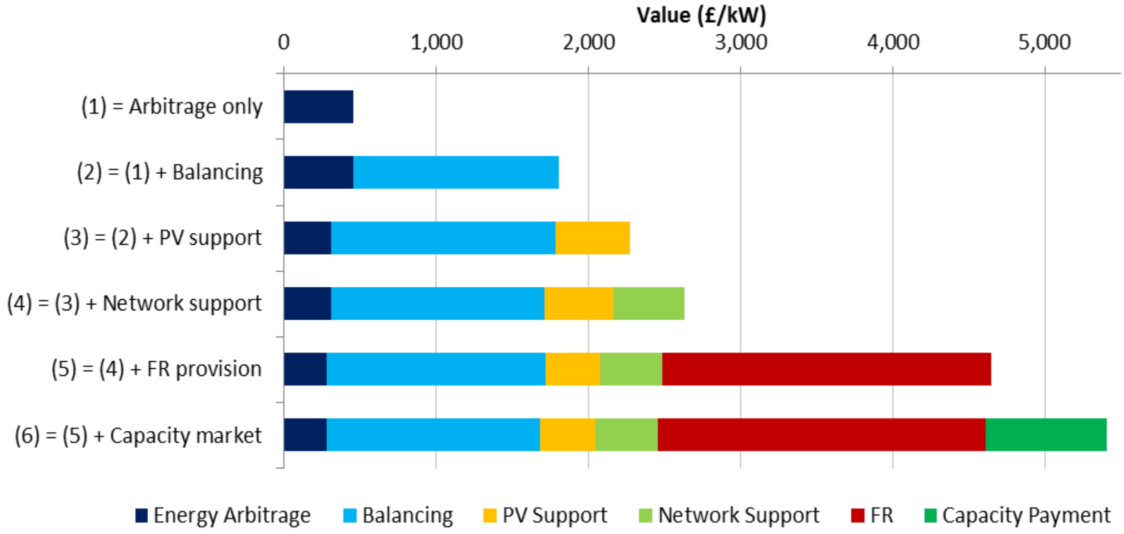
These services are not mutually exclusive and for commercial investment decisions to deliver efficient system development it is important that:

- all potential revenue streams exist and are available to a service or technology; and
- the value of the service to the system is accurately reflected in the market or procurement platforms in operation.

This is particularly important for the emerging technologies and services around flexibility provision as, in contrast to conventional generation investment, a higher proportion of their value will be dependent on ancillary service and network support revenue streams.

For example, Imperial College has modelled the business case of battery storage facilities which can provide a range of system services across multiple revenue streams while taking account of the physical interactions between the different system support services. Figure 14 shows the results for a 6MW battery storage connected in the HV distribution grid supporting connection of 20MW of PV generation. This demonstrates how the value of the asset increases several-fold with access to a wider set of revenue streams.

Figure 14 – A business case for energy storage facilities (illustrative case)



Source: Imperial's modelling analysis of benefits of full market access

From the analysis and stakeholder engagement undertaken as part of this study, it is clear that the GB electricity system needs to ensure that:

- value streams are available for all forms of system service and that they are accessible to all potential providers;
- the price signals for these services are efficient and reflect the value to the system at the time; and
- there is some transparency for providers over the longer-term requirements for these services in the market.

The following sections expand on these observations and identify appropriate actions to address current challenges.

3.1 Availability and accessibility of revenue streams

3.1.1 Availability of flexibility services

In order to ensure future investments in the power system take account of the flexibility requirements of the system, all types of flexibility services need to be valued. Under the current arrangements, this is not always the case, with the main gap identified in the valuing of system inertia.

One of the key challenges associated with integration of renewable generation is the reduction of system inertia. This may be provided through conventional generators manufactured with a higher inertia constant or from wind generators providing "synthetic inertia" (SI). However, the current flexibility market does not reward the provision of inertia and this has contributed to a lack of interest by investors to develop alternative ways for enhanced inertia provision. Without a remuneration mechanism for inertia, there will be higher cost to the system.

3.1.2 Access to revenue streams

Even where revenue streams exist, flexibility providers do not always have access to all of the services that they can technically offer. This means they may not be able to be rewarded for the full value they offer to the system, leading either to insufficient flexibility being available to the system or, more likely, to a higher cost of delivering flexibility due to inefficient investment and operational decisions.

Examples of limitations to some flexibility providers include:

- Independent aggregators need to be a Balancing Mechanism Unit (BMU) or need to reply on third parties to have access to the balancing mechanism (BM) as they do not have a defined role in the Balancing and Settlement Code (BSC). This involves administrative costs and sharing of some revenues with third parties which discourages small scale aggregators from accessing value in the BM as well as in the wholesale market.
- Enhanced Frequency Response (EFR) providers, which includes all storage facilities, are excluded from participation in the Capacity Market (CM).
- Holders of long-term STOR contracts are ineligible for participation in the Capacity Market.
- Low-carbon capacity sources that receive support payments such as the Renewables Obligation (RO), Contracts for Difference (CfD) or Feed-in-tariffs (FITs) have no incentive to provide flexibility even if they are capable of providing.

Ofgem has recently taken several initiatives to assess and improve the flexibility procurement process in order to provide a more level-playing field for different flexibility providers. These include identifying barriers and proposing changes in the current Capacity Market rules for participation of small generators and DSR capacity by initiating consultations with the relevant stakeholders.[7, 8]

3.1.3 Recommended action on availability and accessibility of revenue streams

Our recommended actions in these areas are outlined below.

Periodical assessment of existing portfolio of flexibility services to identify services that may be procured more efficiently through transparent and technology-neutral processes in the future and reform their procurement processes accordingly.
Responsible: SO/DSOs   *Initial assessment by 2020*   *Medium priority*

[7] Electricity Market Reform: Open letter and consultation on changes to the Capacity Market Rules, September 2016 https://www.ofgem.gov.uk/system/files/docs/2016/09/open_letter_cm_rules_150916.pdf

[8] Capacity Market Rules change proposal submissions, November 2016 https://www.ofgem.gov.uk/electricity/wholesale-market/market-efficiency-review-and-reform/electricity-market-reform/change-proposals

3.2 Efficiency of pricing signals

In order to deliver the full benefits of flexibility, price signals should reflect the overall value of smart technologies to the electricity system. In this section we discuss the enablers for improving the efficiency of price signals to encourage deployment of flexibility in the future system.

3.2.1 Provision of dynamic pricing signals

The need and value of flexibility is time dependent – it varies across different seasons as well as across different times of the day, driven by system demand conditions. With significant growth in intermittent generation, variation in supply is becoming more pronounced. At the same, the nature of demand variability is changing as new sources of demand (e.g. heat pumps and electric vehicles) bring additional variability in demand-supply balance from the demand side.

In GB, the dynamic value of required flexibility services – e.g. the Firm Frequency Response (FFR) is procured through a monthly tender based on the demand for this service which is assessed up to several weeks ahead of real time. This can result in a risk of over/under procurement of services and a lack of availability of flexibility resource for other services. Although the balance (i.e. in case of under procurement) can be procured through mandatory frequency response, it has cost implications. In case of over procurement, depending on the contract terms, at least the availability fees will be paid to the providers whose services were not required by the system.

In the future with growing need of flexibility, dynamic price signals (i.e. time dependent cost of energy and value of flexibility) can potentially incentivise availability of flexibility during periods when it is most needed by the system. This will also encourage consumers to change their energy consumption behaviour (i.e. reduce consumption when the system is under stress or the electricity cost is high and vice versa) in order to lower overall system costs as well as their bills. In the energy market this is likely to improve as a result of developments such as half-hourly settlement and reserve scarcity pricing schedule[9].

Imperial has investigated the value and need for EFR across days with different system conditions[10]. As shown in Figure 15 and Figure 16, during high system demand and low wind days, the benefit of EFR saturates at £350k after 300 MW of EFR become available, suggesting low demand for EFR. However, during low system demand and high wind days, more than 600 MW is needed and saves £9000K in operating cost. It is clear that the value and need for EFR vary significantly across different days and times within a day depending on the system conditions. This informs that there is a significant uncertainty in the required volume of EFR and PFR at any time and if procured over longer timeframes then there is a risk of over-procurement and increase costs associated with these services. Therefore, these should be procuring over shorter timeframes taking account of their mutual trade-off more efficiently reflect the variation in their value in the system.

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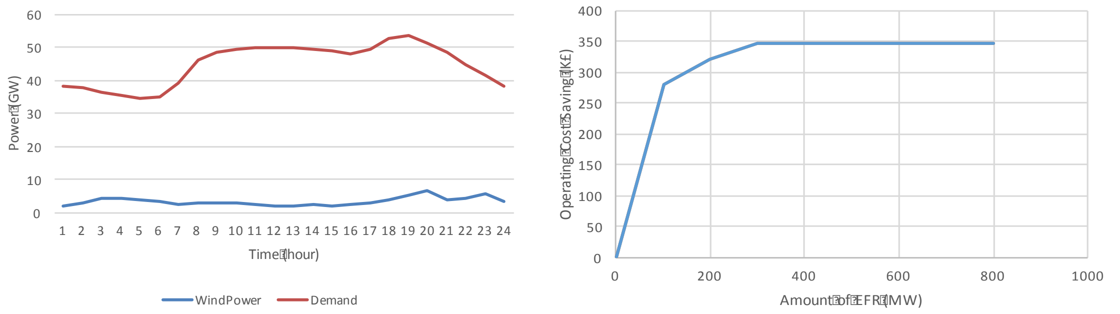
9 Electricity Balancing Significant Code Review (EBSCR) - Draft Business Rules, Ofgem, 2015

10 An advanced stochastic unit commitment (ASUC) model was applied to simultaneously optimise scheduling energy production, standing/spinning reserves and inertia-dependent frequency response in the light of uncertainties associated with wind production and generation outages. All key dynamic frequency requirements, (a) ROCOF, (b) frequency nadir and (c) quasi-steady-state frequency, are explicitly considered in the optimisation model. This model is therefore capable to maintain the post-fault system frequency within the limits, while optimising the portfolio of EFR and PFR.

Figure 15 – Operating cost saving from enhanced frequency response in the day with high demand and low wind

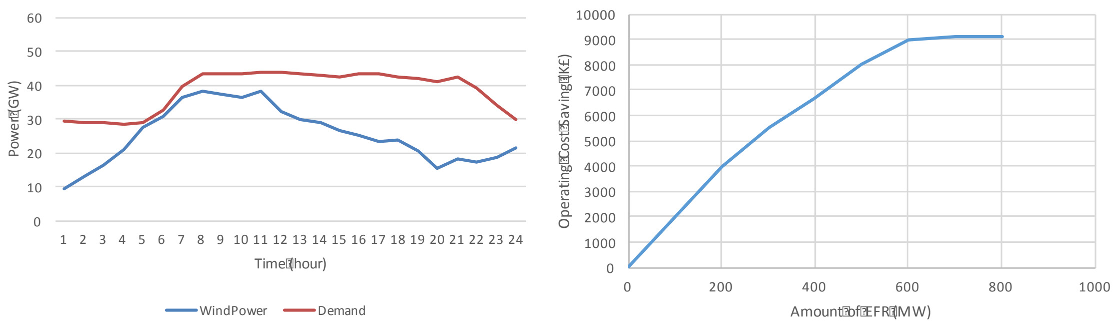


(a) System condition

(b) Operating cost saving from EFR

Source: Imperial's modelling analysis

Figure 16 – Operating cost saving from enhanced frequency response in the day with low demand and high wind



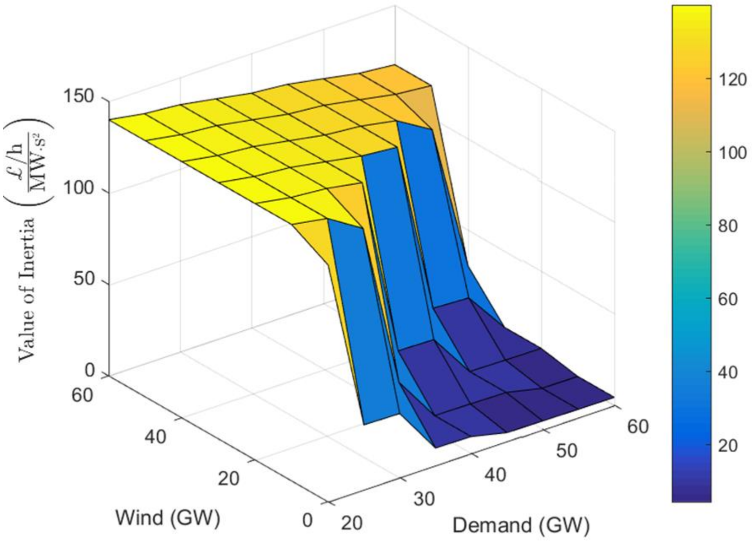
(a) System condition

(b) Operating cost saving from EFR

Source: Imperial's modelling analysis

Similarly, the marginal value of inertia for different demand-wind conditions is shown in Figure 17. It varies from almost zero under the high demand – low wind condition to more than 140 £/h/ MW-sec^2 under the low demand and high wind condition. This is due to the fact that under the high demand and low wind condition, the overall system inertia is high as conventional generators are the main source of supply and hence the requirement for frequency response is driven by the steady-state frequency requirement and vice versa.

Figure 17 – Growing need for remuneration of inertia



Source: Imperial's modelling analysis

With greater variability in system conditions in the future, there will be a corresponding variability in the value of the associated flexibility services, meaning that more dynamic pricing (e.g. half hourly prices), reflecting more accurately the value to the system at different times, will become more important for effective investment and system operation decisions.

Ofgem has recently announced its plans and a timetable[11] on moving to mandated half-hourly settlement to sharpen short-term signals in order to better reflect the cost to the system and enabling smart technologies to realise more value and suppliers to develop innovative dynamic retail offerings.

3.2.2 Improvements in network charging

For more efficient investment decisions, cost impacts of alternative flexibility solutions will need to be addressed alongside revenue and pricing signals.

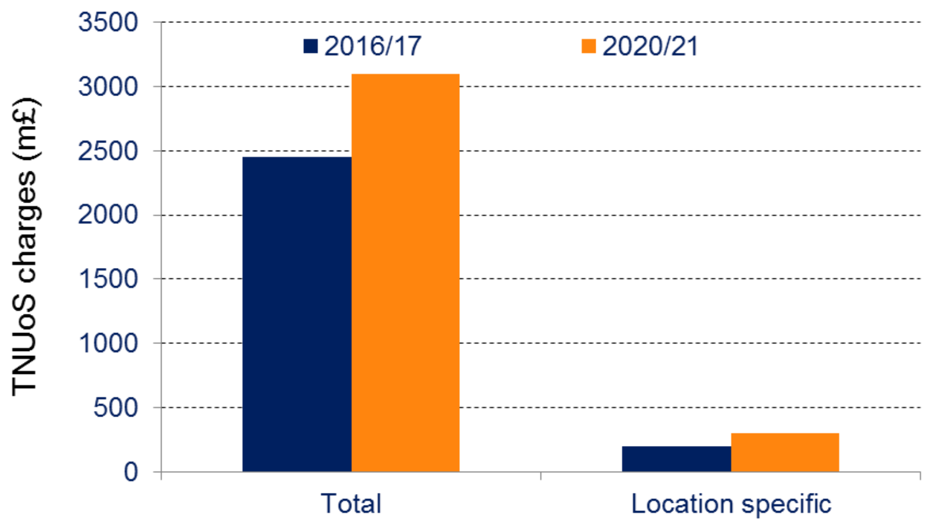
The proliferation of distribution-connected generation, the increase in intermittent renewable generation, the recent growth of storage assets and the potential for demand side management means that the old network charging regime is increasingly becoming less cost-reflective. The nature of flows is changing radically and the peaks on individual parts of the network (which drive losses and the network investment needs) are becoming increasingly disconnected from overall system peak demand. Therefore, the underlying objective of cost-reflective charges cannot easily be fulfilled without considering both time and location, reflecting the actual flows on the network at the time.

11 Mandatory Half-Hourly Settlement: aims and timetable for reform, Ofgem, November 2016 https://www.ofgem.gov.uk/ofgem-publications/106472

The current allocation of network charges has been frequently challenged[12] to be over-compensating some network users and/or penalising others affecting both consumers and flexibility investors. Typical issues include:

- **Representation of location specific element in TNUoS charges:** currently the location specific part of the overall Transmission Network Use of System (TNUoS) charges is very small, see Figure 18. As a consequence it does not allocate charges to parties responsible for incurring network reinforcement and addition affecting locational incentives for generation, demand and storage.
- **Under-charging of rooftop solar:** currently unit charge for distribution costs is based on net usage (i.e. energy consumed minus energy produced). Without adequate onsite storage, consumers with rooftop solar panels rely on electricity from the distribution system. Therefore, they do not necessarily reduce the costs of the distribution system and are therefore under-charged at the expense of the remaining consumers.[13]
- **Double-charging to storage:** at present there is a lack of guidance on the treatment of storage in the network charging methodologies. This creates difficulties and uncertainty for storage developers in estimating their network charges.[14] For example, the transmission and distribution tariffs are levied twice on storage as it is treated as both an electricity consumer and generator. These doubled charges arguably do not reflect the complementary benefits of energy storage to the transmission network in balancing the wider electricity system.[15]

Figure 18 – TNUoS charges



Source: Imperial's modelling analysis

12 Ofgem has recognised these issues in their July 2016 and December 2016 open letters:
Open letter: Charging arrangements for embedded generation, 29 July 2016
Open letter: Update on charging arrangements for Embedded Generation, December 2016

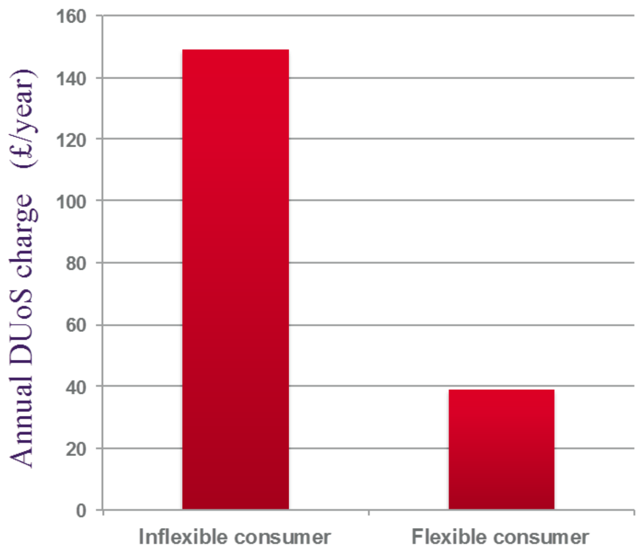
13 A response to BEIS' and Ofgem's call for evidence – 'A Smart Flexible Energy System', Citizens Advice Bureau, January 2017

14 BEIS and Ofgem Call for evidence – 'A Smart Flexible Energy System', November 2016

15 http://www.restless.org.uk/documents/briefing-paper-1

Imperial's analysis of the impact of a fully cost-reflective Distribution Use of System (DUoS) charges, as shown in Figure 19, indicates that on the average flexible consumers would have a 4 times lower share of DUoS charges in their annual electricity bills compared to inflexible consumers.

Figure 19 – Potential Impact of customer's flexibility on their bills



Source: Imperial's modelling analysis

If an increasing proportion of electricity demand is supplied by embedded generation, there is a concern that the burden of system costs could be spread over a declining residual demand. Therefore, Ofgem has been proposing several changes in the current network charging arrangements, based on the argument that the current charges have the potential of distorting the investment decisions due to the additional burden of costs to the residual generators in order to compensate the cost avoidance (i.e. benefits) of the embedded generation. Some of these proposals include:

- the reduction of the demand residual charge that the embedded generators are currently receiving as a benefit[16]; and
- a more structural change in the current network charging methodology related to the forward-looking and sunk (residual) costs, with a focus on the current benefits and cost avoidances that behind the meter generation receives[17].

Both of the above proposals aim to eliminate market distortions due to the current network charging structure and to encourage investment in flexible resource such as storage and DSR (e.g. removal of double network charging for storage facilities).

16 Minded to decision and draft Impact Assessment of industry's proposals (CMP264 and CMP265) to change electricity transmission charging arrangements for Embedded Generators, Ofgem, March 2017
https://www.ofgem.gov.uk/system/files/docs/2017/03/minded_to_decision_and_draft_impact_assessment_of_industrys_proposals.pdf

17 Targeted Charging Review: a consultation, Ofgem, March 2017
https://www.ofgem.gov.uk/system/files/docs/2017/03/tcr-consultation-final-13-march-2017.pdf

3.2.3 Improvements in other system integration costs

We have also identified issues with the allocation of other system integration costs / charges of some technologies. For example:

- the magnitude (and corresponding cost) of Frequency Response (FR) required in the system is predominantly influenced by the largest unit (typically a nuclear power plant or interconnection to a connected system), however, it is currently being socialised; and
- some technologies such as solar power on their own offer no capacity value and wind power offers only limited capacity contribution, however, both of these technologies need back-up capacity but are not charged for that.

We recognise that the assessment and allocation of system integration costs is a challenging task however, it is important for establishing a level playing field for all users of the system. Therefore, a review of the allocation of all system costs – i.e. network charges, back up capacity costs and cost of ancillary services – to the parties that are responsible for causing these costs is required.

3.2.4 Improvements in balancing services procurement

Currently, a wide range of flexibility system balancing services is procured by the system operator. Table 3 shows the technical requirements and the type of contract for procurement of frequency response and reserve services by the SO.

The procurement of these services differ in terms of technical requirements, validation processes[18], contract type and procurement platform, increasing complexity and reducing transparency. Three of the nine services reported (i.e. FFR bridging, FCDM and STOR Runway) are procured under bilateral contracts of different lengths with limited visibility to the rest of the market players. There is a significant range of minimum size (MW) requirements among the various services with lack of transparency on the sizing rationale. Another key issue is the limitation in offering bundled services as these different services are procured at different times in isolation without full consideration of their mutual interactions, particularly from the provider's perspective.

[18] These include the requirements and the processes involved in qualifying the eligibility criteria for providing a specific flexibility service to the system.

Table 3 – Technical requirements and types of contracts for Frequency response and reserve services

Group	Scheme	Minimum size*	Notice period	Duration	Regularity**	Value***	Contract
FREQUENCY RESPONSE SERVICES	**Static Firm Frequency Response (FFR)**	10 MW	30 sec	Max 30 min Typically 5 min	10-30	££	Monthly electronic tender
	Dynamic FFR	10 MW	2 sec	Max 30 min Typically 3-4 min	Daily	£££	Monthly electronic tender
	FFR Bridging	< 10 MW	30 sec	30 min	10-30	££	Bilateral contract of 12-24 months to transition in to the FFR market (either Static or Dynamic).
	Frequency Control by Demand Management (FCDM)	3 MW	2 sec	30 min	~10	££	Bilateral contracts for 1-2 yrs. Week ahead notification of daily load able to shed
	Enhanced Frequency Response (EFR)	1 - 50 MW	1 sec Dynamic	Max 15 min Typically 3-4 min		£££	New product – trial tender
RESERVE SERVICES	**Short Term Operating Reserve (STOR)**	3 MW	20 min	2-4 hrs Typically <20 min	Able to deliver 3x per week	£	3 tenders p.a. 'Committed' or 'Flexible' service
	STOR Runway	< 3 MW	20 min	2-4 hrs Typically <20 min	Able to deliver 3x per week	£	Bilateral contract
	Fast Reserve	50 MW	2 min, reaching 50MW in 4 min	15 min		£	Monthly tender
	Demand Turn Up	1 MW	10 min, sometimes requested day-ahead	Min 30 min		£	New product – trial tender

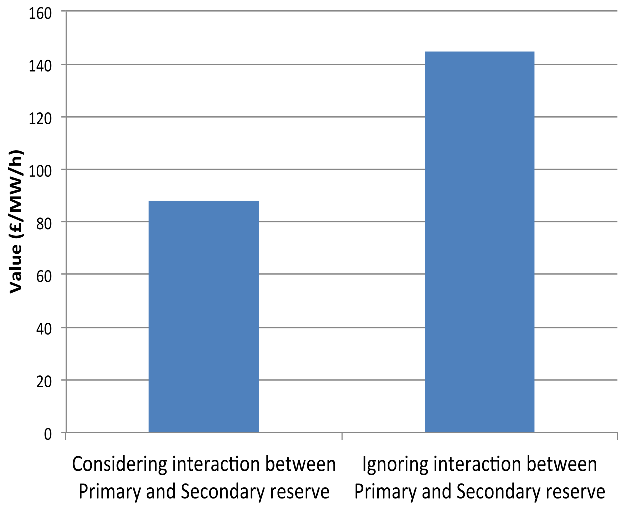
* to contract directly with NG (smaller loads via demand side providers)
** Average number of times called on per year, based on recent data.
Source: National Grid.
*** Relative value to participant
£ the greater number of '£' signs indicates a greater value to the demand side participant

Source: National Grid (UK)

The procurement of services should take account of interactions or trade-offs between services. Under the current arrangements the volumes of various operating reserve are procured separately and do not comprehensively take account of the interactions (e.g. temporal, technical and cost interactions) between the procured products. For example, as both PFR and EFR share the same goal to limit the system frequency nadir above the standard, these two services should, in fact, be procured together based on their mutual interactions to minimise their overall cost. With rise in the amount of flexibility requirement, the optimisation of the portfolio of various flexibility services required by the system becomes more important.

Furthermore, some forms of flexibility sources create additional demand for flexibility at other times which need to be included in the decision process while procuring flexibility. For example, DSR based provision of ancillary services generally redistributes demand across different time. This means that reduction in demand at a point in time aimed at providing reserve services, will be followed by an increase in demand during a subsequent period – e.g. use of Thermostatic Loads to provide frequency response will increase the need for secondary reserve, which should be accounted for, otherwise the value of this flexibility source would be overestimated as depicted in Figure 20.

Figure 20 – Impact of interactions between flexibility products on the accrued value



Source: Imperial's modelling analysis

In New Zealand, the system operator (Transpower) applies a Reserve Management Tool (RMT) to continually identify risk to the demand-supply balance in the system. It then determines an optimised portfolio of flexibility services (grouped into Fast Instantaneous and Sustained Instantaneous reserves) and ensures its provision for each 30 minute trading period through the ancillary services market. This reserve management framework provides a simple and transparent procurement process, where providers are able to bid in reserve products right up to the gate closure time – meaning that the costs are more reflective of the system conditions at that time.

The GB system operator (National Grid, UK) has recognised the complexity and low transparency[19] of the existing flexibility procurement processes such as the following:

- there exist too many markets with differing technical requirements expected from the same provider;
- the criteria for validation of a provider has not been transparent to the market players; and
- SO's requirements of various flexibility products and how they interact with each other has not being transparent.

Consequently, some markets are over- and some under-subscribed.

The SO is currently consulting on simplification and rationalisation of the balancing services and potentially reducing the number of products. This is intended to reduce

19 http://powerresponsive.com/wp-content/uploads/2017/03/SNAPS-SWG-Slide-Deck-13-3-2017.pdf?mc_cid=bc29dbffc5&mc_eid=bcfef9e0be

complexity in the procurement process of these flexibility services. Furthermore, it is also exploring alternative structures of the future market to procure flexibility services.

In the future, significantly more flexibility activity will potentially occur at the distribution level. At present the level of transparency in Distribution Network Operator's (DNO) actions is much less than for the SO. The information on currently procured flexibility services by the DNOs and the future projection of the demand of such services is not openly available to flexibility providers. Therefore, it is expected that the issues National Grid has identified at the transmission level are likely to be replicated at the distribution level. Therefore, earlier actions to pre-empt these issues at the distributed level will be required.

3.2.5 Recommended actions on improving efficiency of pricing signals

Our recommended actions in this area are outlined below.

Review characteristics of current procurement processes (e.g. threshold capacity level to participate, contract terms / obligations) and the procurement route (e.g. open market, auctioning or competitive tendering) that enable more efficient procurement of services without unduly restricting the provision of multiple services by flexibility providers.		
Responsible: Ofgem in conjunction with SO, TOs and DSOs	*By 2020*	*High priority*
Assess the materiality of distortions to investment decisions in the current network charging methodology (e.g. lack of locational charging, double-charging for stored electricity), and reform charging methodology where appropriate.		
Responsible: SO, DSOs and Ofgem	*2020*	*High priority*
Assess the materiality of distortions to investment decisions in the absence of non-network related system integration charging (i.e. back up capacity and ancillary services) and implement charging where appropriate.		
Responsible: SO, DSOs and Ofgem	*Post 2020*	*Medium priority*

3.3 Improved understanding of long-term requirements

Investors and providers of flexibility need clarity and information on how the different types of system flexibility requirements will evolve in the future in order to have confidence regarding 'demand security' of their services and reasonable predictability of potential revenues based on provision of all flexibility services offered to the system.

Currently there is a lack of public understanding and information on how system flexibility requirements will grow in the future. National Grid (UK) annually publishes a forecast of a limited number of flexibility services (frequency response and reserve) for the next five year time horizon.[20] However, given investment cycles are typically longer than five years

20 National grid (UK), Future Requirements for Balancing Services, 2017

(e.g. 8-10 years for battery storage systems, 12-15 years for gas based peaking plants) stakeholders have highlighted a benefit from availability of information for particular flexibility services over longer time horizons. This can be addressed through projection of a longer-term outlook of flexibility requirements including an indication of the uncertainty involved.

Our recommended action in this area is outlined below.

> Publish annual projections (for each future year) of longer-term future procurement requirements across all flexibility services including indication of the level of uncertainty involved and where possible location specific requirements, to provide greater visibility over future demand of flexibility services.
>
> *Responsible: SO/DSOs* *2020 onwards* *High priority*

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4. DEVELOPING CAPABILITY TO MANAGE GREATER COMPLEXITY IN THE SYSTEM

Future electricity systems will be much more complex than their current counterparts, as a consequence of a range of factors including:

- access for system operators to multiple types of resource to maintain system security;
- manifold increase in the number of active (i.e. responsive) demand sources, generation sources and intermediaries;
- dynamic consumer usage patterns and presence of potentially large variable supply sources in the system;
- the availability and growth of distributed flexibility resource;
- the need for location specific flexibility services leading to conflicts/synergies between distribution and transmission level flexibility requirements; and
- large volumes of multidimensional (e.g. electricity prices, consumption and their forecasts) and dynamic data flows involving both technical data as well as monetary transactions.

Accounting for these factors will require:

- system operators and other key market players being prepared to embrace the growing complexity challenge for safe and efficient operation and control of the future smart system; and
- the energy as well as associated Information and Communication (ICT) infrastructure, to be in place for enabling various functions of the future system.

4.1 System operators will need to have clear roles and responsibilities besides developing capability to manage greater complexity of the future smart electricity system

Future smart electricity systems will have interactions in many different ways with a range of loads, generation sources and virtual entities (e.g. aggregators and virtual power plants) as depicted earlier in Figure 4. One key implication will be a more complex and frequent interaction between system operation at the transmission and distribution levels, demanding better coordination. In addition, the wider set of operational choices available to networks will need to be adequately reflected in network planning and management decisions.

4.1.1 Need for increased coordination in network management

Traditionally the Distribution Network Operators (DNOs) own, build, maintain and operate the distribution networks to be able to deliver power to consumers all year round. On the other hand, the responsibility of the transmission network is split between Transmission Owners (TOs) and System Operator (SO). TOs own, build and maintain the transmission network while the SO maintains the demand-supply balance by coordinating activities of market participants such that the safe operation of the system and network is maintained.

A sizeable share of distributed energy resource (DER), particularly the new flexibility resource (e.g. DSR, storage, onsite generation and combined storage & generation facilities) are being connected at distribution networks.[21] As a consequence, there is a need to have stronger coordination between transmission and distribution network operators to enable use of all available flexibility resource to its full effect.

Imperial has analysed three types of network models to assess their relative benefits:

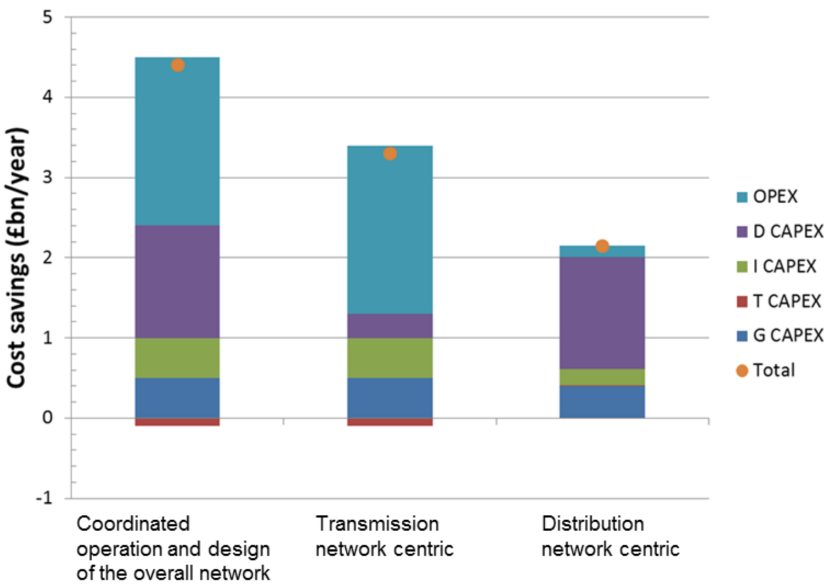
a) **Coordinated operation and design** of the transmission and distribution networks, which would enable DER to be used to maximise the whole-system benefits by managing the synergies and conflicts between local and national level objectives (e.g. maximising the value of combined benefits delivered through energy arbitrage, providing support to local and national network infrastructure, delivering various ancillary services to optimise system operation, while reducing the investment in conventional and low carbon generation).

b) **Transmission centric** model, which focuses on the use of available flexibility resource for deferring transmission/interconnection investment and reducing system operating costs, while ignoring the benefits of DER to the distribution network.

c) **Distribution centric** model, which focuses on managing local distribution network operation and investment through applying DER for peak demand reduction at the local network.

The savings due to integrating new sources of flexibility relative to the use of conventional thermal generation based sources of flexibility, in all three models are shown in Figure 21. It demonstrates that the coordinated (i.e. whole-system) approach may result in significant additional savings in system operation and investment costs, i.e. between £1.1bn/yr and £2.3bn/yr, relative to transmission or distribution network centric models.

Figure 21 – Potential benefits of alternative operation and design models of the network



Source: Imperial's modelling analysis

21 Energy Network Association (ENA) is estimating 27.8GW of distributed generation currently connected to the system. http://www.energynetworks.org/assets/files/news/publications/Reports/TDI%20Report%20v1.0.pdf

However, to realise these whole-system benefits, it will be critical to establish strong coordination between distribution and transmission network operators by clearly defining their future roles and responsibilities and through establishing appropriate regulatory and incentives framework.

Some recent activities have attempted to clarify the future roles and responsibilities of system operators. Ofgem and BEIS have recently proposed alternative models for the future roles of system operators (at both transmission and distribution levels).[22] Ofgem has also proposed[23] several changes in the SO's current role with the aim of creating an independent SO where its role will be separated from the remaining functions of the National Grid.

In this context, Transmission and Distribution Interface Steering Group of Energy Network Association's (ENA), also aims at providing the strategic direction and to identify upcoming issues.[24]

4.1.2 Complex system operation under updated network design standards to facilitate efficient integration of flexibility resource

Network Capex avoidance is one of the main areas where potential savings have been identified from deployment of alternative forms of flexibility. The replacement of network asset-based (build) solutions with alternative commercial (non-build) solutions can reduce the overall cost of developing, as well as operating, the system.

However, existing planning and operational standards for both networks and generation systems were primarily developed around asset-based (build) solutions and did not incorporate alternative solutions to meeting system operational requirements. With the emergence of cost effective non-build solutions, an update of these planning and operational standards is needed to establish a level playing field between traditional network infrastructure and emerging flexible technologies.

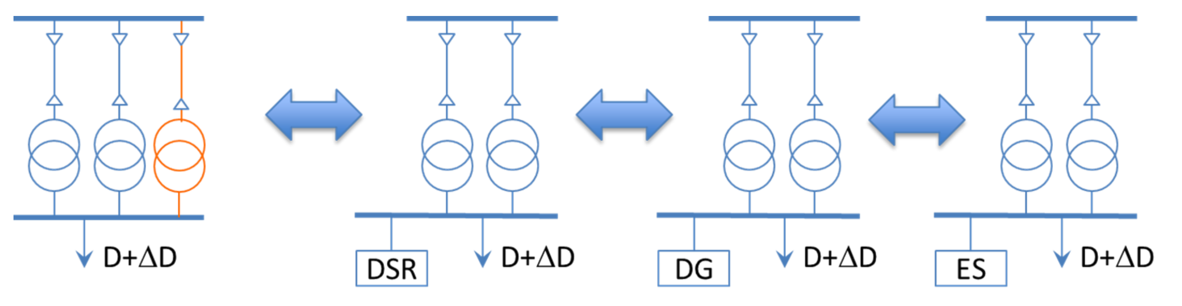
For example, as shown in Figure 22, in order to meet a rise in demand in a given distribution area, conventional network planning standards (e.g. N-1 or N-2) would typically trigger the need to build an additional line with associated network infrastructure. However, depending on the characteristics of demand in the area (e.g. if peak demand turns up for a limited time per year), the use of distributed flexibility resource in network operation (e.g. DSR, distributed generation and storage) can substitute the need for network reinforcement. These flexibility sources can support network flows and voltage management equivalently to the functions of network reinforcement and should be considered where they are a more cost-effective solution.

22 BEIS and Ofgem Call for evidence – 'A Smart Flexible Energy System', November 2016

23 Future arrangements for the electricity system operator: its role and structure, January 2017, https://www.ofgem.gov.uk/system/files/docs/2017/01/future_arrangements_for_the_electricity_system_operator.pdf

24 Transmission and Distribution Interface Steering Group Report, ENA, December 2016 http://www.energynetworks.org/assets/files/electricity/regulation/TDI%20Report%20Dec%2016_final%20v0%2010%20211216.pdf

Figure 22 – Growing complexity in the future systems



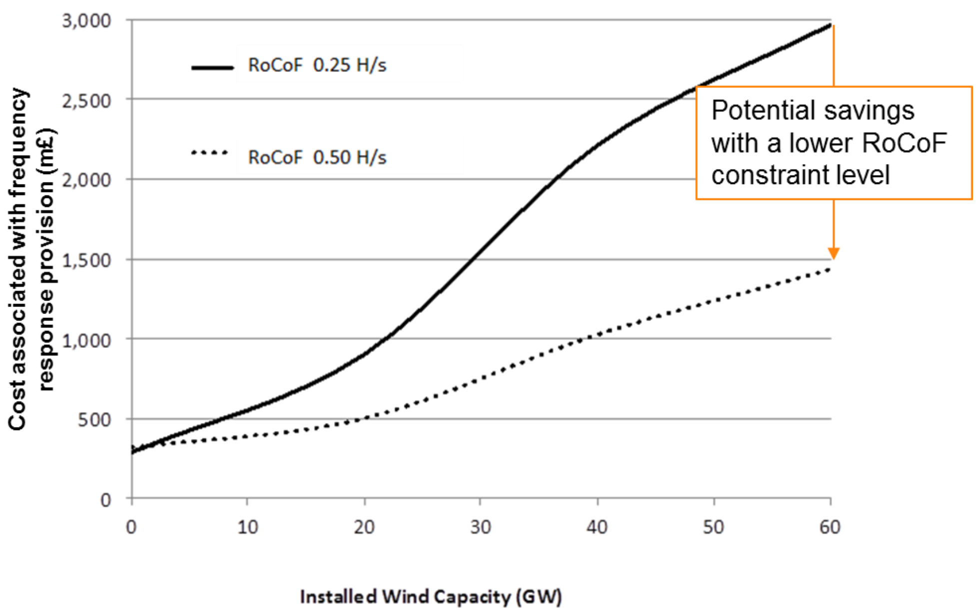
Build solution following conventional planning standard	Smart solutions (i.e. use of flexibility resource) that efficiently serve the same objective as of the traditional planning standard

Another example of the potential for change in operational standards is the relaxation of Rate of Change of Frequency (RoCoF) constraints. This will make the system more flexible in accommodating relatively larger variations in system frequency driven by imbalances in demand and supply.

A relaxation in the RoCoF standard from 0.25Hz/s to 0.5 Hz/s would, according to Imperial's modelling analysis, lower required frequency response and overall costs of operating the system (as shown in Figure 23).

With rising penetration of wind capacity in the system, the savings driven by relaxing the RoCoF constraint increase significantly. This suggests that a review of standards may be appropriate given the changing nature of the electricity system to which they apply.

Figure 23 – Potential benefits of RoCoF constraints



Source: Imperial's modelling analysis

The network companies have initiated a case to carry out a thorough review of Engineering Recommendation (ER P2). ER P2 has acted as the foundation stone for the planning of distribution networks for many decades. It is essentially unchanged from ER P2/5 which was introduced in 1978. It therefore pre-dates the development of smart grids, widespread distributed generation and active customers. Ofgem has fully supported this initiative and the public engagement process assessing the P2 review[25] on the design of the electricity distribution networks and changes to SQSS (GRS 022). Both of these are considering changes related to new technologies like storage.

4.1.3 Growth in system complexity driven by cross-border flexibility sharing

With large increase in flexibility requirements in the future de-carbonised electricity systems there is a need to explore all available flexibility sources including cross-border flexibility resource.

Currently, interconnectors to the GB electricity system offer some flexibility on both sides of the interconnectors based on energy arbitrage. However, system balancing services are not shared across the border with the connected systems. This was mainly due to lower need for flexibility requirements in the past and absence of a mechanism for GB to participate in exchange of cross-border flexibility services. Recently, a pilot project (Trans-European Replacement Reserve Exchange, TERRE[26]) has been initiated for cross-national exchange of operating reserve between GB, France, Spain, Portugal, Italy, Switzerland and Greece.

The cross-border sharing of flexibility, particularly of ancillary services, brings additional complexity in system operation as the utilisation of diverse national flexibility resource (available at both transmission and distribution connected) will need to be optimised alongside the cross-border flexibility resource. This will also need another layer of coordination between GB system operators and cross-border system operators. Therefore, system operators will need to be prepared to utilise this resource and the required coordination functions should be defined in their new roles and responsibilities[27].

Imperial's analysis of sharing balancing services with other systems through interconnectors is shown in Figure 24 for two targets of CO_2 intensities in 2030 (100gCO_2/kWh and 50gCO_2/kWh). This indicates significant benefits for the GB system from accessing cross-border flexibility. These benefits are driven by savings in low-carbon generation capacity and system operation costs while meeting the 2030 carbon intensity target for the power sector. The net savings are higher for a tighter decarbonisation target case. These are driven by avoidance of energy curtailment produced by renewables thus allowing meeting CO_2 targets with relatively lower installed capacity of low-carbon technologies and back-up capacity (i.e. savings in generation capex) and reduced requirements of interconnection capacity to export high volumes of surplus intermittent generation during low demand periods in GB.

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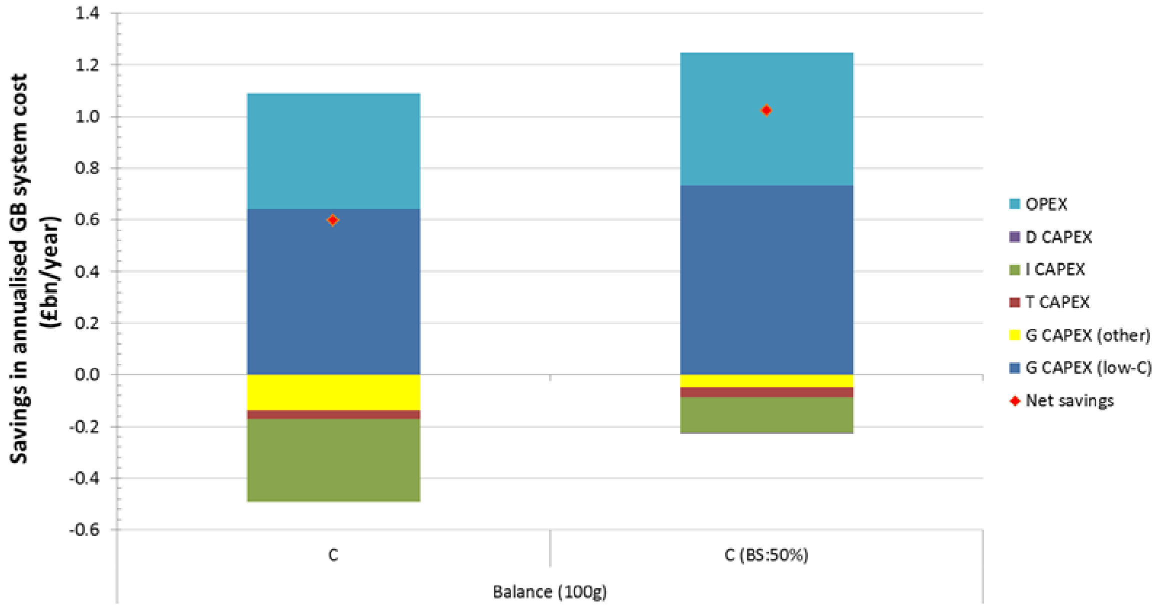
25 The Design of Electricity Distribution Networks – Looking to the Future, Ofgem, May 2015 https://www.ofgem.gov.uk/publications-and-updates/design-electricity-distribution-networks-looking-future

26 TERRE is about setting up and operating a multi-TSO platform capable of gathering all the offers for Operating Reserves and to optimise the allocation of these reserves across the systems of the different TSOs involved.

27 Proposals on required modifications in the GB Balancing and Settlement Code (BSC) are being developed for implementing TERRE in the BSC. (Elexon, Implementing TERRE in the BSC, October 2016)

Figure 24 – Potential benefits of sharing balancing services via interconnection



Source: Imperial's modelling analysis

4.1.4 Actions on roles and responsibilities of system operators

To manage the complexity in the future systems and, indeed, to enable some of the innovative new flexibility solutions to emerge, the system operator role will need to be significantly more proactive. While a core aspect of this will be the interactions between transmission and distribution systems, it also encompasses the linkages with and between consumers, suppliers and third party intermediaries, and increased coordination with cross-border system operators. An efficient operation of the smart system will therefore need a clear outline of the roles, responsibilities and interfaces between the various actors. In addition, there is a need to ensure that the regulatory framework adapts to facilitate the growing diversity of choices open to system operators in managing and controlling their systems.

The following action is proposed regarding the future role and responsibilities of system operators in GB.

Publish a strategy for developing the longer-term roles and responsibilities of system operators (including transitional arrangements) that incentivises system operators to access all flexibility resource and be prepared to handle additional complexity in the system, by making investments and operational decisions that maximise total system benefits.

Responsible: Ofgem in coordination with industry	*2018*	*High priority*

A separate action to support innovation and test new flexibility solutions (e.g. to develop new network design standards, coordination platforms for system operators, etc.) is proposed in Section 5.2.

4.2 Development of energy and smart-enabling infrastructure needs to be well-coordinated

The investment in the enabling infrastructure for future smart energy systems is being undertaken by a number of independent players including not only the energy network operators but providers of complementary ICT infrastructure. Having a strategy that enables coordination of all smart infrastructure will provide:

- a transparent way to map individual investment programmes for identify critical interdependencies and/or misalignments; and
- the risks associated with delays in one area and how those would limit the realisation of the full capability of a smart system and potentially wider implications (including costs) for the energy system and consumers.

Our recommendation for a coordinated strategy could be similar to the National Infrastructure Commission's (NIC) current approach for initiation of coordination in infrastructure developments[28, 29] for which the NIC plans to publish a Vision and Priorities document in summer 2017.

Smart metering is an enabling technology that will help to address a number of challenges in the move towards smart energy systems. However, a number of issues have been identified with the smart meter roll-out programme which may potentially affect the expected benefits and objectives of the programme. Some of the identified include:

- Effect of programme delays on economic benefits – the updated cost-benefit modelling of government's smart meter roll-out programme[30] that takes account of the new evidence on actual smart meters deployment progress, reduces the Net Present Value (NPV) of the programme by around £1,013m (due to a £534m reduction in costs and a £1,548m reduction in benefits. This reduction of benefits is primarily driven by delays in installations of smart meters in comparison to the expectations reflected at the start of programme in 2014.
- Lack of interoperability of first-generation of SMETS1 meters (with over 5 million SMETS1 meters or earlier smart meter versions already installed) – impact of this installation on the market is also not well understood (e.g. risk of stranded costs and customers being deterred to seek best deals).
- Optimistic predictions regarding the ease and cost of installations – between 10-15 percent of properties may require more than one visit (compared to government's expectation of 5 percent of properties) in order to complete installations pushing up the cost by as much £1 billion.[31]
- The central communication system for smart meters is still lacking in a number of core areas. These include a 12 months delay in the major 'go-live' event of the

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28 Cambridge – Milton Keynes – Oxford: 'growth corridor' call for evidence, NIC, May 2016 https://www.gov.uk/government/consultations/cambridge-milton-keynes-oxford-growth-corridor-call-for-evidence/cambridge-milton-keynes-oxford-growth-corridor-call-for-evidence

29 National Infrastructure Assessment Call for Evidence, NIC, November 2016 https://www.gov.uk/government/publications/national-infrastructure-assessment-call-for-evidence

30 Smart meter roll-out cost-benefit analysis, BEIS, August 2016

31 Warning by The Big Deal (a collective switching enterprise), and Utility Week's research showing that currently 13% of properties are requiring more than one visit for completion of installation

system and communication issues with SMETS2 meters, prepay meters and meters in multiple occupancy dwellings with a knock on effect to the deployment of SMETS2 meters.

- The heavy cost burden imposed of the roll-out programme to suppliers investing (in £ billions) in IT systems, regulatory compliance and installation contracts is potentially resulting in resource squeeze for innovation via new products such as Time of Use (ToU) tariffs and connected home services.[32]

The action to enhance coordination of energy and energy-related infrastructure plans is proposed below.

Publish a smart infrastructure strategy to integrate existing plans relating to energy technologies (e.g. smart meter, public EV charging and interconnectors) and associated ICT infrastructure (e.g. broadband roll-out) to ensure coordination of actions based on identifying and managing risks to delivery of a smart electricity system.
Responsible: BEIS and NIC   *By end 2018*   *Medium priority*

[32] EY expert view reported in Utility Week, 12-18 May 2017

5. ENSURING INNOVATION SUPPORT

Innovation will be at the heart of the low-carbon transition affecting the whole value chain, with anticipated developments in:

- network management models (e.g. dynamic network operation and control);
- supplier/aggregator models to facilitate provision of flexibility to system operators;
- emerging and new flexibility providing technical solutions (e.g. DSR, Storage, inertia provision from intermittent generators and highly flexible conventional thermal generators); and
- accessing flexibility from other energy sectors (e.g. heat and has sectors).

Future market and regulatory arrangements should aim to continue to support innovation not only through clear signals and low entry barriers but also, where appropriate, through ongoing support for research and development. This is especially true where solutions are at early stages of commercialisation due to the immaturity of the technology or limited market scope until higher penetration of renewable generation is realised.

5.1 Continued support is required to ensure learning in developing innovative flexibility solutions

As flexibility requirements are growing and technologies emerging, the scope for alternative solutions will also increase. These solutions will need to be investigated to better understand where they can add most value and what the specific costs and risks associated with their use are for users and network operators. Without direct support the development of some of these options may be slow and the adoption by wider industry hindered due to lack of shared knowledge. In the short-term, therefore, we see the need for ongoing support to:

- test and develop new system planning and operational approaches incorporating non-build solutions. This will allow the system operators to assess and manage the risks associated with innovative approaches to network operation & control; and
- encourage development of pre-commercial technologies. Support now should be targeted on continuing technical learning to improve efficiency, reduce costs and to improve understanding and demonstration of the services that can be provided while preventing lock-in to less efficient technologies.

This will also allow the developers of flexibility solutions in GB to export the developed technologies, operational models and knowledge to other countries.

5.1.1 Developing new planning and operational approaches

As discussed in the last chapter (Section 4.1) the smart electricity system will need new planning and operational standards in order to efficiently use non-build solutions. However, in the shift from an asset led conventional system to a smart future system, research and development support as well as appropriate incentivisation will be required for testing new (generation and network) standards. This should address trade-offs between the build and non-build solutions and focus on improving understanding of:

- risks to safe operation of the system;
- the implications to security of supply; and
- costs and benefits of a range of alternatives.

Ofgem reviewed the level of funding and criteria of the projects under the Network Innovation Allowance (NIA) and the Network Innovation Competition (NIC) arrangements with an aim of delivering more value to the consumer from the use of smart technologies. The changes have been proposed in the associated consultation[33] process and the development of an industry innovation strategy.

The current RIIO price control framework is designed with an intention that it would lead to a more innovative approach to managing the transmission and distribution networks. The TOTEX approach is intended to facilitate smart and non-build solutions for network management and system operation. However, we are still in the first price-control cycle under RIIO and much of the innovation is being driven through explicit innovation funding mechanisms such as the NIA and NIC. When networks start to prepare their business plans for the second RIIO controls (commencing in 2021 for transmission and 2023 for distribution) we would expect to see a much stronger role for smart solutions in TSO/DSO network development and operational plans.

In order to support and incentivise innovation in testing and developing new planning and operational approaches and standards the relevant actions are proposed below.

Periodical review of existing system planning and operational standards for networks and generation, assessing whether they provide level-playing field to all technologies including active network management and non-build solutions (e.g. storage and DSR), and revise these standards as appropriate.		
Responsible: Industry codes governance and Ofgem	*Initial review by 2019*	*Priority: High*
Ensure that the second RIIO price-control framework provides a transparent process that incentivises efficient investment and trade-off between build and non-build (e.g. storage and DSR) solutions in future network investment programmes.		
Responsible: Ofgem	*2020*	*Priority: Medium*

5.1.2 Improving technical and cost performance of emerging flexibility resource

The benefits of smart technologies for the system depend on early deployment to realise technical reliability and economies of scale and learning by doing. In this context, the UK can possibly lead innovation in the area of:

- system integration, IT platforms and infrastructure,
- novel commercial arrangements and business models;
- risk identification and their mitigation associated with technologies such as storage and DSR; and
- implementation of promising new operational and planning concepts such as virtual power plants.

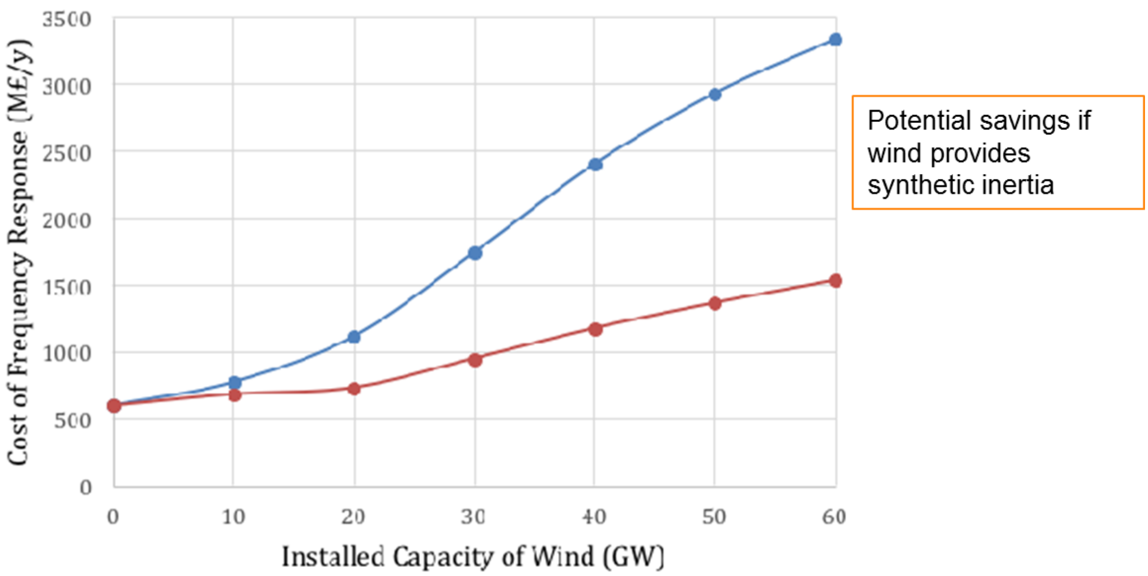
Research and development in this area will allow future technological improvements and avoid technological lock-in.

33 The network innovation review: our consultation proposals, Ofgem, December 2016 https://www.ofgem.gov.uk/system/files/docs/2016/12/innovation_review_consultation_final.pdf

The potential and implications of intermittent generators (wind and solar) in providing flexibility services is not fully understood and there are limited incentives on renewable generators to provide system flexibility in GB. Since the growth in renewable generation drives the need for more flexibility while at the same time displacing conventional thermal plant that traditionally has been the source of this flexibility, enhancements in the capability of renewable generation to offer some of these services would be beneficial.

There is evidence that wind farms can provide some of these services and hence lower the costs associated with provision of flexibility. Studies on provision of synthetic inertia (SI) by wind generation show that at 60GW wind capacity installed, the annual costs associated with frequency response provision can be halved if wind provides SI, as shown in Figure 25.[34]

Figure 25 – Benefits of providing Synthetic Inertia by wind



Source: Imperial's modelling analysis

There are different ways in which SI from intermittent renewable sources can be exploited. For example, through changes in the industry codes as in 2005, Hydro-Québec (North American utility, 40GW peak load) amended its grid code that new wind turbines be capable of delivering a power boost equal to six percent of their rated capacity during low-frequency events. Manufacturers responded with synthetic inertia designs, and the first were installed in 2011. Today, inertia-compliant turbines account for two-thirds of Quebec's wind capacity.[35] However, this may not be the best solution for the GB system as a large amount of wind capacity is already installed and the ease and cost of retrospectively applying the new requirements to existing generators is unknown. Furthermore, we may not need all plant to be able to provide this.

Another approach to exploit the flexibility resource embedded in intermittent generation sources is market incentivisation – for example, through remuneration of inertia provided by generators (i.e. synthetic inertia in case of wind generation).

34 This study assumes 1800MW as the biggest outage in the system.

35 Can Synthetic Inertia from Wind Power Stabilize Grids?, IEEE, Peter Fairly, 2015

5.1.3 Investigating provision of flexibility from other energy sectors

In addition to the flexibility available from technologies within the power sector, there is significant potential to access flexibility embedded in other energy sectors, particularly the heat and gas sectors. However, understanding the effectiveness and implications of exploiting this flexibility resource needs further research and analysis.

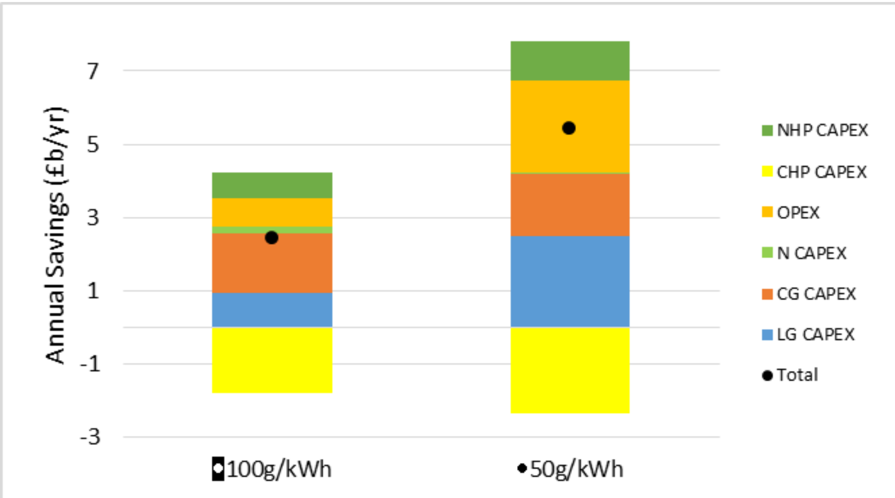
Imperial College has conducted an initial analysis to quantify the potential benefits of exploiting the flexibility potential from the heat and gas sectors. This analysis demonstrates that coordination of design and operation of different energy vectors can potentially bring significant benefits and that coordinated policy, regulation and market measures will be important for cost effective decarbonisation of the energy system.

5.1.3.1 Interaction between electricity and heat sectors

A higher degree of integration between electricity and heat sectors presents unique opportunities to make use of cross-vector flexibility to support the integration of low-carbon generation technologies and to significantly reduce the cost of decarbonisation.

A modelling based analysis of coordinated design and operation of low carbon heat and electricity systems, which assumed heat demand is met by heat networks in which Combined Heat and Power (CHP), industrial network heat pumps (NHP) and thermal energy storage (TES) are used, was carried out by Imperial. Where the heat system was decoupled from the electricity system (i.e. it did not provide flexibility services like reserve and response service), costs of operating the overall system were higher than the case when they were integrated (as shown in Figure 26).

Figure 26 – Savings from integrated heat and electricity system operation paradigm (High wind scenario)



Source: Imperial's modelling analysis

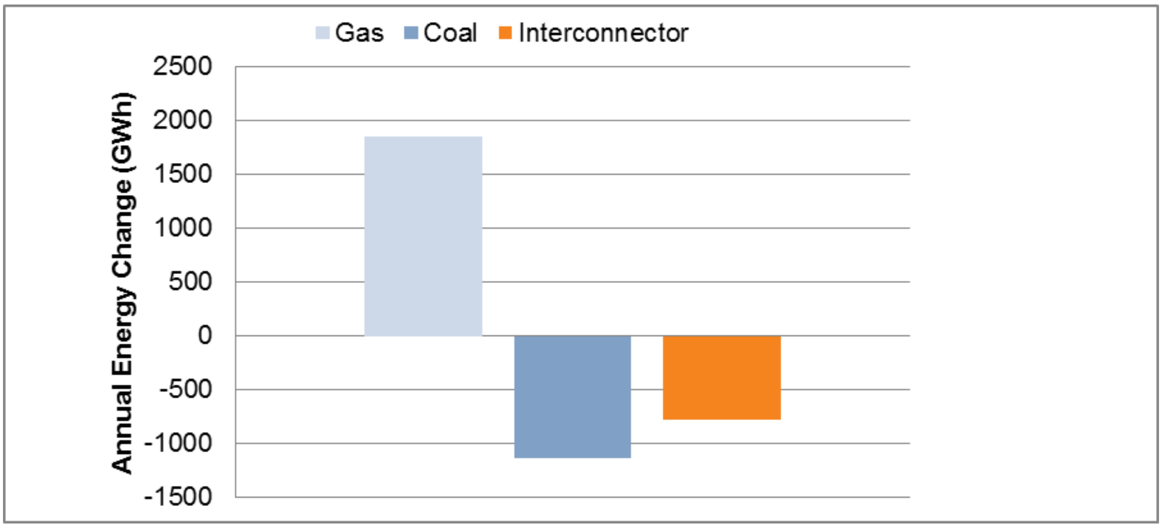
The net benefits of coordinated operation of the heat and electricity system were between £2.4bn/year and £5.4bn/year for 100gCO_2/kWh and 50gCO_2/kWh scenarios (by 2030) respectively. Given that CHP can provide ancillary service to the electricity system besides providing heat, which enhances the overall generation efficiency, CCGT plant would be replaced by CHP in the integrated system, delivering fuel cost savings. Furthermore, increase in efficiency achieved through coordinated operation of heat and electricity sectors can achieve carbon targets with reduced amount of low carbon generation. It can also be observed that a higher penetration of CHP leads to the reduction in the amount of industrial NHP capacity, which also reduces high-voltage distribution network reinforcement requirements.

5.1.3.2 Interaction between gas and electricity system

The future growth of intermittent generation will also increase the complexity of gas network management as gas plant is expected to play a significant role in providing flexibility. Unlike electrical energy, it takes a significant amount of time to transport gas from supply sources (terminals and storage facilities) to gas demand centres. One of the cost effective solutions to deal with this would be to enhance the flexibility of gas network infrastructure by installing multi-directional compressors that can deal with the growing variability in the gas demand across the system.

A high-level modelling analysis was carried out by Imperial for assessing the value of flexibility in the gas system for supporting the electricity system. Figure 27 shows that enhancing the flexibility of gas infrastructure (improves the operability of gas generation and reduces more costly coal generation and interconnection imports. This would deliver annual reduction in operating cost of £612m and does not account for the reduced amount of low carbon generation needed to meet the carbon target.

Figure 27 – Change in energy production facilitated by enhanced flexibility of gas network through multi-directional compressors (illustrative example)



Source: Imperial's modelling analysis

5.2 Action to ensure innovation

We have proposed the following action to ensure that innovation is supported in improving technical performance and costs of emerging technologies and in developing novel system operation and control approaches, and commercial models.

Ensure a supporting environment (e.g. research, development and innovation funding support, price control frameworks, etc.) for continued innovation and learning in the following key areas:

- improvements in the flexibility of conventional technologies and in the reliability and efficiency of emerging technologies;
- managing risks associated with the application of the new system operation model(s) based on emerging technologies and control systems;
- building evidence base on costs associated with DSR in different consumer sectors;
- managing synergies and conflicts in the operation of transmission, distribution and cross-border interconnection functions of the system;
- understanding consumer responses to new tariff offerings (e.g. HH tariffs) by suppliers;
- understand current and future potential and implications (e.g. levels of renewable energy curtailment, impact on CO_2 emissions, etc.) of providing flexibility from intermittent renewables; and
- investigating the provision of flexibility from other energy sectors (e.g. heat and gas sectors).

Responsible: BEIS, Ofgem *Ongoing*

6. ENSURING EFFECTIVE CONSUMER PARTICIPATION

Demand Side Response (DSR) is already an established flexibility option. There is a lot of latent DSR resource available across different demand sectors (i.e. industrial, commercial, public sector and domestic sectors) but currently it does not form a significant share of any flexibility service in GB. Access to this potential flexibility source will require:

- educating and informing consumers about the ongoing changes in the system and the opportunities these bring as a result of their ability to provide flexibility to the system; and
- ensuring that the consumers are protected – i.e. not exposed to undue risks such as those associated with their security of supply, cyber security and affordability.

6.1 Consumers need to be better informed about the benefits that a smart system offers them

The potential flexibility provision through DSR, the nature of the service, the terms on which it would be available and the necessary investment to access it varies across consumer groups. Especially for domestic consumers, the absence or limited information on the implications of DSR provision is seen as a potential barrier to future uptake of DSR-related offerings as technology and market conditions make such opportunities more prevalent in the market

Potential issues that would hinder the uptake of DSR include:

- lack of value as the service is not remunerated for all benefits delivered to the system;
- limited availability of simple and practical offerings by market players to customers enabling them to participate;
- perceived complexity (e.g. managing the DSR/smart enabling kits or devices particularly in case of domestic consumers);
- a culture of maintaining status quo, for example, in the public and industrial sectors;
- perceived loss of control/comfort and autonomy in energy use when it is required;
- lack of trust between consumers and market players, partially due to poor consumer understanding and lack of communication between the two parties; and
- the perception of risk that bills will be higher if consumers are unable to adapt behaviour as anticipated.

Many of the above discussed barriers can be removed through transparent and consumer focused awareness programmes. However, as discussed earlier in Chapter 4, it is critical that DSR providers can access the full range of revenue streams.

According to research by DECC (now BEIS)[36], 76% of British consumers reported knowing either nothing or very little about smart meters[37] which is a fundamental enabler of residential DSR. Similarly, according to another analysis on public perception of the UK

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[36] The British public's perception of the UK smart metering initiative: Threats and opportunities, Kathryn Buchanan, Nick Banks, Ian Preston, Riccardo Russo, Energy Policy, Elsevier, 2016

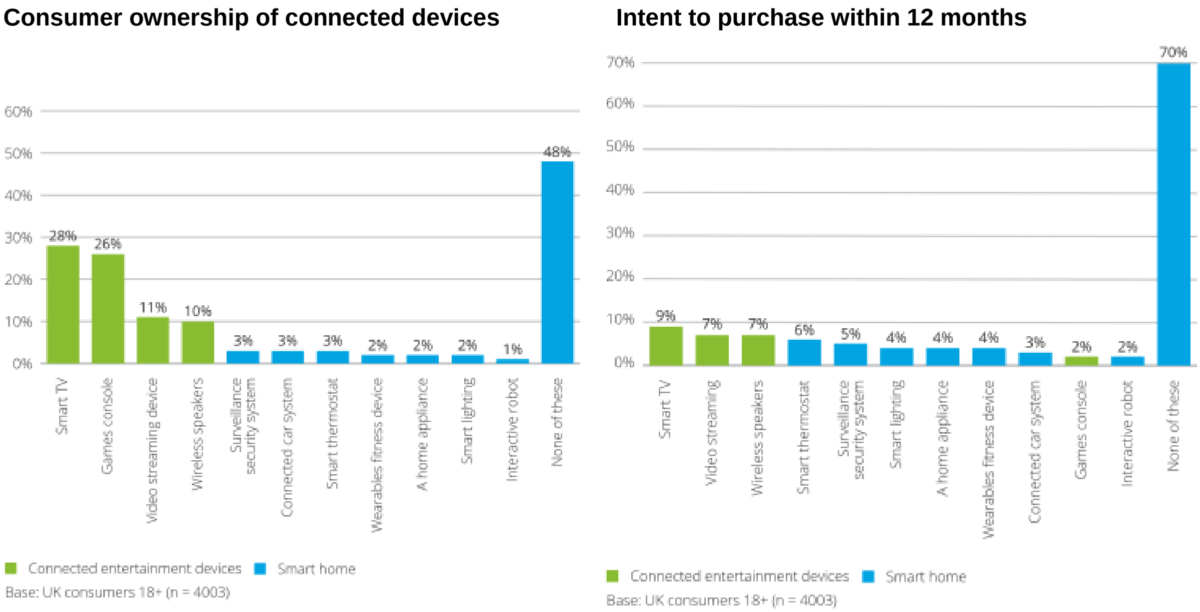
[37] Quantitative Research into Public Awareness, Attitudes and Experience of Smart Meters: Wave 4, DECC (now BEIS), 2014

smart metering initiative[38], consumers are sceptical about the motivation of suppliers to promote smart meters and the services to be offered through these meters.

This demonstrates a need to educate domestic consumers as to how smart meters can widen the types of tariff offering they can choose between and the wider opportunities for active engagement with the market through provision of DSR for the system.

There are also some other natural barriers to large scale uptake of DSR. In particular, since much DSR is linked to the deployment of smart appliances, slow roll-out of smart appliances in line with natural product replacement cycles will prevent the full potential of domestic DSR being accessed quickly. According to a review by Deloitte on internet-connected appliances for households[39], two-thirds of consumers were not intending to buy any such appliances in the next 12 months, as shown in Figure 28. This not only limits the uptake of domestic DSR but also has knock-on implications for incentives amongst manufacturers to increase production of smart appliances.

Figure 28 – Consumer Choice of Connected Devices



Source: "Switch on to the connected home, The Deloitte Consumer Review", July 2016

The 'Smart Energy GB' organisation is building consumer awareness related to smart meters and the benefits it offers. National Grid has been facilitating a campaign[40], which aims to encourage participation in several forms of flexibility technology in the electricity market by raising the awareness on the benefits of smart technologies.

In order to raise consumer trust and awareness regarding opportunities offered by DSR as well as brining transparency and clarity on risks (often perceived) we have proposed the

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38 The British public's perception of the UK smart metering initiative: Threats and opportunities, Kathryn Buchanan, Nick Banks, Ian Preston, Riccardo Russo, Energy Policy, Elsevier, 2016

39 Switch on to the connected home, The Deloitte Consumer Review, July 2016

40 Power Responsive Campaign http://powerresponsive.com/

first action as proposed in the below given below. The second and third actions in the box are related to monitoring the progress on DSR.

Introduce an education / awareness programme to inform industrial, commercial, public sector and domestic consumers of the opportunities (e.g. remuneration for provision of flexibility services and/or reduction in electricity bills), and clarify the materiality of perceived risks.		
Responsible: System operators, Suppliers, CAB, BEIS	*Ongoing, linked to implementation programmes*	*n/a*
Assess uptake of DSR and any constraints thereof, and if required take action to encourage effective DSR participation (e.g. product standardisation and fiscal incentives).		
Responsible: BEIS and suppliers	*2020 onwards*	*Low priority*
Review minimum standards of all smart related equipment (appliances and ICT kits) to ensure their cyber security, interoperability, user friendliness and high energy efficiency performance.		
Responsible: BEIS,SO, DSOs and OEMs	*2020 onwards*	*Low priority*

6.2 Consumers protection will need to be ensured to build trust for DSR participation

In order to facilitate effective participation of consumers in DSR, a critical requirement is to ensure that consumers have trust in the following two aspects:

- security of equipment and software; and
- upholding privacy and appropriate use of data.

These concerns are linked to each other – for example, a cyber-attack can also lead to leakage of data to parties who are not allowed to have access to such information.

6.2.1 Security of equipment and software

Smart technologies are based on information, communication and online data transfer technologies which are being continuously evolved and are vulnerable to cyber-attacks.[41] Therefore, consumers are concerned about the protection of their smart equipment (i.e. smart devices, appliances, kits and the data processing and communication programmes) against cyber-attacks.

41 The internet of things: how your TV, car and toys could spy on you, The Guardian, February 2016 https://www.theguardian.com/world/2016/feb/10/internet-of-things-surveillance-smart-tv-cars-toys,

https://www.theguardian.com/technology/2015/nov/30/vtech-toys-hack-private-data-parents-children

At present, the Government's National Cyber Security Strategy[42] covers the necessary steps for maintaining cyber security of the energy industry covering the increasing usage of smart appliances in the power grid.

6.2.2 Upholding privacy and appropriate use of data

Consumers also see risks around sharing data via the internet that was collected from their smart appliances and smart meters. These concerns have been intensified by reported incidents that smart appliances were spying on people. This requires placement of robust systems to mitigate the risk.

The data privacy framework (for consumption data from smart meters) is set out in the licences of suppliers and DNOs and the Smart Energy Code[43], which sets out the rules on the ownership, access and usage rights of customer data collected from smart meters.

6.2.3 Recommended actions on building consumer trust for DSR participation

BEIS has commissioned a study[44] to build understanding on the motivating factors and barriers that drive small energy users' decision making around demand side response. The study is also expected to propose products, services, policies and engagement strategies that could be most effective at achieving DSR at scale amongst these users.

In order to protect customers and build their trust we have proposed the following actions for their effective participation in provision of DSR.

Ensure that an effective system remains is in place to comprehensively and continuously assess, monitor and mitigate cyber security risks to the operation of future smart electricity system and integrity of related smart infrastructure.	
Responsible: BEIS and DCC in coordination with SO/DSO, NCSC and CAB	*Ongoing*
Keep under review the ownership, access and usage rights of customer data collected from smart meters and other smart devices, and if necessary amend these rights to strike appropriate balance between data access by market participants and consumer privacy.	
Responsible: BEIS in coordination with industry	*Ongoing*

42 National Cyber Security Strategy 2016-2021, HM Government https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/567242/national_cyber_security_strategy_2016.pdf

43 Smart Energy Code, March 2017 https://www.smartenergycodecompany.co.uk/docs/default-source/sec-documents/smart-energy-code-5.5/sec-5-5---15th-march-2017.pdf?sfvrsn=6

44 Realising the Potential of Demand-Side Response to 2025 – A focus on Small Energy Users, (work in progress), BEIS, October 2016

7. SUMMARY OF THE FLEXIBILITY ROADMAP AND INDICATOR FRAMEWORK

This chapter provides a summary of the recommended actions that will be required to facilitate provision of increased levels of flexibility in the future GB system.

In addition to the roadmap actions we have also proposed a set of indicators in order to assess the progress on the roadmap.

7.1 Flexibility roadmap actions

All actions in the roadmap are grouped in the following four key areas:

- **ensure efficient investment** decisions in providing increased flexibility services;
- develop **capability to manage greater complexity** in future smart electricity systems;
- ensure **innovation support** for improvement in technology, testing new operating/business models and to develop understanding of consumer response to alternative offerings by market players; and
- ensure **effective consumer participation** for exploiting demand flexibility potential.

For each action, we describe (a) the primary responsible party; (b) the timeframe over which action is required; and (c) the priority of the action, as set out in Table 4.

Table 4 – Flexibility roadmap

Action	Responsible	Time frame	Priority
Actions to ensure efficient investment			
Publish annual projections (in each year) of longer-term future procurement requirements across all flexibility services including indication of the level of uncertainty involved and where possible location specific requirements, to provide greater visibility over future demand of flexibility services.	*SO and DSOs*	*2020 onwards*	*High*
Periodical assessment of existing flexibility services to identify services that may be procured more efficiently through transparent and technology-neutral processes in the future and reform their procurement processes accordingly.	*SO and DSOs*	*Initial assessment by 2020*	*Medium*
Review characteristics of current procurement processes (e.g. threshold capacity level to participate, contract terms / obligations) and the procurement route (e.g. open market, auctioning or competitive tendering) that enable more efficient procurement of services without unduly restricting the provision of multiple services by flexibility providers.	*Ofgem in conjunction with SO, TOs and DSOs*	*By 2020*	*High*
Assess the materiality of distortions to investment decisions in the current network charging methodology (e.g. lack of locational charging, double-charging for stored electricity), and reform charging methodology where appropriate.	*SO, DSOs, and Ofgem*	*By 2020*	*High*
Assess the materiality of distortions to investment decisions in the absence of non-network related system integration charging (i.e. back up capacity and ancillary services) and implement charging where appropriate.	*SO, DSOs, and Ofgem*	*By 2020*	*High*

Action	Responsible	Time frame	Priority
Actions to develop capability to manage greater complexity			
Publish a strategy for developing the longer-term roles and responsibilities of system operators (including transitional arrangements) that incentivises system operators to access all flexibility resource by making investments and operational decisions that maximise total system benefits.	*Ofgem in conjunction with industry*	*2018*	*High*
Publish a smart infrastructure strategy to integrate existing plans relating to energy technologies (e.g. smart meter, public EV charging and interconnectors) and associated ICT infrastructure (e.g. broadband roll-out) to ensure coordination of actions based on identifying and managing risks to delivery of a smart electricity system.	*BEIS and NIC*	*By end 2018*	*Medium*
Actions to ensure innovation support			
Periodical review of existing system planning and operational standards for networks and generation, assessing whether they provide level-playing field to all technologies including active network management and non-build solutions (e.g. storage and DSR), and revise these standards as appropriate.	*Industry codes governance and Ofgem*	*Initial review by 2019*	*High*
Ensure that the second RIIO price-control framework provides a transparent process that incentivises efficient investment and trade-off between build and non-build (e.g. storage and DSR) solutions in future network investment programmes.	*Ofgem*	*2020*	*Medium*
Ensure a supporting environment (e.g. research, development and innovation funding support, price control frameworks, etc.) for continued innovation and learning in the following key areas: - improvements in the flexibility of conventional technologies and in the reliability and efficiency of emerging technologies; - managing risks associated with the application of the new system operation model(s) based on emerging technologies and control systems; - building evidence base on costs associated with DSR in different consumer sectors; - managing synergies and conflicts in the operation of transmission, distribution and cross-border interconnection functions of the system; - understanding consumer responses to new tariff offerings (e.g. HH tariffs) by suppliers; - understand current and future potential and implications (e.g. levels of renewable energy curtailment, impact on CO_2 emissions, etc.) of providing flexibility from intermittent renewables; and - investigating the provision of flexibility from other energy sectors (e.g. heat and gas sectors).	*BEIS and Ofgem*	*Ongoing*	
Actions to ensure effective consumer participation			
Introduce an education / awareness programme to inform industrial, commercial, public sector and domestic consumers of the opportunities (e.g. remuneration for provision of flexibility services and/or reduction in electricity bills), and clarify the materiality of perceived risks.	*System operators, Suppliers, CAB, BEIS*	*Ongoing, linked to implementati on programmes*	
Assess uptake of DSR and any constraints thereof, and if required take action to encourage effective DSR participation (e.g. product standardisation and fiscal incentives).	*BEIS and suppliers*	*2020 onwards*	*Low*
Review minimum standards of all smart related equipment (appliances and ICT kits) to ensure their cyber security, interoperability, user friendliness and high energy efficiency performance.	*BEIS,SO, DSOs and OEMs*	*2020 onwards*	*Low*
Ensure that an effective system remains in place to comprehensively and continuously assess, monitor and mitigate cyber security risks to the operation of future smart electricity system and integrity of related smart infrastructure.	*BEIS and DCC in conjunction with SO/DSO, NCSC and CAB*	*Ongoing*	
Keep under review the ownership, access and usage rights of customer data collected from smart meters and other smart devices, and if necessary amend these rights to strike appropriate balance between data access by market participants and consumer privacy.	*BEIS in conjunction with industry*	*Ongoing*	

7.2 Progress monitoring framework

This section describes the indicators that can be used by the CCC in order to monitor progress on the flexibility roadmap.

The indicators and monitoring framework serve the following two main purposes:

- monitor whether the proposed actions are being implemented in line with the roadmap; and
- to assess the impact of actions – i.e. actual progress in the market around assimilating 'smart', flexible solutions.

7.2.1 Performance against specific actions

In relation to specific actions recommended in the roadmap we have, where appropriate, defined a time frame for completion of the action. Where actions are ongoing, this is noted separately.

Any delay in the completion of actions will need investigation to understand the reasons for such delay and its knock-on effect (if any) on other actions and wider achievement of decarbonisation objectives.

For the ongoing actions, a periodical monitoring will be required to check that progress is in line with the requirements and objectives set out in the roadmap.

7.2.2 Performance of the market in general

The challenge with developing any quantitative metrics is that there is no precise target for particular forms of flexibility provision. This is driven by the uncertainties around:

- relative costs and technical performance of different types and distribution of flexibility sources;
- long-term evolution of supply mix as multiple generation mixes can deliver the decarbonisation targets;
- the development of market and regulatory framework; and
- the social and cultural aspects associated with effective participation of DSR.

Considering this uncertainty, the roadmap is developed with the aim that it would provide a technology neutral environment that facilitates optimal uptake of most efficient and cost effective flexibility technologies. Therefore, the focus of actions has been around creating unbiased incentives, improving fair access terms and minimising the risk of lock-in to existing or inefficient technologies.

In the above context, we first identified a range of key metrics that can provide information on market entry and participation of new technologies alongside ongoing changes to realise maximum flexibility potential. These include:

- overall deployed volume of low-carbon flexibility resource ((e.g. storage/DSR capacity (MW)) and their impact (e.g. peak demand reduction (MW) due to storage /DSR);
- growth in market penetration of low-carbon flexibility resource (e.g. volume/capacity of DSR and storage participating in relevant market platforms, proportion (%) of DSR and storage operators providing system balancing services, etc.); and
- other progress indicators (e.g. number and size of aggregators in the market, growth in roll-out rate of smart appliances, etc.).

The use of the above metrics as indicators to monitor progress will potentially require:

- a significant amount of underlying data which should be readily available to the CCC in order to quantify the relevant indicator; and
- benchmarks to compare the quantified values of indicators to gauge progress.

Considering difficulties in meeting these requirements – e.g. absence of any established benchmarks of the identified indicators – there is a need for simple and easy to apply indicators. Therefore, we propose that the deployment of additional capacity of flexible technologies should be used as the key indicator to measure the impact of roadmap actions.

Based on the modelling analysis undertaken as part of this study for alternative future generation scenarios, we have assessed the required range of additional capacity of different flexible technologies to efficiently meet 2030 carbon intensity targets. The central levels of additional capacity of flexible technologies are to be used to track progress on deployment of technologies in a given period. It is expected that a trade-off between various technologies will also take place. For example, lower deployment of additional storage may be compensated by higher uptake of another technology thus meeting the system's overall flexibility requirements. However, a consistent low deployment of one or more technologies across several years could be seen as a flag for further investigation – e.g. to identify if there is a specific barrier that is hindering the deployment of the technology or affecting its competitiveness against other flexibility technologies

Figure 29 shows these additional capacity requirements based on the modelling analysis undertaken as part of this study. The low and high levels for a given flexibility technology are based on its range of penetration across the four main future scenarios investigated in this study (see Section A.2 for scenario details) whereas the central level shows the middle point of the range.

The central levels of additional capacity of flexible technologies are to be used to track progress on deployment of technologies in a given period. It is expected that a trade-off between various technologies will also take place. For example, lower deployment of additional storage may be compensated by higher uptake of another technology thus meeting the system's overall flexibility requirements. However, a consistent low deployment of one or more technologies across several years could be seen as a flag for further investigation – e.g. to identify if there is a specific barrier that is hindering the deployment of the technology or affecting its competitiveness against other flexibility technologies.

Figure 29 – Potential levels of flexibility providing capacity (GW)

Flexible technology	By 2020			By 2025			By 2030		
	Low	Central	High	Low	Central	High	Low	Central	High
New flexible generation	1	3	5	2	6	10	3	9	15
Storage	0.8	2.9	5	3.2	11.6	20	5.6	20.3	35
DSR	2.1	6.3	10.5	2.76	8.28	13.8	3.42	10.26	17.1
Interconnection	3.4	3.4	3.4	4.45	5.825	7.2	5.5	8.25	11

Source: Imperial's modelling analysis

Considering the value and scalability of DSR we also propose that the following two indicators can also be used to assess the progress for this particular flexibility resource.

- growth in number and size (i.e. total contracted volume, MW) of aggregators providing DSR-based flexibility in the market; and
- growth in the share of smart appliances as a percentage of total appliances sold each year.

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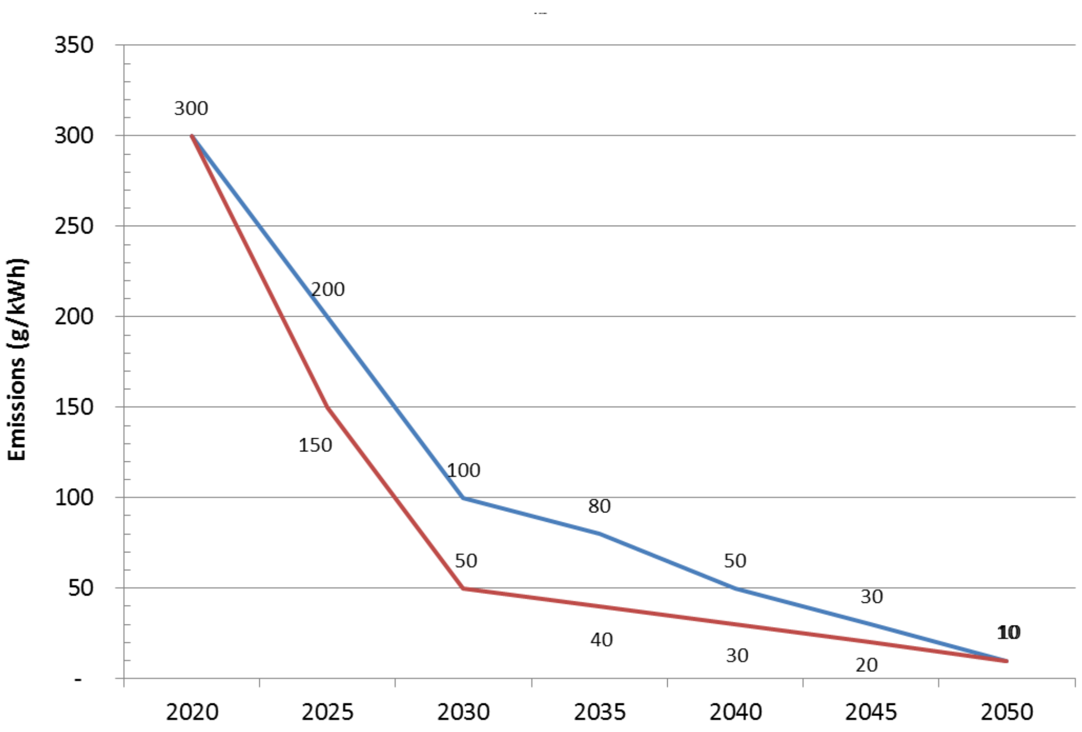
ANNEX A – SYSTEM EVOLUTION PATHWAYS TO MEET THE CARBON INTENSITY TARGETS

This annex provides further details on the scenarios modelled in this study. These scenarios are described in terms of the future demand and supply backgrounds. In addition to the scenario description, a high-level overview of Imperial's modelling methodology and key modelling assumptions are also provided.

A.1 Carbon targets

The core scenarios postulate that by 2030, the carbon intensity of the UK power sector should reach 100gCO_2/kWh and by 2050, it will be reduced substantially to 10gCO_2/kWh. In order to understand the importance and the implications of having more ambitious target, as part of the sensitivity analysis, a second carbon reduction trajectory is also analysed with 50gCO_2/kWh as the target in 2030. The two trajectories of the carbon intensity targets per 5 year period assumed in the study are shown in Figure 30.

Figure 30 – Carbon intensity targets for the GB power sector (gCO_2/kWh)



Source: Imperial's modelling assumptions

In order to reduce carbon intensity, the share of electricity production from low-carbon generation needs to increase. The sharp reduction of carbon emissions from 2020 to 2030 suggests a significant shift from fossil fuel based power generation towards sustainable and low-carbon generation technologies.

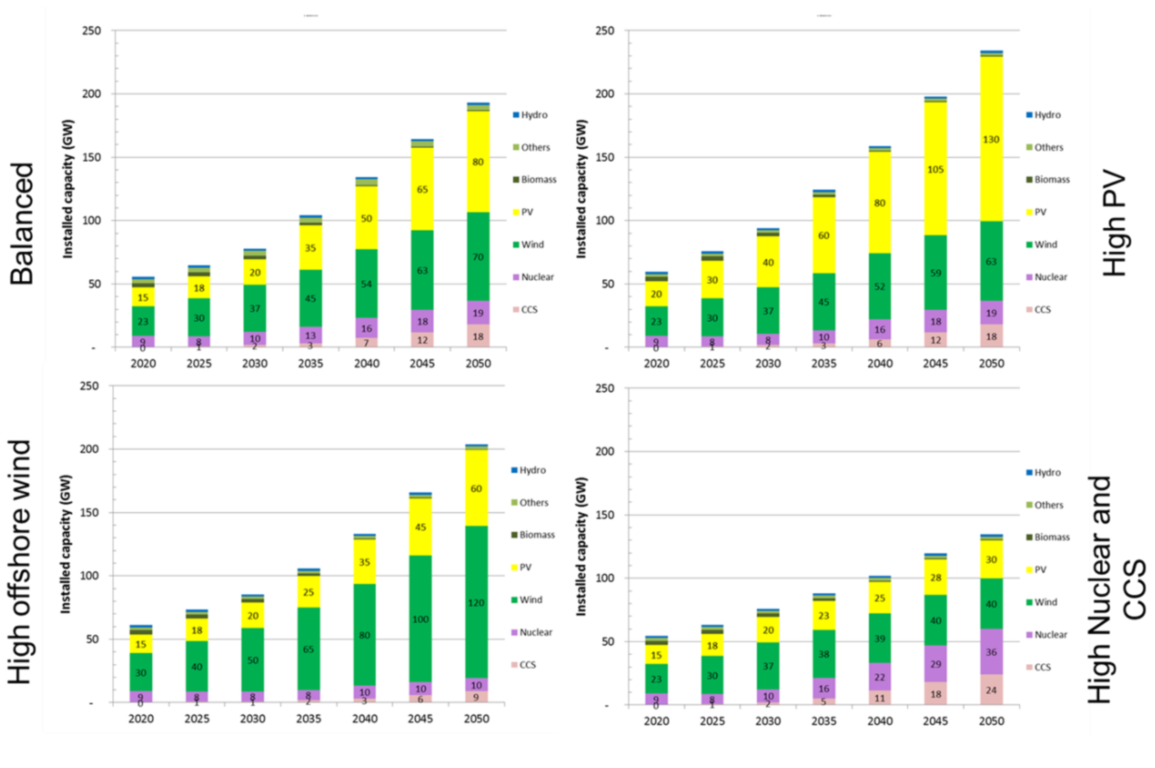
A.2 Modelled scenarios

Four scenarios have been developed and analysed in this study include:

- **Balanced scenario:** assumes balanced development across different low-carbon technologies (i.e. nuclear, CCS and renewables). The scenario is based on the extrapolation of the CCC power sector scenarios.[45]
- **High PV scenario:** assumes a large deployment of PV which significantly exceeds the development of other low-carbon technologies. This would be facilitated by a rapid decrease in the cost of solar cells, massive technology development in this area, and incentives given to the PV industry to stimulate significant growth.
- **High offshore wind scenario:** as the UK has one of the best wind sources in the world, this scenario reflects extensive exploitation of this large energy potential for decarbonisation of the UK electricity industry.
- **High nuclear and CCS scenario:** assumes that the future decarbonisation of the system will depend on the energy production primarily from nuclear and CCS.

Figure 31 shows the projected installed capacity of different low-carbon technologies between 2020 and 2050 in each scenario.

Figure 31 – Capacity of low-carbon generation technologies in different scenarios



[45] Power sector scenarios for the fifth carbon budget, The Committee on Climate Change (UK), October 2015

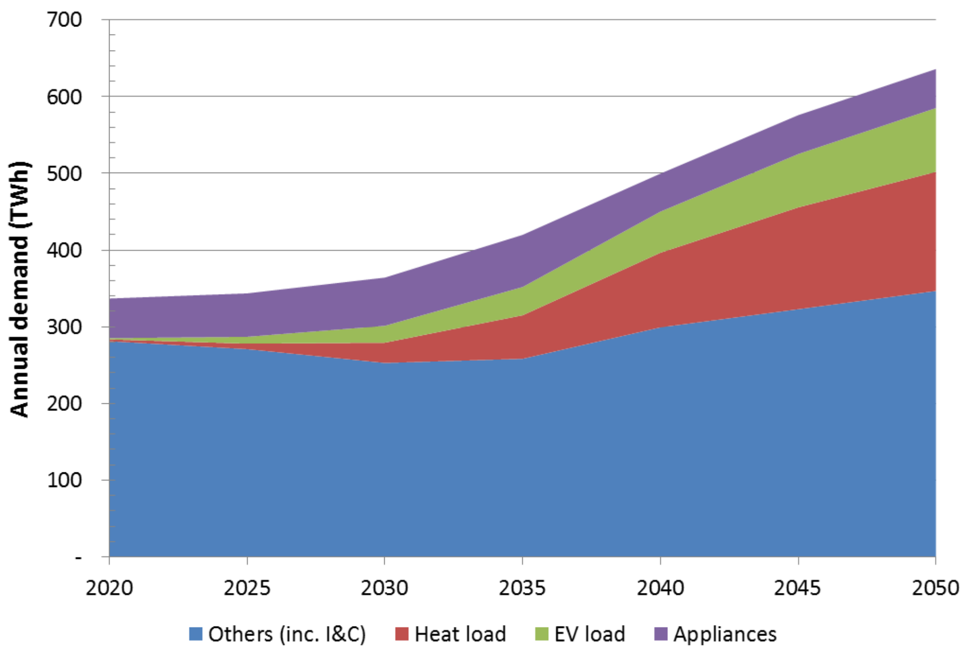
A.3 Modelling inputs and assumptions

A.3.1 Electricity demand

It is envisaged that heat and transport sector decarbonisation by electrification will substantially increase electricity demand in the future. Through our bottom-up modelling of heat and transport demand, the projected growth of the overall annual electricity demand is determined as shown in Figure 32. Our demand projection has considered the increased energy efficiency in all sectors. During this 30 years period, the load will grow almost double from around 340 TWh to 640 TWh.

The net increase in the future electricity demand is primarily driven by the electrification of heat and transport sectors; while the net demand growth in other types of loads is relatively limited. By 2050, electricity demand attributed to heat and transport sectors will reach about 35% of the overall annual electricity demand.

Figure 32 – Electricity demand growth

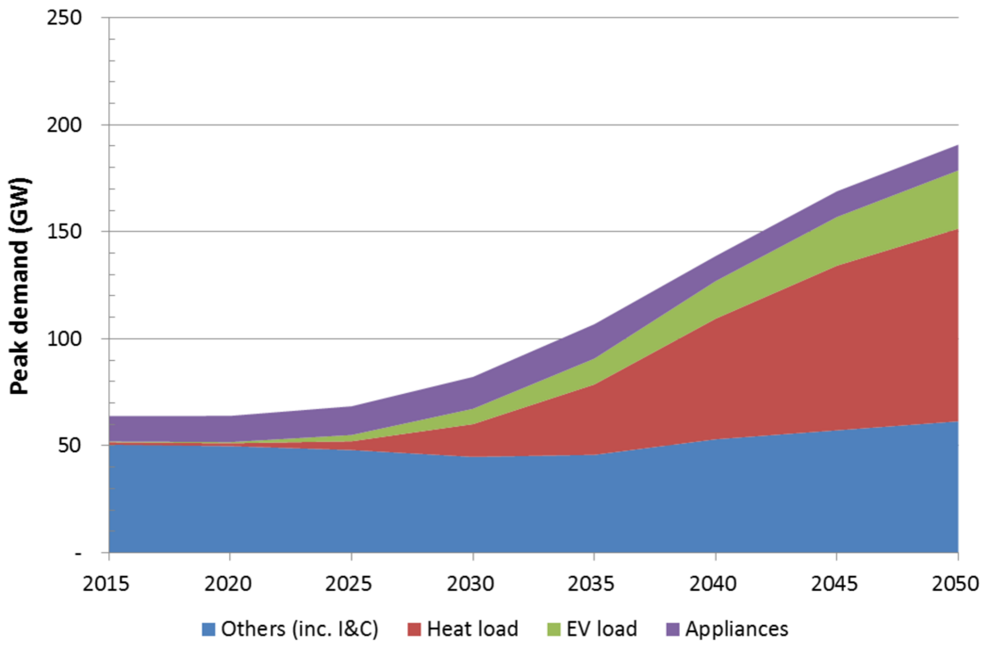


Source: Imperial's analysis of the CCC scenarios

The projected growth in peak electricity demand between 2020 and 2030 is shown in Figure 33. Since the load factor of electric vehicles and heat pumps are relatively low compared to the other demand types, and the peak load of these technologies potentially coincides with the UK peak demand periods, the inclusion of those technologies will increase the peak of electricity load significantly.

The peak demand, without demand side response, will increase about three times from 60 GW today to around 180 GW in 2050. As the rate of growth in peak demand (without DSR) is higher than the rate of growth in annual electricity demand, the average load factor will decrease. Therefore, the utilisation factor of the assets (generation and networks) will reduce indicating a reduction in the investment efficiency.

Figure 33 – Increased peak of electricity demand (without DSR)



Source: Imperial's analysis of the CCC scenarios

A.3.2 Demand side response

It is expected that new electricity demand categories such as electrified heating or transport will play an increasingly important role in decarbonising the energy sector. Based on our understanding of specific features of these demand sectors, and have developed detailed bottom-up models to produce hourly demand profiles employing large databases of transport behaviour and building stock data.

Understanding characteristics of the flexible demand and quantifying the flexibility they can potentially offer to the system is vital to establishing its economic value of DSR.[46] In order to offer flexibility, controlled devices (or appliances) must have access to some form of storage when rescheduling their operation (e.g. thermal, chemical or mechanical energy, or storage of intermediate products). Load reduction periods are followed or preceded by load recovery, which is a function of the type of interrupted process and the type of storage. This, in turn, requires bottom-up modelling of each individual demand side technology to simulate actual service functions while exploiting their flexibility without compromising the service that it delivers. In our analysis, we consider various types of flexible demand.[47,48,49,50,51,52,53,54]

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46 Demand side management: Benefits and challenges, G. Strbac, Energy Policy, Vol: 36, pp. 4419-4426, Dec 2008

47 Efficient System Integration of Wind Generation through Smart Charging of Electric Vehicles, M. Aunedi, G. Strbac, 8th *International Conference and Exhibition on Ecological Vehicles and Renewable Energies (EVER)*, Monte Carlo, March 2013

48 Benefits of Advanced Smart Metering for Demand Response based Control of Distribution Networks", ENA, SEDG, Imperial College, April 2010. Available at: http://www.energynetworks.org/modx/assets/files/electricity/futures/smart_meters/Smart_Metering_Benerfits_Summary_ENASEDGImperial_100409.pdf

The following assumptions regarding demand side flexibility are made in the system modelling analysis:[55]

- electric vehicles: up to 80% of EV demand could be shifted away from a given hour to other times of day;
- heat pumps: heat storage enables that the 35% of HP demand can be shifted from a given hour to other times of day;
- smart appliances: demand attributed to white appliances (washing machines, dishwashers, tumble dryers) participating in smart operation can be fully shifted away from peak;
- industrial and commercial (I&C) demand: 10% of the demand of I&C customers participating in DSR schemes can be redistributed; and
- daily consumption: the modelling assumes that the demand side response will not change the daily energy consumption.

In addition to improving energy management and potentially reducing generation and network capacity requirements due to reduced peak demand, these flexible demand sources are also assumed to be capable of providing ancillary services – for example: smart fridges can provide frequency regulation as it detects the frequency deviation and reduces the load when the frequency is low as long as the temperature in the fridge is still within the permissible limits. Electric vehicles can also temporarily interrupt their charging if the system frequency is low. This simple control mechanism can provide substantial frequency response services to the system at low costs. As the frequency of the events that trigger the utilisation of this service is relatively low, and the duration of having low frequency is relatively short because the system operator will restore the system frequency back to nominal levels within minutes, this will not substantially change the daily operation of the flexible load devices.

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49 Investigation of the Impact of Electrifying Transport and Heat Sectors on the UK Distribution Networks, C.K. Gan, M. Aunedi, V. Stanojevic, G. Strbac and D. Openshaw, *21st International Conference on Electricity Distribution (CIRED)*, Frankfurt, Germany, 6-9 June 2011

50 Smart control for minimizing distribution network reinforcement cost due to electrification", D. Pudjianto, P. Djapic, M. Aunedi, C. K. Gan, G. Strbac, S. Huang, D. Infield, Energy Policy, Vol. 52, pp. 76-84, January 2013

51 Value of Smart Appliances in System Balancing, Part I of Deliverable 4.4 of Smart-A project (No. EIE/06/185//SI2.447477), Imperial College London, September 2009

52 Economic and Environmental Benefits of Dynamic Demand in Providing Frequency Regulation, M. Aunedi, P. A. Kountouriotis, J. E. Ortega Calderon, D. Angeli, G. Strbac, IEEE Transactions on Smart Grid, vol. 4, pp. 2036-2048, December 2013

53 Distributed generation and demand response services for the smart distribution network, M. Woolf, T. Ustinova, E. Ortega, H. O'Brien, P. Djapic, G. Strbac, Report A7 for the "Low Carbon London" LCNF project, Imperial College London, 2014.

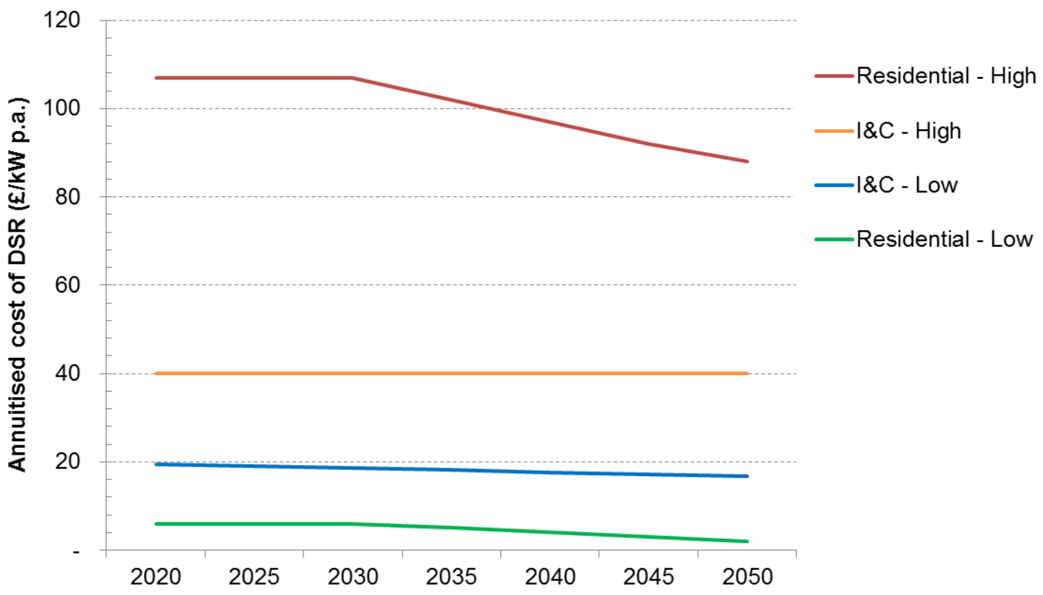
54 Understanding the Balancing Challenge, analysis commissioned by DECC, Imperial College and NERA Consulting, 2012 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48553/5767-understanding-the-balancing-challenge.pdf

55 An overview of the rationale and evidence behind these assumptions is provided in 'Carbon impact of smart distribution networks', M. Aunedi, F. Teng, G. Strbac, Report D6 for the "Low Carbon London" LCNF project, December 2014

The magnitude of demand (and therefore the amount of demand that can be shifted) in each of the above categories changes over time (i.e. it is time-specific). In our analysis the demand shifting is modelled to occur within the timeframe of one day, i.e. no demand shifting over longer time horizons.

There is a large uncertainty in the future cost of demand side response especially for the residential customers. For example, the low cost projection in 2030 for the residential DSR is around £6/kW, while the high cost projections reach to £107/kW. For the I&C sector DSR, the low to high cost estimates vary between £19 and £40/kW of contracted capacity. This uncertainty is primarily driven by the customer acceptance for allowing their electricity load profiles to be adjusted to support the system needs. For this study, we use the projected cost of DSR, as depicted in Figure 34, developed by Carbon Trust; the same data were used in the recent work by Imperial College for the BEIS report.[56]

Figure 34 – Cost of demand side response assumed in the modelling analysis



Source: Imperial's modelling analysis

The cost of the residential DSR is applied to the DSR capacity contracted from the residential loads, i.e. smart appliances, electric vehicles, and flexible heating systems. While the cost of I&C sector DSR is applied to the (generic) capacity procured from the industrial and commercial customers.

56 An analysis of electricity system flexibility for Great Britain, D. Sanders, A. Hart, M. Ravishankar, G. Strbac, M. Aunedi, D. Pudjianto, and J. Brunert, Carbon Trust and Imperial College London, 2016

A.3.3 GB network system and cross-border interconnection

The system used for the study consists of Great Britain (GB) electricity system interconnected with Ireland, Norway and few other regions in the continental Europe. The GB electricity system was modelled using five following regions[57]:

- Scotland;
- Northern England and Wales;
- Midlands;
- South England and Wales; and
- London (embedded within South England in terms of transmission grid).

Given that the GB transmission network is characterised by North-South power flows, it was considered appropriate to represent the GB system using the above mentioned five key regions and their boundaries, while considering London as a separate zone.

The two neighbouring systems, Ireland, and Continental Europe (CE)[58] are considered. ENTSO-E[59] data and other publicly available data were used to construct the generation and demand backgrounds for the CE and Ireland systems. It is important to note that the approach used in the WeSIM model optimises the operation of the entire European system, including seasonal optimisation of hydro energy in Scandinavia, pump storage schemes across CE and DSR across CE.

Currently, there exists 4GW of interconnector capacity listed as below:

- 2GW to France (IFA);
- 1GW to the Netherlands (BritNed);
- 500MW to Northern Ireland (Moyle); and
- 500MW to the Republic of Ireland (East West).

The study also considers the planned development of the GB interconnectors, e.g. additional 1 GW capacity between GB and France (IFA2) by 2020, 1GW new link to Belgium (NEMO) by 2019 and the 1.4 GW GB-Norway(NSN) by 2020. Other potential interconnector developments are captured as part of the optimisation process in the model.

A.3.4 Technical and cost characteristics of modelled technologies

Flexibility related technical characteristics of thermal generation technologies as applied in this modelling analysis are provided in Table 5. These include Minimum Stable Generation (MSG), the response slope, the maximum response capability, ramping up and down capability, and minimum up and down time of different generating technologies.

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57 Value of Flexibility in a Decarbonised Grid and System Externalities of Low-Carbon Generation Technologies, G. Strbac, M. Aunedi, D. Pudjianto, F. Teng, P. Djapic, R. Druce, A. Carmel and K. Borkowski, Imperial College and NERA Economic Consulting, 2015

58 CE is an equivalent representation of the entire interconnected European system.

59 ENTSO-E Ten Year Network Development Plan 2016: 2020 scenario Expected Progress and the 2030 Vision 3 scenario (National Green Transition).

Higher flexibility can be achieved by having a lower MSG, higher response slope, higher response max, higher ramping capability and a lower minimum up and down time of the generator.

The response slope of a generator represents the ratio of the frequency response that can be delivered to the capacity being unloaded. For example, for low flexible gas, the response slope value of 0.4 means that by unloading 1 MW, the generator can deliver 0.4 MW frequency response. There is a maximum bound for the frequency response is determined by the "Response max" parameter.

Table 5 – Dynamic parameters of thermal generators

Technology	MSG (% of rating)	Response slope	Response max (% of rating)	Ramp up (% of rating/h)	Ramp down (% of rating/h)	Min up time (h)	Min down time (h)
Coal	35%	1.00	5%	60%	60%	4	4
CCGT (LF)	50%	0.40	17%	60%	60%	4	4
CCGT (HF)	50%	0.85	17%	60%	60%	4	4
Coal based CCS	40%	1.00	5%	50%	50%	4	4
Gas based CCS	50%	0.50	10%	50%	50%	4	4
Nuclear (LF)	80%	-	0%	10%	10%	24	24
Nuclear(HF)	60%	-	0%	10%	10%	24	24
Peaking(gas)	40%	1.00	40%	100%	100%	0	0
Peaking(oil)	40%	1.00	40%	100%	100%	0	0

LF = low flexible, HF = high flexible

In addition to the technical parameters, the investment costs of different thermal generation technologies as applied in this study are provided in Table 6.

Table 6 – Thermal generation investment costs (real 2015 money)

Technology	CAPEX (£/kW)	Annuitised CAPEX(£/kW/yr)	Annual fixed cost (£/kW/yr)
Coal	2,139.63	168.53	58.55
CCGT (LF)	701.66	58.55	30.79
CCGT (HF)	736.74	61.48	32.33
Coal CCS	4,109.25	510.29	79.81
Gas CCS	1,794.99	226.62	34.09
Nuclear (LF)	7,327.85	638.51	82.76
Nuclear (HF)	7,694.24	670.43	86.9
Peaking(gas)	372.69	31.1	14.28
Peaking(oil)	1,904.77	144.38	41.91

Source: Imperial's modelling analysis

We assume that the Capex of high flexible generation is 5% higher than the Capex of low flexible generation. The capacity of the thermal generators including CCS technologies is optimised, i.e. minimisation of the overall system costs subject to system security and carbon target constraints. The capacity of other generation technologies such as renewables is pre-defined according to the CCC scenarios.[60]

Two types of generic storage facilities, bulk and distributed, were considered in the modelling analysis. Table 7 and Table 8 provide the technical and cost parameters for the bulk and distributed storage systems respectively as applied in this study.

Table 7 – Summary of modelling assumptions for bulk storage

Component	Unit	2015	2030
Capex (high)	£/kW	1,727	1,879
Capex (low)	£/kW	673	673
Fixed Opex	£/kW/year	6.1	6.1
Variable Opex	£/MWh	0.7	0.7
Cycle efficiency	%	81	81
Duration	Hours	12	12
Lifetime*	Years	N/A	N/A

*The annual fixed Opex is assumed to maintain the asset in perpetuity

All monetary values are in real 2015 money

Table 8 – Summary of modelling assumptions for distributed storage*

Component	Unit	2015	2030
Capex (high)	£/kW	1,318	1,130
Capex (low)	£/kW	897	616
Fixed Opex	£/kW/year	4.3	4.3
Variable Opex	£/MWh	0.8	0.8
Cycle efficiency	%	90	90
Duration	Hours	2	2
Lifetime**	Years	5	5

*Based on a basket of lithium ion battery technology

**The annual fixed Opex is assumed to maintain the asset in perpetuity

All monetary values are in real 2015 money

60 Power sector scenarios for the fifth carbon budget, The Committee on Climate Change (UK), October 2015

All technical and cost data applied in this study is sourced from a recent study conducted by Imperial College and Carbon Trust.[61]

A.3.5 Other key assumptions

In this study the following assumptions regarding the GB electricity system were modelled as specific constraints in the model.

- System reliability standard: a reliability criterion of Loss of Load Expectation (LOLE) being less than 3 hours per year is applied.
- A self-sufficient system: i.e. there is no contribution from other regions to the capacity margin in the UK and vice versa in order to maintain the LOLE criterion.
- An energy-neutral system: this means that the net annual energy import / export is zero. This allows UK to import power from and export to Europe / Ireland as long as the annual net balance is zero. In other words, the UK is still able to export power when there is excess in energy available, for example when high wind conditions coincide with low demand, and import energy from Europe when economically efficient e.g. during low-wind conditions in UK.

A.4 Overview of the methodology for whole-system analysis of electricity systems

In order to carry out this study, we use the *Whole-electricity System Investment Model* (WeSIM) developed by Imperial College, which is specifically designed to perform this type of analysis. WeSIM has been extensively tested in previous projects studying the interconnected electricity systems of the UK and the rest of Europe.[62]

WeSIM simultaneously optimises system operation decisions and capacity additions to the system, while taking account of the trade-offs of using alternative measures, such as DSR and storage, for real-time balancing and transmission and distribution network and/or generation reinforcement. For example, the model captures potential conflicts and synergies between different applications of distributed storage in supporting intermittency management at the national level and reducing necessary reinforcements in the local distribution network.

The optimal decisions for investing into generation, network and/or storage capacity (both in terms of volume and location) are based on modelling the real-time supply-demand balance in an economically optimal way while ensuring security of supply. Capturing the interactions across different time scales and across different asset types is essential for the analysis of future low-carbon electricity systems that include alternative balancing technologies such as storage and demand side response. Applications of these technologies may improve the economics of real time system operation as well as reduce

61 An analysis of electricity system flexibility for Great Britain, Carbon Trust and Imperial College, November 2016

62 WeSIM model, in various forms, has been used in a number of recent European projects to quantify the system infrastructure requirements and operation cost of integrating large amounts of renewable electricity in Europe. The projects include: (i) “Roadmap 2050: A Practical Guide to a Prosperous, Low Carbon Europe” and (ii)“Power Perspective 2030: On the Road to a Decarbonised Power Sector”, both funded by European Climate Foundation (ECF); (iii) “The revision of the Trans-European Energy Network Policy (TEN-E)” funded by the European Commission; and (iv) “Infrastructure Roadmap for Energy Networks in Europe (IRENE-40)” funded by the European Commission within the FP7 programme.

the investment into generation and network capacity in the long-run, as captured in the integrated modelling framework of WeSIM.

Our approach to quantifying the value of flexible balancing technologies considers total system costs (including both investment and operation) for a given generation and demand scenario. It compares various types of system costs between two cases: (a) the case when the model is allowed to add new capacity of alternative flexibility technologies (such as interconnection, flexible generation, storage or DSR) in a cost-optimal manner; and (b) the case where no such addition is allowed in the system i.e. only conventional flexibility solutions (fossil fuel based generation) is allowed. The difference (i.e. reduction) in the total system cost between the two cases, as a result of deploying flexible balancing technologies, is interpreted as the value generated by these technologies.

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ANNEX B – FLEXIBILITY SERVICES AND TECHNOLOGIES

This annex provides a review of the flexibility services that are currently utilised by the system operator in GB. We have also analysed how improvements in various technologies in the future can change this services-technology mapping.

B.1 Flexibility services procured under current arrangements

Table 9 summarises the balancing services managed by the GB system operator (National Grid)[63]. These balancing services are procured from the independent power producers or other flexibility service providers in order to balance demand and supply while maintaining the security and quality of electricity supply across the system.

At the distribution level, the commercial framework for distributed generation, storage, and DSR to support the operation of the distribution system under Active Network Management scheme has not been developed as complex as at the transmission level. The commercial agreement is still largely in the form of bilateral contract between the utility and the service providers or the aggregators. In the distribution system, the focus of the services is normally on the voltage and flow management by adjusting the output of Distributed Energy Resources to minimise the requirement to increase distribution system capacity.

Table 9 – System balancing services

Abbreviation	Balancing services	Definition
BMSU	BM Start-up	Access to additional generation BMUs that would not otherwise have run, and which could not be made available in Balancing Mechanism timescales.
BS	Black Start	The capability to recover from a total or partial shutdown of the GB Transmission System which has caused an extensive loss of supplies.
CBR	Contingency Balancing Reserve	DSBR is targeted at large energy users who volunteer to reduce their demand. SBR is targeted at keeping power stations in reserve that would otherwise be closed or mothballed.
DTU	Demand Turn Up	Enable demand side providers to increase demand (either through shifting consumption or reducing embedded generation) as an economic solution to managing excess renewable generation when demand is low.
EFR	Enhanced Frequency Response	A new service to achieve 100% active power output at 1 second (or less) of registering a frequency deviation.
EOSTOR	Enhanced Optional STOR	Additional STOR Service from non-BM Providers on a trial basis for this winter.
ERPS	Enhanced Reactive Power Services	A market based provision of voltage support which exceeds the minimum technical requirement of the Obligatory Reactive Power Service.
FCDM	Frequency Control by	Frequency response provision through interruption of

63 Source: National Grid, available at: http://www2.nationalgrid.com/uk/services/balancing-services/

Abbreviation	Balancing services	Definition
	Demand Management	demand customers
FFR	Firm Frequency Response	The firm provision of Dynamic or Non-Dynamic Response to changes in Frequency.
FFR-BC	FFR Bridging Contract	Enabling smaller parties a route to access the FFR tendered market.
FR	Fast Reserve	Fast Reserve provides the rapid and reliable delivery of active power through an increased output from generation or demand reduction, following receipt of an electronic despatch instruction from National Grid.
Ittr	Intertrips	Automatic control arrangement where generation may be reduced or completely disconnected following a system fault event.
MFR	Mandatory Frequency Response	An automatic change in active power output in response to a frequency change and is a Grid Code requirement.
MG	Maximum Generation	Access to capacity which is outside of Generator's normal operating range during emergency circumstances.
ORPS	Obligatory Reactive Power Service	The provision of mandatory variation in Reactive Power output.
SO-SO	SO to SO	Services that are provided mutually with other Transmission System Operators connected to the GB Transmission System via interconnectors.
STOR	Short Term Operating Reserve	Short Term Operating Reserve (STOR) is a service for the provision of additional active power from generation and/or demand reduction.
STORR	STOR Runway	A contracting opportunity for Demand Side Response providers to support additional reserve volume in to the STOR market.
TCM	Transmission Constraint Management	Management of power flow across the network due to thermal, voltage constraints taking to maintain network security.

B.2 Mapping flexibility technologies to existing flexibility services

We have analysed the improvements in the technical characteristics of flexibility providing technologies that will enable them to provide significantly more services in the future. Table 10 summarises the types of potential improvement across technologies and maps them to the various relevant balancing services.

Table 10 – Potential flexibility improvement mapped to the relevant balancing services

Sources of flexibility	Potential improvement in the flexibility	Flexibility services	Current status of technology
Thermal generation			
- gas fired CCGT and coal/gas fired CCGT with CCS	Lower minimum stable generation	BMSU, EFR,ERPS,FFR,FR,MG,ORPS,STOR,TCM	Under development and demonstration of highly flexible plant
	Shorter minimum up and down time		
	Faster start-up and shorter synchronisation time		
	Enhanced reactive power capability		

Sources of flexibility	Potential improvement in the flexibility	Flexibility services	Current status of technology
Wind power			
	Provision of synthetic inertia	FFR, MFR, STOR (when curtailed), ORPS, Ittr	Early commercialisation
	Voltage control and reactive power sources		Early commercialisation
	Fault-ride through capability		Fully commercialised
	Intertripping scheme		Fully commercialised
Solar PV			
	Smart PV inverter	FFR, MFR, STOR (when curtailed), ORPS, Ittr (at transmission and distribution)	Fully commercialised
	Voltage control and reactive power management		Early commercialisation
	Intertripping scheme		Fully commercialised
Demand Side Response			
Industrial and Commercial Load (HVAC, interruptible load, back-up DG)	A combined load management with ancillary services to provide multiple services which include: - Interuptible load - Load-shifting - Back-up capacity	BMSU, CBR, DTU,FCDM ,FR, STOR, STORR, TCM	Fully commercialised
Electric vehicles	Load-shifting, interruptible load (in charging mode),	DTU, FCDM, STOR	Early commercialisation
	Vehicle to Grid (V2G)		Demonstration
Smart fridges	Frequency sensitive operation	MFR	Early commercialisation
Washing machine, tumble dryer, dishwasher	Load-shifting	DTU	Early commercialisation
Heat pump with heat storage	Load-shifting, interruptible load	DTU, FCDM	Demonstration
Energy storage			
Bulk storage, e.g. Pumped Hydro Energy Storage (PHES), CAES, batteries, flywheels	Energy arbitrage as well as multiple types of ancillary services.	EFR, ERPS, FFR, Fast Reserve, MFR, ORPS,STOR,TCM	Early to full commercialisation
Distributed storage, e.g. CAES, batteries, hybrid storage (heat and electricity)	- Primary and secondary frequency response (in both charging and discharging modes).		Early to full commercialisation (hybrid storage at demonstration level)
	- Reserves		
	- Services for network congestion management and network security		
	- Back-up capacity		
	- Voltage control and reactive power management		

Source: Imperial's analysis

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ANNEX C – FIRST STAKEHOLDER WORKSHOP

(09 January 2017, London)

C.1 Introduction

This first stakeholder workshop was focused on identifying the barriers to deployment of different types of flexibility options and developing ideas on actions to address these barriers.

The workshop participants identified a number of barriers to the full deployment of flexibility services in the GB electricity system. This was followed by prioritising the identified barriers and developing actions to address the prioritised barriers. The barriers identified in the workshop are grouped into the following four categories:

- policy and regulatory barriers;
- market and commercial barriers;
- consumers related barriers; and
- technical barriers.

Some of the identified barriers fall into one or other category therefore, some overlap or repetition of barriers exists in the below provided details on the identified barriers.

C.2 Workshop participants

The following table provides names of the participating organisations and their representatives in the first workshop.

Organisation	Representative	Organisation	Representative
AES Energy Storage	*Claire Addison*	*National Grid (UK)*	*Paul Lowbridge*
Committee on Climate Change	*Eric Ling*	*Pöyry Management Consulting*	*Gareth Davies*
Committee on Climate Change	*Mike Thompson*	*Pöyry Management Consulting*	*Anser Shakoor*
Committee on Climate Change	*Mike Hemsley*	*Pöyry Management Consulting*	*Benedikt Unger*
EDF Energy	*Guy Buckenham*	*Renewables UK*	*Gordon Edge*
EDF Energy	*Andrew Jones*	*Renewable Energy Systems*	*John Prendergast*
Electricity Storage Network	*Zoltan Zavody*	*Scottish power*	*Stuart Noble*
Energy UK	*Rosie McGlynn*	*SP Energy Networks*	*Geoff Murphy*
Eon UK	*Laurence Barrett*	*UK Power Network*	*Sotiris Georgiopoulos*
Imperial College London	*Goran Strbac*	*UK Power Reserve Ltd*	*Janine Freeman*
Infinis Limited	*Jon Crouch*	*Western Power*	*Roger D. Hey*

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ANNEX D – SECOND STAKEHOLDER WORKSHOP

(08 February 2017, London)

D.1 Introduction

The second stakeholder workshop tested the draft flexibility roadmap with stakeholders by presenting the future flexibility requirements and discussing the actions for facilitating provision of enhanced flexibility out to 2030.

D.2 Workshop participants

The following table provides names of the participating organisations and their representatives in the second workshop.

Organisation	Representative	Organisation	Representative
AES Energy Storage	*Claire Addison*	*National Infrastructure Commission*	*Katie Black*
Committee on Climate Change	*Eric Ling*	*Origami Energy Limited*	*Alex Howard*
Committee on Climate Change	*Mike Thompson*	*Pöyry Management Consulting*	*Gareth Davies*
Committee on Climate Change	*Mike Hemsley*	*Pöyry Management Consulting*	*Anser Shakoor*
Drax Power Limited	*Ian Foy*	*Renewables UK*	*Caroline Bragg*
EDF Energy	*Guy Buckenham*	*Renewable Energy Association (RES)*	*Frank Gordon*
Electricity Storage Network	*Zoltan Zavody*	*RWE/Npower UK*	*Ben Willis*
Energy UK	*Rosie McGlynn*	*Tempus Energy*	*Sara Bell*
Flextricity	*Jill Cox*	*UK Power Network*	*Sotiris Georgiopoulos*
Imperial College London	*Goran Strbac*	*Upside Energy*	*Graham Oakes*
National Grid (UK)	*Paul Lowbridge*		

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