IET The Institution of Engineering and Technology

CATAPULT Energy Systems

Future Power System Architecture

A report commissioned by the Department of Energy & Climate Change

3. International Study

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The Future Power System Architecture (FPSA) project was commissioned by the Department of Energy & Climate Change (DECC) and undertaken through a collaboration between the Institution of Engineering and Technology (IET) and the Energy Systems Catapult.

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

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

About the Institution of Engineering and Technology

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

The IET is working to engineer a better world by inspiring, informing and influencing its members, engineers and technicians, and all those who are touched by, or touch, the work of engineers.

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About the Energy Systems Catapult

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

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

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Executive Summary

The purpose of this international fact-finding study is to explore electrical power systems in other countries that are known to be facing similar system challenges to those we might envisage in future impacting the national GB power system. It is not the purpose of this study to advocate approaches adopted in other countries, or to recommend if, or how, initiatives or policies adopted for their electricity power systems should be applied to the GB system. Rather, the purpose of the study is to:

- Provide evidence of challenges currently being faced, or anticipated, elsewhere.
- Discover how the relevant industry players and authorities in those countries are addressing or proposing to address those challenges.
- Identify initiatives and policies that might be particularly relevant to the GB context.

In conducting this study, care has been taken to establish contact with reliable sources of information within the countries studied and to ensure that the findings documented in this report are factually accurate. By way of further assurance, peer reviews of the findings have been conducted where practicable.

The Future Power System Architecture Project has used the findings of this study to inform its evidence base for justifying requirements and options for future electrical power system functions.

The study has looked at the main system level challenges facing the electrical power sectors of Germany, Ireland and regions of the US (with a high level desktop study on South Korea). They correlate strongly with those facing the GB system, namely around:

- Integration of large renewable generation sources (and a corresponding reduction in system inertia).
- The growth in distribution-connected energy resources (distributed generation, electric vehicles, heat pumps, demand side response, energy storage).
- The trend towards microgrids, community energy systems and engaged customers.
- Greater interconnection with neighbouring grids, both alternating and direct current (AC and DC) technologies.

It is widely recognised that the effects of these represent both threats and opportunities to the successful planning and operation of the respective power systems. The potential scale of the changes and their materiality has led to greater system-wide thinking for those power systems from both technical and policy perspectives.

It is evident that a business-as-usual approach has been discounted as each of the countries (or regions in the case of the US) has developed new thinking to meet these challenges. They vary from a highly collaborative working forum with strong governance (Ireland) through to a radical overhaul of regulatory frameworks and markets (New York). Germany and other regions in the US are taking a broader systems-wide perspective to identify areas where roles and responsibilities need to evolve to meet these challenges.

These approaches are highlighting new functions required and identifying those that need to be significantly enhanced. For example, in New York a formal Distribution System Operator function is being created whereas California's Distribution Resource Plan (DRP) calls for a significantly enhanced distribution planning function that forecasts and models distributed energy resources for inclusion in long term planning. All share the same purpose: to ensure their electrical power system remains resilient while incorporating technology evolution and maximising clean energy resources.

The key messages from this International Study are that:

- The challenges faced by the GB electricity sector are similar to those faced in the other countries reviewed. However, none of them face all of them to a similar extent if we assume National Grid's Gone Green scenario. For many varied reasons, not all of these challenges appear in any particular country to the same extent. This indicates that the scale of the change anticipated on the GB system is greater and potentially poses a greater co-ordination and integration challenge.
- Many experts consulted expressed the need for greater system wide planning and indicated that they believed the scale of changes anticipated represented a real risk to system resilience and reliability if not fully co-ordinated. Equally, the value that Distributed Energy Resources (DERs) can bring is being accepted. Policies in the countries reviewed are aimed at promoting and encouraging the adoption of DERs.
- This review has identified a number of significant change programmes happening in these countries to meet these challenges. The approaches are varied, though all are pro-active and consistent in aiming to incorporate the challenges identified into their power systems. There is no evidence of inaction.
- There is evidence of greater central co-ordination and planning in the countries examined to ensure that system security is preserved and the value of DERs is fully realised. In California and New York greater co-ordination is coming from the Independent System Operators (ISO) and Public Service Commissions. In Ireland it is through a system operator/transmission owner (SO/TO) led, cross-industry working group.
- Distribution systems are highlighted as facing the greatest challenges in defining and implementing comprehensive distribution management systems. In addition, these will need to integrate with ISO systems, home area networks (HAN), microgrid controllers, supervisory control and data acquisition (SCADA) systems and market mechanisms to name a few. While many of these have their own well developed architectures and defined interfaces, there is an absence of a system-of-systems overview. This is beginning to be actively discussed, with the Pacific Northwest National Laboratory (PNNL)[1] and the Electric Power Research Institute (EPRI)[2] both being cited as thought leaders.
- There are many new functions that are being developed across the sectors that will need to be incorporated, either into existing functions or through developing new ones. Examples include modelling of DERs, interconnection rules and standards, situational awareness, data exchange and common information models.

[1] Pacific Northwest National Laboratory (http://www.pnnl.gov/)
[2] Electric Power Research Institute (http://www.epri.com)

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1. Background and Purpose

The Institution of Engineering and Technology (IET), the Energy Systems Catapult and the Department of Energy & Climate Change (DECC) have together delivered the Future Power Systems Architecture (FPSA) project to "set out, and provide evidence for, what functions will need to be performed in the future power system as a result of its on-going transformative change, and by when". As part of this, research has been carried out on electricity supply industries from other countries, with the following questions in mind:

- What specific current and future system planning and operational challenges in other countries are relevant and comparable to those in GB?
- Do these challenges require (i.e. in the view of the each country) functional changes in planning and operational practices?
- If so, how are these functional changes being conceived, introduced and managed?

The countries chosen for initial analysis by the Project Steering Group include Ireland, Germany and the United States (California and New York) as the power system challenges in these countries are believed to be sufficiently similar given, for example:

- That they all have stretching renewable targets and there has been notable deployment in their power sectors (and they have seen early effects of the change in generation mix, for example lack of inertia and system control issues).
- There have been notable technology deployments at scales greater than that seen on the GB system and therefore it is believed that there may be some key learnings and advanced thinking around system development.
- They share a similar energy policy in that balancing renewable targets, security of supply and affordability are cornerstones of their policies.
- At a high level, they have similar market structures in that there are levels of competition at various points in the sector, most networks are covered by regulatory frameworks, there is a system operator, there is an active balancing market and there is a degree of separation in retail markets.

Many other countries are also facing similar challenges in their power sectors and are probably developing various approaches to address them. It is beyond the scope of this study, within the timeframe and resource constraints, to review other countries in detail. However, a short summary on South Korea is included as the Jeju Island project is considered one of Asia's leading projects. The purpose of this high level review is to identify aspects of system planning and co-ordination that appear to be taking place to help those countries with the development of their electricity systems to meet future needs. This study has been prepared from desktop research and conversations with a number of experts in the various countries reviewed.

2. Comparable Current and Future System Planning and Operational Challenges Relevant to GB

A number of transformational technologies are approaching commercialisation and either are, or likely to be, deployed at scale on the GB network over the next decade or so. These include:

- Distributed generation (primarily photovoltaic (PV) and wind, but also biomass, gasification, anaerobic digestion, micro and small combined heat and power (CHP)).
- Heat pumps to support the drive towards decarbonising heat.
- Plug-in hybrid and electric vehicles to decarbonise transport and improve air quality.
- Microgrids and community energy schemes promoting more autonomous local grids.
- Greater deployment of Interconnectors, partly aided by advances in high voltage direct current (HVDC) technology.
- Large scale renewable deployment which decreases volumes of synchronous plant and reduces system inertia.

Each of these in isolation offers a number of key challenges for integration into the electricity system. Combined together, their impacts are more difficult to quantify and understand. Some naturally work well together whereas others have the potential to create significant stress in the event of poor planning and assessment. Their impact is often felt across many parts of the electricity delivery network affecting different parties. Some may be incorporated as business-as-usual if deployed at relatively small scale, while others have a natural tipping point after which parts of the system will come under undue stress leading to possible failure.

None of these disruptive technologies are unique to the GB system. Some are well advanced in other countries (e.g. combined large scale wind and solar capacity being higher than peak demand on some days in Germany) whereas others have less relevance (e.g. heat pumps in California).

2.1 Germany

The German system contains a number of commercial generators, four main transmission system owners (independently owned), a single power market and approximately 890 distribution companies (mainly municipalities though four large utilities make up 25%). There are a number of interconnections to neighbouring grids and this is expected to grow.

German energy policy is characterised by the *Energiewende* or 'energy transition' which aims to cut CO2 emissions by 40% by 2020 (from 1990 levels) through renewable energy support mechanisms moving from feed-in tariffs to auctions. It also aims to phase out nuclear power by 2022. Its two pillars are renewable energy and energy efficiency. As a result Germany has the second highest residential tariffs in Europe (behind Denmark) and a number of technical issues to resolve.

Installed capacity, as of 2014 is 192GW, with wind and solar making up 72GW (38%), fossil fuel being 101GW with nuclear and others making up the balance. In terms of energy delivered, circa 24% was from renewables and 15% from nuclear. Winter peak for 2014 was 84GW. It also has 21GW of interconnection to neighbouring countries.

Germany has aggressively supported the deployment of distributed PV generation at residential and small community scale. This has been viewed as a success with PV reaching 38GWp[3] in 2014 and delivering 6.8% of Germany's net electricity consumption[4]. Transmission connected wind generation reached 36GW in 2014. Due to the climate in Germany, wind and PV tend to have an inverse correlation and total power from both rarely exceeded 30GW. The PV deployment has created local issues on distribution grids and with over frequency set to 50.2Hz, the potential existed for a mass disconnect in the event of a transient frequency event. To help address this issue a directive was issued in January 2012 to enable remote control of newly installed inverters from a grid operator to curtail power at 70% in the event of network constraint. A retrofit programme is also underway to reset trip frequencies. Both of these issues could have been addressed at the planning stage and this indicates insufficient long term planning to assess the system wide impact of widespread deployment of distributed PV. The effects of the variability of wind output are typically resolved through a competitive balancing market.

Heat pumps have not yet reached significant deployment levels largely due to their upfront cost and the difficulty of retrofitting in existing buildings. The energy policy does support their roll-out, incentives are available and large scale penetration is envisaged. Similarly, electric transportation is encouraged and supported, though to date penetration levels have been lower than European averages and are not expected to meet the stated goal of 1m vehicles by 2020. There are no purchase credits for electric vehicles (EV) or plug-in hybrid electric vehicles (PHEV), but there are tax and other social benefits available (preferred parking, access to bus lanes etc.). To date neither heat pumps nor electric vehicles have created system issues but are recognised as having the potential to do so.

[3] Germany Trade and Invest, 'Business Opportunities in Germany', 2015
[4] Recent Facts about Photovoltaics in Germany, Fraunhofer Institute, October 2015

The concept of interconnectors is well understood and the four transmission companies have carried out extensive analysis into the type and size of interconnection (and network reinforcement between themselves) required. This has been published and projects are being taken forward. These are captured within the ENTSO-E (European Network of Transmission System Operators) European Ten Year Development Plan[5]. Germany has significant interconnection (21GW in 2012) to neighbouring countries including Austria, Switzerland, Czech Republic, Denmark, France, Luxembourg, Netherlands, Poland and Sweden, primarily using AC interconnectors. Germany typically exports around 10% of its energy production annually with typically only half the available interconnector capacity being used at any given time[6]. There are plans for DC interconnectors to Norway (NordLink) and Denmark. Overall Germany is a net electricity exporter with interconnectors being viewed as means of providing reliability.

There is a large number of ‘aerial networks’ in Germany which essentially describe a form of microgrid where a local factory or housing company has sufficient onsite generation to provide power to the local community. Typically these don’t have storage or grid management systems and are MW scale. From a balancing or net energy perspective they can be described as ‘islanded’ however they all have electrical connection to the local grid. Many of these are a form of community energy system, but do not fully meet the conventional interpretation of a microgrid.

Microgrids and community energy systems at a smaller scale featuring integrated storage and grid management capable of islanding have not generated widespread interest or deployment. A small number of demonstration projects are underway to assess the feasibility and economics but significant deployment is not expected in the near term.

[5]ENSTO-E, Ten Year Network Development Plan (https://www.entsoe.eu/major-projects/ten-year-network-development-plan/ten%20year%20network%20development%20plan%202016/Pages/default.aspx#tyndp-2016-rgip)
[6]Agora Energiewende, Report on German Power System, February 2015 (http://www.agora-energiewende.de/fileadmin/Projekte/2014/CP-Deutschland/CP_Germany_update_1015_web.pdf)

2.2 United States

The electricity system in the US varies significantly from state to state. Some states maintain vertically integrated, state owned electricity systems while others are fully deregulated with the majority of the generation and networks being privately owned. There are 3 Independent System Operators (California Independent System Operator (CAISO)), Electricity Reliability Council of Texas (ERCOT) and New York Independent System Operator (NYISO) and 4 Regional Transmission Organisations (RTO), Midcontinent Independent System Operator (MISO), PJM Interconnection, Southwest Power Pool (SPP) and Independent System Operator – New England (ISO-NE). For the purposes of this report they will all be considered ISOs. Combined they cover around 60% geographically and 80% of power delivery. The ISOs are all 'not for profit' organisations.

The US system is interconnected to the Canadian grid through alternating and direct current (AC and DC) interconnections. Canadian utilities and grid operators (RTO/ISOs) closely coordinate with the US entities in regional reliability standards led by the North American Electric Reliability Corporation (NERC).

Transmission and distribution networks are owned both by private companies (circa 200) and municipalities (circa 3,000) with the former covering some 70% of the US. Some states have energy deregulation and either allow customers to choose energy suppliers or have a structure of 'rate decoupling' to separate network cost from energy costs. Each state has its own regulatory framework and approaches vary. Interstate transmission is regulated at a national level by the Federal Energy Regulatory Commission (FERC).

The majority of the states have their own renewable targets, often characterised by an RPS (Renewable Portfolio Standard), which is a regulatory mandate to increase production of energy from renewable sources such as wind, solar and biomass. It is similar to the UK Renewables Obligation Certificates.

It is helpful to bear in mind the significant scale of US activities compared with GB (GB installed capacity being circa 80GW).

New York's grid has an installed capacity of 40GW with a peak typically 34GW. There is circa 1.8GW of transmission-connected wind generation. Nuclear and hydro make up about 50% of the state's energy production. The state has an independent SO (NYISO), four large IOUs (Investor Owned Utilities: National Grid, Iberdrola, Fortis and ConEd) and a small number of municipalities.

Installed capacity in California is circa 78GW (2014 data). Natural gas comprises some 46GW with the remainder coming from nuclear and other renewables. In terms of energy demand, the state total is 198GWh with 30% of that coming from renewables and hydro, 8% nuclear and the balance primarily natural gas (circa 61%). In-state generation comes from some 1,100 plants (over 100MW). The state also has the world's 2nd and 3rd largest solar farms (580MWp and 550MWp). The vast majority of transmission and distribution is provided by six IOUs (circa 70% of the state load), the remainder is by local municipals.

New York state (NY) has seen growth in wind generation upstate and greater interconnection into Canada and the interconnected 'lakes' grid. This has created some transmission challenges as excess power flows from hydro sources into the north of the New York grid. Typically, the majority of demand in NY is in the south of the state in and around New York City. The 'Reforming the Energy Vision' (REV) proceeding, led by the state regulatory body, has placed emphasis on the creation of Distributed System Platforms (DSPs), adoption of networks capable of microgrid operation (to promote local resilience and distributed energy ownership) and encouragement of community energy systems. There are a number of microgrids in pilot phase and the changes being proposed by REV would create the framework for their acceleration and deployment. REV also encourages and promotes greater distributed generation and facilitates the role of a Distribution System Operator, conventionally known as a DSO though also referred to as a Regional System Operator across the US.

California has some of the US's most aggressive climate change targets and as a result is seeing significant deployment of renewable technologies. Both solar (5.4GW) and wind (6.1GW) have seen significant penetration and combined with geothermal, small hydro and biomass make up 30% of the state's electrical energy usage. They appear to be on target to meet the 2020 target of 33%[7]. The effects of these for the system operator (CAISO) is often described using the well-publicised 'Duck Curve'[8] which demonstrates some of challenges in managing ramp rates (rapid changes in demand and generation that are challenging to accommodate) in the future[9]. The system inertia implications of this changing generation mix have been investigated[10] and are understood and a number of programmes are looking to implement alternative solutions. Distributed generation has seen widespread growth, especially PV in the south. This is actively supported, encouraged and seen as crucial to meeting the state's carbon reduction targets. The state is supporting adoption of electric vehicles through a number of financial and non-financial schemes. In 2014, battery EV (BEV) and PHEV sales made up 3.2% of all car sales and were 47% of all BEV and PHEV sales in the US. Local grid issues have been experienced in the metro areas of San Francisco and San Diego but have been manageable. The state has some interconnectors to adjacent grids but has no plans for any significant expansion.

ERCOT (Electricity Reliability Council of Texas) and the Texas grid are also integrating significant levels of transmission connected wind generation. This is expected to continue to increase as the state moves towards achieving its renewable targets. There is some deployment of solar on the distribution system but this is not at a level that creates any notable system issues, though it is believed some local circuit issues have been encountered. To help manage the variability, Oncor (the state's largest IOU) in partnership with ERCOT commissioned analysis on the value of distributed storage, which initially looks positive[11]. The state also has an aggressive approach to promoting the adoption of electric vehicles to help meet state environmental targets and improve air quality. Many of the distribution companies are collaborating on EV charging networks.

[7] California energy commission website
[8] CAISO Fast Facts – What the Duck curve tells us about managing a green grid (https://www.caiso.com/Documents/FlexibleResourcesHelpRenewables_FastFacts.pdf)
[9] CAISO – Fast facts – what the duck curve tells us about managing a green grid
[10] NERC & CAISO, 'Maintaining Bulk Power Reliability while Integrating Variable Energy Resources- CAISO Approach (http://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC-CAISO_VG_Assessment_Final.pdf)
[11] The Value of Grid Integrated Storage in Texas, Brattle Group, November 2014 (http://www.brattle.com/system/news/pdfs/000/000/749/original/The_Value_of_Distributed_Electricity_Storage_in_Texas.pdf?1415631708)

North America comprises of two major AC 'interconnections' (Eastern and Western) and three AC minor interconnections (ERCOT (Texas), Quebec and Alaska). All of the utilities and ISOs in their respective interconnection areas are electrically connected operating at a synchronised frequency of 60Hz. The western interconnection stretches from southern Canada, through California and into Mexico. The eastern interconnection includes central and eastern Canada (except Quebec), the central states, Northeast region and south to Florida. There is limited interconnection between these 'interconnection' regions, comprising of both DC and AC links. Where HVDC is deployed in the US, it is more of a point to point transmission link than a commercial interconnector linking wholesale markets.

2.3 Ireland

The electricity system in Ireland (Republic of Ireland and Northern Ireland) is effectively state owned by the Republic of Ireland. The state owns two companies, Electricity Supply Board (ESB) and Eirgrid, which between them own the transmission, distribution and system operations in Northern Ireland. In the Republic, ownership of transmission and distribution is by ESB and system operations by Eirgrid. In Northern Ireland, ownership of transmission and distribution is by Northern Ireland Electricity (NIE) Networks and system operations by the System Operator Northern Ireland (SONI). ESB own NIE Networks and Eirgrid own SONI. Additionally there is the Single Electricity Market Operator (SEMO) and two regulators.

There are a number of commercial generators competing in a wholesale market. Total installed generating capacity is around 9GW of conventional plant and 3GW of wind generation (with about a further 4.5GW of wind in the contracted/advance planning stages). Peak demand is typically circa 6.8GW. The island is connected to the GB system through two 500MW interconnectors (with more in the planning stages, circa 2GW).

Ireland has seen significant deployment of wind generation, with output often meeting 50-60% of total system demand. This is a significant proportion by international norms, and has required close attention to operational management. In 2014, energy from renewable sources made up 21.4% of the island's (Republic and Northern Ireland) electricity generation[12]. Ireland expects to continue deploying large scale wind generation to contribute further towards meeting the 2020 targets. Electric vehicles are also seen as a cornerstone as Ireland moves to a low carbon future. A number of subsidies and rebates are available to help promote the take-up of electric transportation. Ireland's target is for 1% of all vehicle sales to be electric by 2020. The Republic of Ireland's ESB Group has a proactive and engaged approach to help its customers adopt EVs. EVs are also seen as a key tool in providing network services and as such are seen as part of the overall energy system.

Interconnection to GB and France is seen as a key tool to help balance the Irish grid. A number of interconnectors have been proposed that will most likely deliver renewable power into GB. Further linking of the Irish and GB systems is seen as a

[12] DS3 Programme (http://www.eirgridgroup.com/how-the-grid-works/ds3-programme/)

means of ensuring reliability in Ireland whilst helping the UK achieve its renewable goals through import of renewable energy. Similarly, the proposed interconnector to France will improve security of supply, enhance flexibility and increase competition in the electricity market. The current (and proposed future) interconnectors use HVDC technology. The additional functionality that VSC (Voltage Source Converters) can bring is being considered by Eirgrid.

2.4 Summary of power sector structures

The structures of the power sectors vary greatly from region to region and they all have various market designs, competition and levels of deregulation. In some scenarios this appears to make implementing solutions to the challenges a little more straightforward, though it must be said in all the regions it was expressed that the power sector structure is often a barrier to progressing integrated solutions to challenges that cut across the sector. This seems to be acknowledged as a challenge in itself though there does not appear to be a consensus or consistent approach to addressing this particular organisational challenge.

Power Sector Component	Ireland	Germany	United States		
			New York	Texas	California
Large Scale Generation	Competitive (privately owned)	Competitive (privately owned)	Competitive with some state owned	Competitive (privately owned)	Competitive (privately owned)
System Operations	Independent, though state owned	Performed by 4 privately owned transmission companies	State owned independent system operator	State owned independent system operator	State owned independent system operator
Transmission	Owned and operated by two state owned companies	Monopolies, private ownership unbundled from generation	State owned and private/ competitive	Private - competitive	Privately owned and regulated monopolies
Distribution	Owned and operated by two state owned companies	Largely owned by municipalities (circa 860)	Mainly private ownership with some municipalities	Mainly private with some municipalities	Primarily through 6 IOUs and circa 55 municipalities
Metering	Distribution companies	Responsibility of distribution companies	Responsibility of distribution companies	Utility (DNO) led	Utility (DNO) led
Electricity Retail (Supply)	Competitive	Competitive	Competitive – ESCO or incumbent utility	Competitive, DNO can also supply electricity	Decoupled regulated rates from utilities cover majority of the state
Customer engagement and Energy Efficiency	Supplier led	Energy retailers	The DNOs, though there is an internal revenue decoupling	Energy retailers and utilities	Utility led

2.5 Summary of challenges affecting the countries / regions

A precise comparison is not entirely straightforward, however balancing individual viewpoints, programmes, declared issues, public policies and future plans the table below provides a correlation with the issues facing the GB system. Three ticks indicates a very strong correlation in that those issues are very relevant through to a cross which indicates that that challenge area is not particularly relevant or not expected at any notable scale.

Challenge Areas	Ireland	Germany	United States			GB
			New York	Texas	California	(*Gone Green* Scenario)
Distributed generation	✓	✓✓✓	✓	✓	✓✓✓	✓✓✓
Heat pumps	✓	✓	✓	×	×	✓✓✓
Electric transportation (BEVs & PHEVs)	✓✓	✓	✓	✓✓	✓✓✓	✓✓
Microgrids and community energy systems*	×	✓	✓✓	✓	✓✓	✓✓
Interconnections	✓✓✓	✓✓	✓	×	×	✓✓✓
Large scale renewables and inertia challenges	✓✓✓	✓✓✓	✓✓	✓✓✓	✓✓✓	✓✓✓

*The 890 or so municipal distribution grids are not viewed as microgrids or community energy systems in the context of this report

The GB column provides a reference and demonstrates that none of the other countries face all of the challenges to the same degree. The GB power sector structure is also more deregulated and dispersed than those detailed in the table in section 2.4. On balance, this probably adds to the implementation challenge. Many consulted indicated that their (less complex) industry structures were often a barrier to taking forward technical solutions to meeting the challenges.

In addition, data, smart meters, communications networks and information flows have been consistently highlighted as being increasingly viewed as part of the energy system. As the future unfolds these are likely to become critical components of distribution system planning and facilitating integration of distributed energy resources. The task of converting data to information was highlighted as a new function/capability required in the sector, while this has begun, its complexity is likely to significantly increase as more devices connect to and become part of energy systems. Cyber security is not covered in this report though its importance seems to be uniformly acknowledged.

Though heat pumps are not relevant to Texas and California, in those regions they have a similar challenge in managing air-conditioning loads, which at domestic level have a similar energy load, though their load profile is quite different. They are not considered here as electrical powered air conditioning is already very widespread and the load impacts of it are forecast to fall as technology improvements and more efficient ways of cooling are designed and developed.

3. How Are the Electricity Systems in These Countries Planning to Meet These Challenges?

3.1 Ireland

Ireland initiated (in 2011) a wide ranging programme to look at the many aspects and implications of meeting its renewable targets. The DS3 programme[13] "Delivering a Secure Sustainable Electricity System" brings together key industry participants (transmission and distribution companies, regulators, system operators (EirGrid and SONI) and generators) to develop solutions to operating the power system in a secure, reliable and economic way. At its core, the programme is about making the necessary operational changes to manage significant levels of renewable generation, but it is also about the evolution of the island's wider electricity system and implementing broad changes in market and regulatory spheres that will ultimately benefit consumers. Holistically, it considers technical, commercial and regulatory needs of the system. The programme is chaired by the regulator but follows a very collaborative approach. The programme commissions technical studies and analysis as required with recommendations being discussed openly and taken forward/ rejected as required. The programme has the authority to initiate detailed changes such as modifications to the grid code.

The programme consists of 11 workstreams within three pillars:

Pillar	Workstreams
Performance Monitoring	• Performance monitoring • System services • Demand side management • Grid Code • ROCOF
System Policies	• Renewable data • Voltage • Frequency
System Tools	• Wind security assessment tool • Control centre tools • Model development studies

The interface between the transmission companies and distribution companies is facilitated by the programme with regular meetings to discuss progress, issues and implications arising from the DS3 programme. This governance arrangement (TSO/ DSO plan) ensures transmission originating issues have a formal route to distribution assessment. DS3 complements a number of other distribution oriented programmes, for example ESB's Integrated Vision for Active Demand Management and NIE's Project 40. These are both closely aligned with DS3.

The primary purpose of the programme is to meet the 2020 renewables targets but has found itself dealing with adjacent areas, for example demand-side response

[13]DS3 Programme (http://www.eirgridgroup.com/how-the-grid-works/ds3-programme/)

(DSR), which whilst not explicitly required to meet 2020 targets is a key enabler. This has led to suggestions that the programme could take on a similar role in looking at 2030 and 2050 targets which could cement it as an enduring body rather than a targets-based transient programme. This is currently being discussed.

Though operationally focussed the programme does often initiate demonstration projects and helps focus on areas for inclusion in the various smart grid programmes in Ireland and Northern Ireland. In some ways it is comparable to that of the GB Smart Grid Forum. However, it appears to have a wider remit to be able to take decisions and implement changes. Costs for the involvement in the programme are borne by the participants but are generally covered within their allowable regulatory costs.

Key achievements of the programme to date include:

- Review of the system services requirements identifying market changes required.
- Review of technical standards which has fed into grid code changes.
- Development of an all island rate-of-change-of-frequency (ROCOF) standard.
- Harmonisation of the Northern Ireland and Republic of Ireland systems.
- Enhancement of the performance monitoring processes.

3.2 California

The landscape of the electricity sector in California is slightly more complex with a regulator (California Public Utilities Commission), government energy policy and planning department (California Energy Commission) an independent system operator (CAISO), a number of independent generators and four large investor owned utilities (IOUs) Pacific Gas & Electric (PG&E), Southern California Edison (SCE), Pacific Corp and San Diego Gas & Electric (SDG&E) and two smaller ones. In addition there are many municipal utilities, though the three main IOUs cover the vast majority of the electricity network in California.

CAISO's role covers around 80% of the transmission system, operating assets owned by the main IOUs in the state plus assets in the wider western interconnect region. Its role, summarised below, is broader than that of the GB SO as it covers wider planning activities for transmission, interconnections and a broader role to ensure reliability standards are met:

- Generator interconnection, process for connecting generation facilities.
- Reliability requirements, ensuring adequate resources to serve all customers.
- Transmission planning, open and transparent process engaging stakeholders.
- Inter-regional transmission planning.
- System operations and market administration.

At the highest level, CAISO tends to be the catalyst for most industry changes bringing together interested and affected parties to discuss and review events and issues. This can involve changes expected at distribution level with a possible impact at transmission scale. Although CAISO doesn't own any infrastructure, it is seen as the entity responsible for ensuing system reliability and resilience and to take a broader and deeper role than that of the GB system operator. The 2015 strategic vision outlines its priorities with respect to grid reliability and carbon reduction goals[14]:

[14]CAISO 2015 Strategic Vision (http://www.caiso.com/Documents/2015StrategicVision.pdf)

Pillar	Workstreams
Encourage low carbon energy solutions such as energy storage, demand response and expanded energy efficiency standards.	• Support pilot projects that help inform state and local authorities on the characteristics needed to ensure grid reliability as new solutions are designed. • Develop technical requirements and related tariff provisions to enable participation of low carbon energy resources in our markets.
Facilitate renewable generation contribution to grid reliability.	• Define the characteristics needed for renewable generation to provide grid services such as ramping and voltage control to enable less reliance on conventional generation. • Develop market mechanisms to incentivise renewable generation and facilitate participation through effective interconnection processes.
Provide incentives for consumers to adjust energy use in response to changes in supply and demand.	• Inform state and local regulatory authorities responsible for rate design about seasonal and time-of-day system needs.
Leverage the electrification of the transportation system to reduce greenhouse gas emissions and help consume energy when renewable generation is abundant.	• Inform state and local regulatory authorities regarding the most effective time and place to encourage low-carbon vehicle charging. • Study and incorporate the infrastructure needed to support increased electric vehicle charging into transmission plans.
Encourage development of more flexible generation resources that can adjust to constantly changing system conditions.	• To inform policy decisions, model and study the flexibility characteristics needed to ensure grid reliability.
Increase regional collaboration to expand the diversity of resources and to leverage opportunities for infrastructure and operations efficiencies.	• Demonstrate the benefits of the Energy Imbalance Market to interested parties across the region. Lead the effort to develop a governance framework that enables expanded regional collaboration.

As an example of how CAISO are taking a lead on implementing some sector changes and meeting the first item in the table above, they led the analysis on the type and size of flexible resources the system is likely to need and worked with the CPUC to develop the Energy Storage mandate[15]. This mandate sets targets for the state's IOUs to procure and install storage to help meet reliability standards in a more decentralised and renewable based energy system.

The challenges created by the changes in the sector are felt to be well understood. The state has many energy thought leaders, a vibrant digital economy and a positive business culture for innovation. As a result many new innovative energy technology solutions find their way to Californian utilities for early demonstration helping the state be at the forefront of technology deployment.

In response to the changing nature of technologies on their networks, two of the IOUs have initiated far reaching programmes to understand the grid required in the future and help with technology understanding. SCE's programme is called 'Preferred Resources Pilot'[16] and PG&E's is called 'The Grid of Things'[17]. Whilst the SCE pilot may appear at first to be a smart grid type project it does have a wider remit which covers (in UK terminology) distribution engineering and DSO, distributed generation, rate design, time of use tariffs, commercial mechanisms and end user engagement (DSR, EVs etc.). Though not a whole system approach, it does cover many aspects from the distribution network downwards in the electricity delivery network. In parallel they have published an outline architecture for a Grid Management System (GMS). This is positioned as more of a 'system of systems' than a typical DMS that we may first think of in this context. It provides a more defined link between human interface,

[15]California energy storage mandate (https://www.caiso.com/Documents/Advancing-MaximizingValueofEnergyStorageTechnology_CaliforniaRoadmap.pdf)
[16]Preferred Resources pilot (http://on.sce.com/preferredresources)
[17]PG&E Grid of Things (http://pge.com/en/about/newsroom/newsdetails/index.page?title=20150319_pge_president_says_utility_is_investing_today_for_the_grid_of_thingstrade_of_tomorrow)

business systems, grid edge devices, external systems and the physical electricity distribution infrastructure. It covers eight key systems:

1. Reliability system – facilitates the consistent, reliable and safe flow of electricity.
2. Optimisation system – facilitates optimal generation, consumption and efficient exchange of electricity across the distribution network. It interfaces with devices on the customer side of the meter.
3. Planning system – guidance providing updates and changes to the network.
4. Economic system – interaction with markets and contracts to ensure economic implications of the network are realised.
5. Grid infrastructure management – management of IT and operations technology (OT) that comprise the GMS.
6. Data repository system – centralised data management and warehousing.
7. Communication system – connectivity across systems and services and behind the meter.
8. Integration system – integration between disparate GMS entities and services.

It does not describe new or enhanced functions in detail, but from the definition of the role of the systems that it encompasses, there is a strong correlation with the functionality identified in the FPSA work. The GMS was highlighted as the nearest correlation SCE have to a power systems architecture development.

In a similar way PG&E's 'Grid of Things' covers similar ground though appears to be at a higher level and covering a broader remit, including for example competitive transmission. The phrase 'system' is often used in the programme materials however it's not clear how far the remit extends.

SDG&E have moved a little further with the concept of 'transactive energy' which aims to provide a platform for distributed energy resources to 'transact' services across a grid infrastructure. This is a similar approach to New York's REV, however it doesn't involve the formal DSP role, believing that it is more likely to be executed very locally within a microgrid type framework and probably containing a high degree of automation. At a technical level, SDG&E have defined the functions a microgrid will need to perform, such as reactive and power factor control, voltage regulation, response to frequency excursion, anti-islanding, overcurrent protection, power quality provision, grounding and isolation and fault monitoring. All of these are functions expected on the distribution system. The open question is where are they best located and this is being investigated.

Many of these programmes are aligned with the CPUC issued proceeding that called on the IOUs to develop and publicise long term Distribution Resource Plans (DRP) by July 2015. These plans set out how the utilities will integrate a range of DERs (defined as distributed generation, energy storage, energy efficiency, demand response and electric transportation) covering:

- Evaluation of locational benefits and costs of DERs. The evaluation should take account of:

    - Reduction or increase in local generational capacity needs.
    - Avoided or increased investments in distribution infrastructure.
    - Safety benefits.
    - Reliability benefits.
    - Other savings or costs to ratepayers.

- Recommendation for tariff structures, contracts or other commercial mechanisms for deployment of cost effective DER.
- Propose effective co-ordination of existing programmes, incentives and tariffs to maximise locational DER benefits.
- Identify additional utility spending to integrate cost effective DER into distribution planning to yield benefits to ratepayers.
- Identify barriers to deployment of DER (including operation of the distribution system that ensures reliability).

At the core of the DRPs are the methodologies used to establish integration capacity and locational net benefits based on three DER growth scenarios. These are currently under open review with interested parties. A separate DRP is being produced by each of the IOUs, there is no integration across them though clearly the IOUs work closely with one another in many areas. The local municipally-owned utilities (“munis”) are not required to produce DRPs as they are not governed by the CPUC.

The locational benefits assessment seeks to aggregate benefits across a broad spectrum of the energy delivery processes which hasn't been attempted before. Examples of the value components identified include:

	Value Component	Description
Wholesale	Wholesale energy	Reduced quantity of energy produced based on net load
	Resource adequacy	Reduction in overall capacity required
	Flexible capacity	Reduced system balancing resources
	Ancillary services	Reduced operational requirements for grid reliability
	Transmission capacity	Reduced need for system and local area transmission capacity
	RPS generation and interconnection costs	Reduced RPS energy prices, integration costs
Distribution	Substation and feeder capacity	Reduced need for distribution upgrades
	Losses	Value of energy due to losses between generation and distribution points of delivery
	Power quality and reactive power	Improved transient and steady state voltage, harmonics and reactive power
	Reliability and resilience	Reduced outages and ability to withstand and recover from external threats
	Safety	Improved public safety
Customer and Societal	Customer choice	Customer and societal value from robust market for customer alternatives
	Emissions	Reduction in state emissions, public and private health costs
	Energy security	Reduced risks from greater supply diversity
	Water and land use	Synergies with water management, environmental benefits and property value
	Economic impact	e.g. local jobs, investment, tax income

It is the responsibility of the IOUs to consistently assess the above benefits as part of developing their DRPs in order that the full value of DERs is visible.

In a business-as-usual sense, there are many working groups within the industry that review and seek solutions to many of the challenges from an operational perspective. These are not necessarily covered under the piloting recommendations within the DRPs. These are typically very focussed on particular areas. The lack of established standards for distribution grid connections and operating standards is seen as a hurdle preventing widespread adoption of DERs, as well as for industrial and commercial users who have multiple devices distributed throughout the state. CPUC is advocating that DERs be aggregated into Load Aggregation Points (LAP) and then bid into the CAISO market, unlike in New York where the PUC is advocating a distribution level market with a looser connection to their wholesale market (see next section).

3.3 New York

New York (NY) has recognised the many significant changes happening in the industry and embarked on two wide ranging change programmes:

- The Energy Highway – focussing on generation and transmission.
- Reforming the Energy Vision (REV) – focussing on distribution networks, distribution system operations, new markets and community engagement.

REV aims to better align markets and regulatory frameworks with new technologies and innovation ensuring that renewable energy is maximised while costs are kept low through enhanced competition whilst maintaining system security. Part of the driver for REV is to enable more resilient networks which are able to cope with more extreme weather events such as superstorm Sandy.

At the heart of the change is the aim to open the distribution network to new market entrants who can provide access to distributed energy resources to utilities. It also aims to promote networks capable of microgrid operation, community energy systems and active involvement by consumers.

Its primary focus is in and around distribution networks, distribution system operations and end user energy efficiency measures. The programme proposes a new entity called the Distributed System Platform (DSP), which will act as an integrator of distributed energy resources (DG, EVs, DSR, storage, and energy efficiency). In UK terminology, we would call the DSP a DSO. However, the DSP has a responsibility to set up and run a competitive market for DER services. Initially the DSP role will be provided by the incumbent utilities as a 'ring fenced entity'. However, in the longer term the option remains to create a truly independent DSP (mirroring that of the role of an ISO on a transmission system). There have been some calls to formally set a timetable to achieve an independent DSP but there is no set timescale as yet. The first component is to create the platform, called REV Connect. The state's commission is inviting interest from interested parties to set up and operate the platform.

It is proposed that the DSPs have a number of new (or enhanced) functions to enable the state to make the best use of distributed energy resources. These are:

- **Distribution planning** – enhanced planning to incorporate DERs, value those resources and improve co-ordination with transmission planning.
- **Distribution grid operations** – improvements to load and network monitoring including effective multidirectional power flow to improve value from DERs.
- **Distribution market operations** – administer RFPs (Requests for Proposals), run auctions, commercial agreements, performance management of DERs and participants.
- **Data access** – collection and provision of customer and distribution system data to facilitate a DER market and spur investment (respecting data privacy and security).
- **Platform technologies** – it is recognised that the different IOUs are at different states of technology advancement. This function sets a minimum standard to be met to enable a functioning DSP, namely DER management system, geospatial system, optimisation tools and communications network.

In addition the main IOUs in the state are required to submit long term distribution system implementation plans (DSIPs) in June 2016. These are intended to be the roadmaps for each utility's transformation, including alternative supply and demand resource procurements, cost benefit analysis and business model evolution. The DSIP documents are expected to serve as templates to the workings of the new Distributed System Platform. Specifically, they will offer a source of public information about system needs, so that distributed energy companies can identify opportunities to engage in the new market. The regulator has described these activities as 'animating distributed energy resources'.

The operation and structure of the NY ISO will continue with the new DSPs complementing the ISO's role rather than duplicating it. Initially there will be four DSPs mirroring the existing IOUs' service territories. Interoperability has been a key consideration and the working groups continue to develop standardisation to ensure that service providers can participate in all the markets without undue extra cost.

REV is a good example of system wide thinking as it defines functions for a new entity (DSP) with existing utilities in order to best accommodate new technologies to the benefit of end users. It is a complex and new proposal that hasn't been implemented elsewhere. It remains to be seen whether this will lead to more integrated, more resilient and better planned networks.

At transmission scale, long term planning and procurement of transmission is carried out between the Public Services Commission and NYISO. It tends to be market driven with overall responsibility residing with the PSC. In recent years the system has developed whereby load growth has been downstate (in and around New York City) while additional power has been connected in the north of the grid through interconnection into the 'lakes' grid[18] and upstate wind installations. Issues have arisen where there has been excess hydro power from Ontario flowing in to the northern NY grid creating voltage and capacity issues. A number of grids are interconnected on the lakes grid and participants operate with different energy policies, which have the potential to create system wide issues.

To solve a recent near critical issue in July 2015, NY Power Authority (NYPA) had to reduce output from Niagara hydro plant to the minimum possible resulting in excess water at the foot of the falls flooding the falls' tourist boat landing point on the Niagara River. This resulted in tourist boats being unable to operate at peak season. While inconvenient for tourists, it did highlight system wide issues and created negative publicity. As a result, an investigation was set up which will probably lead to system wide recommendations.

At present system planning is carried out between working groups of NYPA, NYISO, state transmission owners and the PSC. Solutions are then typically administered through PPRs (Public Policy Requests) for market mechanism solutions or changes to various grid codes if recommendations are more operational.

The Energy Highway blueprint[19] has four main objectives to develop the generation portfolio and transmission network to improve resilience, facilitate renewable generation and drive innovation. They are:

[18]Transmission grids in Ontario, New York, Michigan, Pennsylvania and Ohio which are connected around lake Erie and lake Ontario
[19]NY Energy Highway Blueprint (http://www.nyenergyhighway.com/PDFs/BluePrint/EHBPPT/9C12DE69F8607804AB68476B2A4AF916/Blueprint_FINAL_3.0_11.15.12.pdf)

- Expand and strengthen the Energy Highway – plan and build new transmission, connecting upstate New York to load centres in the south of the state, public-private partnerships.
- Accelerate construction and repair – advance investments in generation and transmission to enhance reliability, safety and storm resilience. Similar for the gas network.
- Support clean energy – commercial contracts to accelerate large scale renewables (inc. transmission upgrades) to meets the state's renewable portfolio standard.
- Drive technology innovation – support for deployment of smart grid technologies on transmission systems and proposal to create a smart grid hub for technology development.

3.4 Texas (ERCOT)

ERCOT operates the transmission system and is the state's ISO. It manages around 85% of the state's electricity and is overseen by the state regulator. It often takes the lead role in looking at future system wide issues and orchestrating discussions, analysis and recommendations. It works closely with the state regulator to take forward recommendations.

A current high priority is managing ramp rates associated with wind generation. Primary responsibilities lie with ERCOT to meet this challenge and it is being addressed through long term planning and review of innovative solutions. This is being done collaboratively with a number of industry parties and solutions involve curtailment, commercial levers, use of peaking plants and an element of demand side response. While the market ultimately provides services, meeting this challenge is viewed by ERCOT as being part of their core remit with the assistance of the state regulator and other industry participants. Their role is a stronger one than that of the GB SO in that they have a leading role in defining the market structures such that adequate resources are made available to maintain system security. Their role includes:

- Ensuring reliability and adequacy of the regional electricity network.
- Ensuring non-discriminatory access to transmission/distribution systems for all buyers and sellers of electricity.
- Facilitating retail registration and switching.
- Ensuring accurate accounting for electricity production and delivery among the generators and wholesale buyers and sellers in the region.

As a result ERCOT has had to, and continues to, reinforce its detailed technical understanding of the power system as it takes a greater role in shaping system developments. Interestingly, additional interconnection (outside of the small AC links they have) is not being pursued as a solution. It believed that this could possibly add to system issues through lack of control.

Texas has what it terms 'electricity deregulation'. In other parts of the US it would be termed 'rate decoupling' and in GB terms it would be retail competition. Customers are allowed to buy tariffs from a variety of providers in addition to the incumbent utility who continues to own and maintain the distribution network. Around 80% of the state is covered by 7 large IOUs, many of these are national companies who have many smart grid and 'utility of the future' projects underway. ERCOT liaises with those programmes to pick up key learnings and will act as a catalyst if there are any state wide regulatory changes that should be adopted. There is an informal network amongst those utilities to collaborate and share learnings through various working groups, but there is no formal, targeted strategy for the state around the role or functions of a more active distribution network. Each of the utilities is taking forward plans and implementing changes as per their own business strategy.

There is no overriding vision or prescribed architecture for the networks below transmission level. At present the view is that this is not required; as policy changes are enacted it is left to utilities and industry parties to implement them within the architecture they have. Similarly, there is no overriding policy around interoperability; however ERCOT felt that utilities and participants understand its importance with technical and engineering representatives working to achieve solutions in the best interests of customers. Though absent of formal requirements, interoperability is actively supported. Some care is needed in interpreting what is taking place here and time will tell whether this apparently ad hoc approach to whole-system architectural thinking is adequate. It is informative to note that there are a number of government-led initiatives in the US (see next section) that are informing whole-system thinking across companies, although they do not have formal mandate or oversight. An approach of 'informal guidance' may appear attractive, but its sufficiency might be challenged in regard to issues critical for system security and resilience.

3.5 United States - New England

The New England ISO (ISO-NE) provides system operations covering six states; Massachusetts, Rhode Island, Vermont, New Hampshire, Connecticut and Maine. It has three core responsibilities:

- Operate the regional power system.
- Administer the regions competitive wholesale electricity markets.
- Plan for the regional power system.

The ISO has highlighted that they are preparing and planning for the transition to a hybrid grid, which they define as 'a grid with grid connected and distributed resources and a continued shift toward natural gas and renewable energy'. Enhanced activities they are now undertaking and expanding echo many enhanced or new functions highlighted in the FPSA study including:

- **Enhancing the power market**
  - o Enhanced price signals to improve their resource performance and/or build new resources.
  - o New price signals that promote investment reflecting New England's transition to a gas and renewables system.
  - o Simpler, more predictable capacity market design to ensure resource availability and to allow variable resources to more effectively participate in wholesale markets.
  - o Further enhancement of the energy market.
  - o Overall market improvements to promote flexibility, innovation and cost effective deployment.

- **System planning**
  - o Significant transmission planning to identify transmission needs to accommodate growing levels of variable generation and highlighting flexible resources required for successful integration.
  - o Leading efforts to account for solar resources connected to the distribution system.
  - o Predicting and planning for solar and wind development 10 years ahead.
  - o Solar forecast incorporated into installed capacity requirements (implemented 2015).
  - o ISO now creating daily forecasts of PV production to incorporate into load forecasts.
  - o Leading the discussion on interconnection standards and requirements to reduce reliability concerns.

As an example of system wide impacts and a system wide approach to finding a solution, there is a strong correlation between high wholesale electricity costs and times of gas infrastructure constraints (which happens frequently in winter months). This will have a higher impact as the state moves towards a greater gas contribution in the generation mix. NE-ISO is leading the thinking about market solutions which trade off gas infrastructure investment against other mechanisms such as DSR. The former is not viewed as part of the electricity system and the latter is a developing market not entirely within the ISO's remit.

The Department of Public Utilities (DPU) in Massachusetts began a Grid Modernisation programme in 2012. Its core aims were to achieve a cleaner, more efficient and reliable distribution grid that will help customers manage and reduce their energy costs. It was also to ensure that the state makes progress towards meeting its clean energy goals by maximising the integration of solar, wind and other renewable energy sources. The programme resulted in an order in June 2014[20] requiring each utility in the state to develop and implement a 10 year grid modernisation plan that:

- Empowers customers to better manage and reduce energy costs.
- Enhances reliability and resiliency of the electricity service in the face of increasingly extreme weather.
- Encourages innovation and investment in new technologies and infrastructure strengthening the competitive electricity market.
- Addresses climate change and meets clean energy requirements by integrating more clean and renewable power, demand response, electricity storage, microgrids, electric vehicles and provides for increased amounts of energy efficiency.

In principle the utility costs for implementing the 10 year plan are recoverable from customers, subject to further review and scrutiny.

In addition, a separate order is underway to consider the implementation of time varying rates (time of use tariffs). In November 2014 the DPU issued an order to adopt a policy framework for time varying rates setting in motion the transition to implementation.[21]

[20]DPU Order 12-76-B (Massachusetts Department of Public Utilities)

Though the orders do not specify in detail how the utilities implement the directives, it is clear from reading the orders that new and enhanced functions, similar to those identified in the FPSA work, will be required now that the activities are mandated. Utilities in the state are currently developing and submitting their plans to implement the order.

3.6 United States - Department of Energy (DoE)

More broadly in the US, the DoE in conjunction with the National Labs is embarking on a multi-year grid modernisation programme targeting three national outcomes by 2025: i) a 10% reduction in economic costs of power outages; ii) a 33% decrease in cost of reserve margins while maintaining grid reliability; and iii) a 50% decrease in net integration costs of distributed energy resources. Six technical areas have been highlighted as the core of the programme largely covering the technical side of the grid system:

- Devices and integrated systems testing.
- Sensing and measurements.
- System operations, power flow and control.
- Design and planning tools.
- Security and resilience.
- Institutional support.

The programme has a strong governance structure, approved funding with wide active industry participation (utilities, ISOs, PUCs, IPPs, technology vendors and other communities). In many ways this combines elements of the GB Smart Grid Forum, FPSA work and network innovation project areas. It is led by the DoE and reports directly to the Secretary for Energy and has an initial three year budget of $220m.

Though not explicit, reviewing market structures is implied under the 6th technical area. It remains to be seen how recommendations could be implemented given that each state has its own mandate to develop its power markets.

In addition DoE has commissioned 'Grid Architecture' development with PNNL[22]. The work has several purposes:

- Provide organised views and insights about the existing US grid as a means of identifying structural constraints to grid modernisation.
- Provide selected potential future views of portions of grid architecture that address important and emerging trends and systematic issues.
- Help identify issues that may have public policy issues.
- Explain the principles of system architecture and apply them to model the potential futures of the electricity system.

The intended audience for the work includes all stakeholders to the electricity system, but primary targets are the technical representatives of utility companies to help their understanding of how the systems can develop and aide their system development methodologies. It is not intended to lay the foundations for a specific grid architecture that should be adopted nor is there a mandate for its contents to be implemented.

[21] DPU Order 14-04-C (Massachusetts Department of Public Utilities)
[22] Grid Architecture, 2015 (http://energy.gov/sites/prod/files/2015/04/f22/QER%20Analysis%20-%20Grid%20Architecture_0.pdf)

The work is being widely cited and being used as an input to the REV programme in NY as they develop their new frameworks.

A key insight from the work is that 'the industry has recognised that the complexity of the power grid has passed the point where intuitive or silo-based approaches to changes are workable'[23]. Architecture provides the disciplines and methods to view the grid from a system standpoint and to share those views with stakeholders. The value of grid architecture is in its ability to aid in managing complexity. The work highlights the dangers of not taking a grid architecture approach:

- Increasing risk of creating unintended consequences detrimental to resilient operations (such as those emerging at the interaction of certain grid functions previously considered in isolation).
- Increasing the risk of massive stranded investments in infrastructure.
- Blockage of energy innovation and resultant value streams associated with new products and services.
- Mismatch of policy directives and operational realities associated with the grid.

The key conclusions from the work that are relevant to (and consistent with) the FPSA project are:

- The grid is a complex network of structures that has evolved over the past century, driven by a patchwork of economic drivers, diverse business models and variable regulatory structures.
- A number of current trends (as outlined in the first section of this report) are adding additional complexity, as well as providing the potential opportunity to create new value streams and enhance system resilience.
- Grid architecture is a strong tool for managing this complexity with key stakeholders.
- Leveraging the discipline inherent in the exercise of this architecture is a key means of actively shaping the grid of the future.

The work does not explicitly identify new or enhanced functions, though they can be inferred from the descriptions of many of the key architectural insights included which align with those areas covered in the FPSA work. As an example:

> **Architectural Insight 8:** "the structure of the dense urban mesh limits any services that buildings might supply to grids except for those that reduce net load and thus do not attempt to put power back into the grid."

[23] The future of the Grid, Gridwise Alliance (https://www.smartgrid.gov/files/Preread_materials_National_Summit.pdf)

With corresponding policy Implication:

Policy Implication 4: “The enablement of two-way power flows within distribution systems in the face of structural limitations such as described above can have costs that go beyond those related to new premises equipment and software. Some amount of change at the utility level may be needed just to unblock the potential for certain building-to-grid energy/power services”

3.7 United States and Canada – NERC (North American Electricity Reliability Corporation)

NERC is a not-for-profit regulatory authority whose role is to oversee the reliability of the bulk power system in the US and Canada. Bulk power in this context covers transmission, large scale generation and system operations (ISOs and RTOs). It doesn’t have any direct operational role. It does set reliability standards and oversees the health of the bulk system from a reliability perspective. Its role was enhanced following the investigation into the Northeast blackouts in 2003 which identified a number of systematic failures. The 2003 blackout review noted that while NERC had a track record of many years of excellent work and had developed a significant range of standards, their adoption by network companies was voluntary. This has led to the strengthening of NERC’s role.

Its vision is to promote effective collaboration, cooperation and communication around important risks to reliability. It defines and mandates relevant standards and uses expertise from the industry to produce outcomes to manage risks in a cost-effective manner. It is accountable for the reliability standards it sets for the industry to adhere to and conducts reviews to verify compliance with those standards. It also takes the lead with reviews into significant system incidents, the last one being the polar vortex of January 2014, making recommendations for system wide improvements.

The organisation has no visibility or remit for reliability standards for distribution networks or community energy systems / microgrids / private networks.

3.8 United States – NIST (National Institute of Standards and Technology)

NIST is the US measurement institute with a similar role to that of NPL (National Physical Laboratory) in the UK, though with a broader role. Part of that wider remit covers smart grid interoperability standards. Working with stakeholders and partners from industry, government, and academia, NIST has published a framework and roadmap for smart grid interoperability standards. The framework includes protocols and model standards for information management to achieve interoperability of grid devices and systems.

3.9 Germany

The first formal progress update on the German ‘Energy Transition’ (December 2014) provides a commentary on progress since its launch in 2011. It describes a new target architecture for Germany to meet those goals. It was developed by the Government on the basis of the recommendations of an expert committee following an analysis of the first two Monitoring Reports. The new target architecture prioritises and structures the objectives of the Energy Concept. In many ways it is a very high level systems architecture which brings together policy, markets and programmes to meet the transition. The update suggests development of the two core market functions, firstly to ensure adequate capacity is available and secondly that it is available at the right time (at the right scale).

Faster enlargement and expansion of the grid is envisaged as core to achieving the energy transition. Grid development plans, the Power Grid Expansion Act (Energieleitungsausbaugesetz – EnLAG), the Grid Expansion Acceleration Act for the transmission grid (Netzausbaubeschleunigungsgesetz Übertragungsnetz – NABEG) and the Federal Requirement Plan Act (Bundesbedarfsplangesetz – BBPlG) lay the foundations for the coordinated, accelerated and transparent expansion of the power grids.

To meet the requirements of these acts the four German TSO's (50Hertz, Amprion, TenneT and TransnetBW) jointly produce a 10 year network development plan that sets out network reinforcements and investments required to meet the energy policy. The plan is co-ordinated by the federal network agency (Bundesnetzagentur). Though primarily to accommodate the transition to renewables, the plan does take account of resilience, European interconnection, security, consumer protection and market access. The plan is developed collaboratively, takes into account future scenarios and is subject to public acceptance.

The development of the plan covers many functions envisaged by the 'Investment Planning' section of the FPSA functions matrix, though critically it only covers the transmission system (both gas and electricity). With each iteration the investment planning function is enhanced as more information becomes available. It is considered to be a robust methodology delivering the plan required to outline the development of the transmission system. There are no plans to extend its remit to cover distribution systems, or private networks/community energy systems.

The German Commission for Electrical, Electronic and Information Technologies (DKE) and Association for Electrical, Electronic and Information Technologies (VDE) have developed the 'German Roadmap, Smart Grids 2.0' with the subtitle 'smart grid standardisation, status, trends and prospects'. A number of industry experts provided input to the work and in many ways it mirrors elements of the IET Power Network Joint Vision (PNJV - www.theiet.org/pnjv) expert group work and the FPSA project. The document covers smart grid architecture, security and use cases.

The German government is also intent on accelerating the modernisation of the distribution networks, though there is little co-ordinated or published information on how that will be achieved.

The German power grid is already amongst the most reliable in the world[24], with reasons for this cited as:

- The existing strength of its power grids and extensive cabling (vs overhead lines).
- Flexible operation of coal and nuclear plants (and to a lesser extent gas and pumped hydro).
- Better design of the balancing (ancillary) power markets, to make them more effective, faster, and open.

[24]Council of European Energy Regulators (CEER), benchmarking report (http://www.ceer.eu/portal/page/portal/EER_HOME/EER_PUBLICATIONS/CEER_PAPERS/Electricity/Tab3/C13-EQS-57-03_BR5.1_19-Dec-2013_updated-Feb-2014.pdf)

- Better system control software and day-ahead weather forecasting.
- Modest technical improvements to local-level distribution systems.
- Exports of power to neighbouring countries.
- Speed of implementing a solution to the over-frequency challenge (often termed the “50.2 hertz” inverter problem).

Some distribution utilities have had to carry out grid upgrades to substations, transformers, and power lines to meet additional power requirements. Some utilities have installed tap-changing transformers to manage reverse flows where this has become an issue. However many distribution grids have not yet required upgrades at any notable scale. For many distribution utilities, reverse flows (as a consequences of the high penetration of solar in concentrated areas) are cited as the main challenge they currently face. In particular, some distribution utilities are starting to monitor voltages on the distribution grid to better manage reverse flows. But in general, distribution utilities are at the early stages of the investment planning of the new capabilities that will be required in the future.

It is believed that a variety of additional measures (functions) will be required on distribution grids to manage storage, demand response, smart inverters, two-way flows, virtual power plants, flexible loads, integration with heat supply and heat storage. For example, some German distribution utilities are starting to forecast local renewables output to better manage the local grid. Others are considering how to integrate local balancing and peak-shaving with local combined-heat-and-power plants and heat storage. Some utilities are experimenting with smart inverters installed on distributed solar power systems as a new way to regulate distribution system voltage and reactive power and some utilities are thinking about long-term planning and modelling for their local networks. However there is no evidence of extensive systems analysis highlighting requirements for new or improved functions, though much of the functionality identified in the FPSA (around distribution networks) work is under consideration.

There are examples of ‘smart grid’ labelled projects that do incorporate behind-the-meter technologies and active community involvement. One leading example is in the town of Wildpoldsried, where the local grid operator AUW and Siemens have teamed up for a $6m project to integrate renewables and e-mobility into the local grid. It features a suite of grid edge technologies which are managed holistically to stabilise local power quality. Elements of the project also cover microgrid architecture and it will test operations in an islanded mode, though at present it is not expected that islanding microgrids will play a significant role in the future energy system. E.On are conducting a similar community energy project on the island of Pellworm that includes local generation, storage, flexible loads, storage heaters and network intelligence.

Germany has taken steps to implement smart meters. The energy act requires implementation of measurement systems for three categories of users:

- New buildings or those undergoing major renovation.
- For consumers with annual consumption greater than 6,000kWh.
- For installations with a generating capacity greater than 7kW.

These are the categories where the use of a smart meter was assessed as having a positive payback for the end user. A national roll-out programme has not yet been developed and installation of meters for the above three categories is being taken forward by DNOs and 3rd parties independent of any system wide strategy.

Furthermore Germany has created a distinction between smart and intelligent meters. The former requires connection to a communication network in order that consumption and time of use can be recorded, whereas intelligent only requires the installation of an in-home display to show users their energy usage. Intelligent meters do not require connection to a communications network.

For most typical residential consumers the business case is not yet deemed sufficient for a targeted roll-out, therefore meters are being replaced with intelligent meters as part of the normal replacement cycle. It is believed that intelligent meters can be upgraded to smart meters at a later date when proven economic to do so.

The term microgrids is not well used with the common term for a private network being ‘aerial networks’. These are larger systems, for example housing companies and large industrial units. They typically don’t have storage or a complex network management/balancing system, but typically generate as much as they consume. So, from an energy balancing perspective, they could be considered an island, though they have to be connected to the grid. Historically, most of these aerial networks have conventional generation at their source. With the deployment of new technologies these are expected to grow in number. Grid operators expect to develop new functions to be able to offer services to these aerial networks (possibly for example storage and local balancing).

In response to the threat of unplanned electricity flows, German TSOs have taken steps with neighbouring countries. Phase shifting transformers, which limit flows cross-border, have been deployed to limit transit flows through the Netherlands to Belgium. More recently 50Hertz agreed a virtual phase shift agreement with the Polish SO which is a contractual arrangement defining maximum limits for cross border flows. Phase shifting transformers are expected to be installed in 2016/17 to limit flows to Czech Republic and Poland. HVDC technology provides greater control and is one aspect of the suitability of the technology to the planned Norway link.

Heat pumps are seen as having the capability of offering flexibility to the power sector (in addition to their other benefits). It is expected that functions will be developed to make better use of this characteristic once there is greater visibility of how and where they are deployed and control networks are put in place.

3.10 South Korea

One of the largest and most comprehensive smart grid / future energy system projects is being carried out on Jeju Island in South Korea[25]. Jeju Island is a prime holiday destination for South Koreans and hosts many visitors. The project is a collaboration between the Government (local and national), Korea Electric Power Corporation (KEPCO), Korean Smartgrid Institute, research institutes, academia and leading vendors. The primary driver for the deployment of smart technologies in Korea is to meet the carbon reduction targets and provide the platform for a low

[25]Korea Smart Grid Institute (http://www.smartgrid.or.kr/10eng3-1.php)

carbon, green growth economy. Building Korean capabilities for products, services and exports is no doubt a key driver for the government.

The Jeju project includes all aspects of a future energy system including many of the challenges outlined in section 2 of this report. There are five sections to the project:

- **Smart power grid system** – smart and interoperable grid system with automatic grid protection and recovery.
- **Smart place system** – homes, buildings and factories with two-way communication system with the utility with automatic energy management to improve energy efficiency.
- **Smart transportation system** – intelligent charging infrastructure for an electric vehicle service system.
- **Smart renewables** – large scale renewable power generation infrastructure (solar, wind, biomass) integrated with large scale storage.
- **Smart electricity services** – development of commercial systems, pricing schemes and consumer peer-to-peer trading.

The test bed is regarded as a launch pad for wider country deployments. It aims to demonstrate the management of next generation utility networks and how they can be supported by IT platforms and communications networks through public–private collaboration.

Central to the project is the establishment of 3,000 smart places (homes, buildings, factories) and how they can play an active part in a more decentralised interconnected energy system. Within the power grid section KEPCO is focussing on four key areas; peak load reduction, reduction in transmission and distribution losses, integration of variable energy resources and reduction in supply interruptions.

Combining all five sectors in one location creates the opportunity to evaluate how the technologies interact with one another in order that an integrated proven plan for the widespread deployment of smart grid technologies can be developed. The first phase (2009 – 2012) was focussed on design and implementation of the core suite of technologies not the test bed. The current phase (2013 – 2020) introduces more activities around operation of the test bed and integration of the technologies through new commercial arrangements and business models. Many of the activities listed in this phase echo functions identified in the FPSA project, for example 'smart power management of buildings/factories' and 'optimal operation of the power system with microgrids'. Most of the activities in this phase are concerned with the decentralised power sector and focus heavily on the interaction between consumers (and communities of) and the wider power sector. As yet there is little information available on any learnings that are coming out of the project. Given the similarities with the main area of new functionality highlighted by the FPSA project, it would be recommended to investigate further in any subsequent phases.

4. Summary of Functional and Operational Changes and How They May Be Implemented

Appendix 1 provides a table correlating the new and enhanced functions identified by the detailed FPSA study with evidence found from this International Study. In many places there is a strong correlation with the accepted need for functional changes, however the picture is mixed on how, where and when these functions are likely to be developed and implemented. This suggests that there is still some uncertainty about the best means of incorporating them into existing power sector arrangements.

It is clear that the functions highlighted by the FPSA study resonate closely with the challenges faced in the reviewed countries and it seems accepted that wide ranging functional changes are going to be required to accommodate the evolution of the power sector to meet technology developments.

In summary:

Country	Changes
Ireland	*Changes:* Focus on ensuring system resilience as renewable penetration grows and technical issues become acute.
	How: Creation of a new collaborative programme (DS3) to bring together industry participants to discuss, analyse and agree on market and industry changes. Covers wide ground and although not 'architect' in name is considering a whole systems approach. The programme was designed to be temporary but may pivot into a more formal role. All existing industry roles and responsibilities remain unchanged. Changes executed through established bodies and codes and updates to market mechanisms.
Germany	*Changes:* The energy transition which sets a policy of moving to a renewable economy phasing out fossil fuel and nuclear generation. It also aims to promote distributed generation and community energy systems.
	How: Primarily through long term generation and transmission planning with new investments, wholesale and balancing market developments and continued support for distributed generation through a variety of supportive feed-in-tariff type commercial and community ownership type arrangements.
US – New York	*Changes:* Creation of a formal DSO entity which will have greater responsibility for long term planning and integration of a variety of DERs.
	How: structural changes to the distribution and end user community involving creation of new markets, new entities and easier access for new market entrants all covered by new regulatory framework. Solutions and long term development of the networks will be largely market driven with greater long term planning to encourage innovation and system development. Begins to 'unbundle' the distribution network and allow market forces to prevail. Significant change to distribution companies' role.
US – California	*Changes:* Focus on ensuring system resilience with growth in renewables and EV adoption. A number of change programmes in the sector assessing impacts and recommending solutions.
	How: CEC, CPUC and CAISO taking a greater role in guiding/shaping the market to encourage more renewable generation and enabling distributed resources (storage, DER, DSR, EVs etc.). Main IOUs developing and implementing very broad demonstration programmes to prove technical and operational capabilities with changing resource mix. No plans for single or co-ordinated architecture. More decisive actions to guide solutions to manage system security in light of growing renewable penetration (e.g. storage mandate). Requirement for IOUs to produce longer term detailed plans (DRPs) explicitly valuing and accommodating DERs.
US – Texas	*Changes:* Greater penetration of renewables (primarily transmission connected wind) driving system operator challenges.
	How: No structural changes to industry roles envisaged. Greater planning and co-ordination between ERCOT and regulator being taken forward. No substantial structural changes to the distribution networks outside of implementation of smart grid technologies being taken forward by the IOUs following their own strategies. Creation of DSO still in early stages of discussion.

5. Discussion and Conclusions

5.1 Renewables

It's clear that all the countries reviewed see genuine system security issues associated with the penetration of renewables and distributed energy resources as they implement policies towards meeting climate change targets. These translate to operational challenges for system operators, through variability of output and corresponding reduction in system inertia. This is widely understood and viewed as a pressing issue that requires action to mitigate. Response to this challenge appears to be actively taking place, but through a variety of mechanisms with evidence of actions to shape the existing markets to bring additional resources to provide flexibility to ISOs. For large scale renewables (typically transmission connected), this activity is being led by ISOs in conjunction with respective regulators, though the driving force appears to be ISOs. In the US, the DoE is taking supportive measures through the Grid Modernisation programme and commissioning the grid architecture work by PNNL.

The resulting lack of inertia seems to be a uniform concern. Ireland began its DS3 programme largely to address that issue and other countries accept the issue will need a long term solution. No uniform solution is emerging though combinations of storage, DSR, gas plants and interconnectors are highlighted as tactical solutions. Most are relying on guidance to markets to bring forward solutions.

5.2 Distributed Generation and Distributed Energy Resources

Penetration of DG has occurred in all the regions, with Southern Germany and Southern California seeing very high levels of residential DG, whereas in Ireland and the US Northeast, the take up has been more subdued. Where high levels have been seen this has created some local grid issues leading to resilience concerns. Both Germany and California have reviewed DG's impact and put in place technical solutions, primarily around curtailment in the event of over-generation. California has progressed a little further by opening up network access to 3rd parties who may be able to provide local solutions (e.g. storage) and be rewarded for it.

In California and the US Northeast, the long term approach appears to be to create a market for distributed energy resources to allow their integration into networks and secure additional value. NY is taking a step further and beginning the process towards creating a DSO and possibly moving to an independent DSO in the future. This echoes the general US approach of opening markets and creating competition. The widely held view is that ISOs and DSOs will provide technical oversight and ensure system resilience. The interaction between ISOs and DSOs in the same region is yet to be fully addressed, though acknowledged as a potential system issue. The Californian DRPs from the main IOUs set out a longer term vision and plan for the locational value of DERs and set out how the networks will integrate the capacity. In both California and NY, the adoption of DERs is seen as much as an opportunity as a threat, hence the generally supportive policies to encourage deployment.

Establishing information models and a common language that enables interoperability of DGs and DERs to facilitate their integration into networks is well understood. There is consensus that to facilitate high penetration of DG, measured and modelled representations of generation units need to be accurate and validated to allow for detailed system planning and operations. There are many activities looking at interconnection rules and detailed functions for smart devices (e.g. smart inverters) and the importance seems to be well understood and bought into, though it could be argued that it has taken initial deployments to focus attention whereas this could have been anticipated.

All of the countries reviewed expect to see a growth in distributed generation and more progress towards decentralised energy systems. Views varied as to whether this is best facilitated through a more open market approach or stronger system wide planning.

5.3 Electric transportation

Supportive policies towards the adoption of EVs are seen in each county/region with California notably having the strongest support and therefore seeing the highest penetration. All areas have conducted many studies into the grid impacts of mass adoption, the potential for V2G (Vehicle to Grid), charging infrastructure and business models. There is common understanding of the impacts and potential for EVs to become part of the energy system along with the need for interoperability, standard charging connections and development of a back-office commercial system.

To date, deployment has not reached levels to invoke smart charging and V2G services outside of a few pilots which have demonstrated the capability. It is too early to say whether infrastructures are able to seamlessly integrate EVs if adoption rates accelerate. There is broad concern that battery cost breakthroughs could lead to rapid deployment that infrastructures are unable to cope with. There does not seem to be any consistent plan or strategy to deal with this eventuality apart from forced curtailment or controlled charging. Rapid take up on EVs would appear to represent a risk to the resilience of networks.

5.4 Heat pumps

Heat pumps are most likely to have impacts in the European countries due to supportive policies for the decarbonisation of heat (California and Texas have little heat demand and NY is content with oil and gas heating). As with electric vehicles, mass adoption would put considerable stress on infrastructures, however overall deployment has been slow. This is partially due to lack of incentives, lack of residential understanding and the relatively low cost of gas which undermines the business case for home owners. There seems to be little confidence that heat pumps will see mass adoption in the near term and therefore appears to be less of a priority issue. While Europe considers the implications of electrification of heat, the US has significant electric cooling load. There is considerable innovation to improve the efficiency of cooling and programmes to integrate HVAC (Heating, Ventilation and Air Conditioning) into energy management systems through making them controllable as part of DSR programmes or as a grid connected DER. They typically represent the highest load item in a residential home and similar in some ways to that of a heat pump (in load terms). However, load profiles are typically better aligned to PV output.

5.5 Microgrids and community energy systems

These find the most active interest in New York and California of the regions reviewed, while in Texas there are some examples of community energy systems orientated more around the commercial side of group buying and agreements. The NY REV process actively supports and encourages the development of microgrids as it is consistent with the aims of the DSP. In the state there are a small number of MW scale pilot projects assessing the benefits and feasibility of setting up and running a microgrid. It is believed that microgrids improve the reliability and resilience of networks. In Germany there have been a number of community based purchases of smaller distribution networks. In some circles these are viewed as community schemes, however some view them more as a regular network having a shared ownership structure. Where microgrids are referenced it is important to understand whether they are intended for off-grid (islanded) operation on a normal basis, or only in the event of emergency conditions. This makes a significant difference to both their technical design and service provision, and the regulatory/commercial implications for the local network company.

There are a number of challenges with setting up, owning and operating a microgrid. They are associated with technical (islanding, costs, protection, communications), standards (absence of), legal and regulatory, market monopoly and interfaces with the main grid (or adjacent grids). It is acknowledged that there are a number of new functions and operational changes required to be able to operate a microgrid successfully. Many in the US express the view that the benefits will outweigh the challenges and their development is consistent with a more decentralised energy future.

It is too early to say whether these will be treated as load point by utilities or have their internal resources more broadly integrated into the wider grid. Either approach will require detailed functional and operational planning to ensure they operate safely within a wider interconnected 'grid of grids'.

5.6 Interconnectors

Curiously, there were markedly different views about the value interconnectors can bring to meeting disruptive challenges. European countries believe that interconnectors add flexibility through providing a conduit for extra capacity to meet system peaks and an ability to export excess energy, whereas at best the US regions were ambivalent to further interconnection with NY indicating that connection to neighbouring grids is contributing to system stress and needs review. Texas has no further plans for interconnection, believing on balance they offer reduced ability to control the grid and California does not expect interconnectors to make any significant contribution to meeting new system challenges.

It's clear that all regions viewed interconnection as a very important component of the system requiring careful modelling and understanding of their long term effects.

5.7 Industry structures

Of the countries reviewed, the two extreme approaches are highlighted between Ireland and New York. The former has an almost entirely state run infrastructure with a competitive power market and intends to retain that model, whereas New York is extending the concept of independent system operations to the distribution networks and opening the sector to a more market based approach. In effect, the natural monopoly of the incumbent distribution utilities will be further opened to competition.

Both seem to be at the forefront of recognising and attempting to address future system challenges, though by taking two entirely different approaches. Ireland's through adopting a highly collaborative working group and implementing changes through existing industry structures, whereas New York is redefining the regulatory framework to promote more competition. It is difficult to assess which is the most likely to preserve system resilience whilst facilitating more renewables integration. However, they both share similar goals as far as the system is concerned and are examples of system wide approaches (though neither are fully end-to-end).

In all the countries reviewed it is apparent that central co-ordination is strengthening, whether it be provided by a change programme (Ireland), the CPUC (California) or a mix of DPS and utilities (NT and Massachusetts). In none of the countries reviewed was there an approach of leaving the future architecture of the sector to the market to develop. Where there are markets (new and existing) these appear to be strongly defined and viewed as delivering part of the system, rather than delivering the whole system.

6. Key Messages for the Future Power System Architecture Project

6.1 While the challenges faced by the GB electricity sector are similar to those being addressed in the other countries reviewed, none of those countries face them to the extent presented by National Grid's *Gone Green*' scenario. For many varied reasons, not all of these challenges appear in any particular country to the same extent and the impact of the challenges is influenced by the nature of the respective national system. In general it can be observed that the scale of the change anticipated on the GB system is greater and potentially poses a greater co-ordination and integration challenge.

6.2 There are elements of system wide approaches elsewhere with some good examples on sections of the system. However, there was no evidence of true end-to-end system co-ordination in any of the countries/regions reviewed. Of the countries reviewed, the nearest example to a systems wide approach is Ireland's DS3 programme.

6.3 Many experts consulted expressed the need for greater system wide co-ordination and indicated that they believed the scale of changes anticipated represented a real risk to system resilience and reliability. Those consulted commonly indicated that they are on a learning journey with respective stakeholders who often believed the 'system' is just large scale generation, wholesale markets, transmission and system operations (neglecting distribution and end user components, regarding them as largely passive).

6.4 In the US, the remit and accountability of the Independent System Operator is broader than that of the System Operator in GB. Being closely aligned with their public utility commissions and being not-for-profit entities provides greater responsibility to shape and guide market developments to ensure adequate resources are made available to meet energy needs. At the moment the remit of the ISOs for long term planning typically only covers transmission and generation. However, discussion with ISO staff not infrequently reveals a good awareness of 'whole-system' considerations including distribution and customer issues, which is perhaps a consequence of many ISO staff having a background in vertically integrated utilities.

6.5 Most ISOs and utilities are attempting to remain technology agnostic, however there are signs that some are beginning to mandate a technology portfolio in order to preserve system resilience. For example, the storage mandate in California is an example of the Commission and CAISO selecting a technology (and its sub components) they believe will be required, acknowledging that the current market cannot adequately value it.

6.6 In the most comprehensive system wide programme (Ireland's DS3), all infrastructure participants are quasi-government and this may be a contributory factor to its success in being able to safely integrate high levels of variable generation. The programme actively involves generators and other parties in the working groups and benefits from a strong international advisory group comprising of individual experts rather than company representatives.

6.7 Distribution systems are highlighted as facing the greatest challenges in defining and implementing comprehensive distribution management systems. In addition, these will need to integrate with ISO systems, home area networks, microgrid controllers, SCADA systems and market mechanisms to name a few. While many of these have detailed architecture and defined interfaces, there is an absence of a system-of-systems overview. This is beginning to be actively discussed, with PNNL[27] and EPRI[28] both being cited as thought leaders.

6.8 There are many new functions that are being developed across the sectors that will need to be incorporated, either into existing functions or through developing new ones. Examples include modelling of DERs, interconnection rules and standards, situational awareness, data exchange and common information models.

6.9 The 'trilemma' that is often discussed in the UK is common to the countries reviewed here and is widely understood. The US regions and Ireland have prioritised 'clean' and 'secure' in the near term. Across the US, energy prices are relatively low, though pockets of California are quite high (where there are ToU tariffs). Ireland's electricity costs are around 20% higher than European averages but this has not led to a curtailing of renewable ambitions. In Germany, the electricity costs for residential and industrial consumers rose to be the second highest and highest (respectively) in Europe. This has triggered a policy review, primarily to ensure Germany's industry remains competitive.

6.10 Interoperability and standardisation are accepted as best practice. There is evidence of many working groups investing time and effort to agree on outputs and recommendations, so it is not being left to vendors and market forces to resolve. Many organisations are helping facilitate this including IEEE[28], the US National Labs, EPRI, CEN-CENELEC[29] and SGIP (Smart Grid Interoperability Panel)[30] to name a few. Though often time consuming, there was uniform belief that this approach is in the best interests of consumers and the industry at large.

[26]Pacific Northwest Laboratory (http://www.pnnl.gov/)
[27]Electric Power Research Institute (http://www.epri.com)
[28]Institute of Electrical and Electronic Engineers (www.ieee.org)
[29]CEN-CENELEC, European Standards (http://www.cencenelec.eu/Pages/default.aspx)
[30]Smart Grid Interoperability Panel (http://www.sgip.org/)

Appendix 1 – Functional Alignment with International Study

This table provides a high level correlation between the main functional areas highlighted as part of the main study with information found from discussions with experts and literature review for the countries identified. It's beyond the scope of this study to provide a detailed mapping of the precise functions as:

- For many there will not be a single point of contact to approach; many of the functional areas are covered by many different companies/organisations within varying industry structures.
- Identifying and securing the time of an individual with direct responsibility for these areas in each of the countries would not be achievable within the accelerated timescales the project has been working to.
- The terminology varies from country to country so even a document-based correlation may be not be a true comparison.
- Many of the functional areas identified are under active debate within these countries, so detailed documents describing how the function operates are not available.

In support of recommendation three from the FPSA Main Report, a more detailed and functional analysis should be undertaken in specific areas with countries identified here that have made progress in defining and implementing similar functions. There will be key learnings that can be transferred and used as part of GB's development of these functions.

The colour coding signifies strength of correlation to functions identified in the main study work. The table should be read in conjunction with the detailed functional description from the Main Report. Green indicates that there is strong correlation, while this may not be an exact match, it can be assumed that the proposed functional area is well understood and acknowledged as an area either currently being addressed or there are plans to. Yellow indicates that the functional area is consistent with their understanding of what will be required, but at present analysis is at an early stage. No colour indicates weak or no correlation identified.

Functional area	Candidate Requirement / Function area	Ireland	Germany	US
1. Investment Planning	0. Plan in power sector flexibility and resilience against change	Largely through collaboration between the energy commission, regulator and the state owned network companies Eirgrid and ESB (and various other owned participants including NIE, SONI and SEMO). Largest change vehicle to focus on delivery of future is the DS3 programme.	Transmission planning led by TSOs and overseen by the regulator, all aligned to meet the national energy policy 'The energy transition'. The respective parties have roles and responsibilities defined in various codes.	Very PUC led in New York (NY) with the commission setting the agenda for the energy sector. In California (CA), industry structures largely defined by the CPUC in partnership with long term planning and forecasting by CAISO.
	1. Plan plant portfolio	Has a clear ambition for GHG reductions which has been translated into a renewables portfolio that is being built (1.1). There are no specific technology mandates though (2.1). One objective of DS3 programme is to develop markets to accommodate plant portfolio (1.3) and value flexibility.	The energy transition sets out a GHG ambition (1.1) though it does not appear that there is a pre-prescribed generation mix (1.2), more of a direction of travel that market mechanisms will find solutions for. The planning does include promotion of distributed solar and wind as part of the overall low carbon generation mix.	There are individual state renewables targets which are seen as a proxy for GHG emissions (1.1). CA and NY have extended the planning function of the large IOUs to fully accommodate DERs into their Distribution Resource Plans (DRPs). This includes grid operations and long term planning and investment processes (3.1).
	2. Plan for power system operability	Threats to the reliable operation of the power sector to accommodate high penetrations of variable renewable generation have been assessed and are under ongoing review within DS3 (2.1). The sector is moving towards implementing these functions through a variety of means (though not behind the meter, other than evaluating the potential of DSR).	System operability is acknowledged as an important activity that requires a variety of solutions. At TO level, the SOs address primarily transmission level issues through long term planning to meet energy policy. Beyond the meter issues are being addressed as they arise rather than via a consolidated function (2.1).	Most evident in CA though CAISO analysis leading to various actions (e.g. Storage mandate) (2.1). SDG&E acknowledge local issues created through PV and have active programs to identify and remedy emerging threats (2.1). NY developing a new function DSP as part of REV which will have remit to manage threats to operability.
	3. Forecast future electricity sources and demands	The system is incorporating better forecasting with significant improvements in wind forecasting. Although multi energy vector issues/ advantages are acknowledged, no evidence of a formal function to perform this (3.1) though modelling of additional sources is undertaken (3.2.1).	It appears that there is good cross vector thinking and power-to-gas is a concept being pursued. It is seen as an important topic (3.1). It is being acknowledged that greater DG forecasting and estimating is required (3.2.1). The system does include distributed PV and wind forecasting. There doesn't appear to be any active monitoring of real time PV output.	Limited evidence in the states reviewed of cross vector alignment. Shale gas seen as plentiful, cheap (and clean cf oil) for heating. NYs REV will create a market for DERs that will necessitate a greater forecasting and planning activity for the DSPs (aka DSOs). There is evidence of detailed forecasting in southern California with real time output monitoring of some distributed PV. The expectation is that with deployment of more capable grid management systems this will be put in place.

Functional area	Candidate Requirement / Function area	Ireland	Germany	US
1. Investment Planning	4. Resolve or manage capacity shortfalls- whole system basis	The system is looking to implement greater demand side participation (4.1) as part of the planning process. In addition many 'smart' technologies are being piloted, e.g. smart EV charging. It is envisaged that data from these will contribute to better generation and demand visibility (4.1).	Not yet established though a number of smart grid and community energy demonstration projects are underway. It is expected that these will lead to new operational planning functions (4.1).	Greatest evidence is in CA and NY. The former has extended the planning function of the large IOUs to fully accommodate DERs into their Distribution Resource Plans (DRPs). This includes grid operations and long term planning and investment processes (4.1).
	5. Coordinate planning across all appropriate organisations.	No evidence that the extended view of the function is being implemented whereby planning incorporates private networks, community energy and smart cities. Has not been an issue to date as there have been few deployments and they have not generated any issues to date.	There are established large private networks already in place (termed Aerial Networks). These can provide services to the grid, but typically don't feature storage and are not truly controllable or integrated. Domestic demand side participation is expected to be part of the future energy system, but no formal markets or functions in place (outside of established ancillary services market).	Evidence of greater long term planning by ISOs in CA and NY, though not a complete sector view (Transmission and distribution linked but not integrated). Limited evidence of planning accommodating private networks and micrograms, though this may become more visible through the REV market developments in NY which will encourage and support DSM. REV also provides a means for microgrids to secure additional service value which may accelerate their deployment. Utilities are developing planning functions for how this will be accommodated.
2. Operational Planning	6. Validate investment planning assumptions for operational use	There is an intention to extend current markets to enable demand side participants who could include aggregators and smart energy communities. This is in the early stages of consideration.	Similar to Ireland in that the concept and requirement is understood but implementation of formal functionality will follow demonstrations and development of models (and once scale is reached).	REV creates the platform for microgrids and community energy systems to become a more active part of the energy system. This is core to the design and expected to deliver financial, community and resilience benefits.
	8. Identify and manage resulting constraints	Focus has been at transmission scale where long term planning and forecasting has led to new transmission infrastructure projects and development of ancillary services such that constraints are minimised and demand side measures can be taken.	Focus has been at transmission scale where long term planning and forecast has led to new transmission infrastructure projects and development of ancillary services such that constraints are minimised and demand side measures can be taken.	There is evidence in CA of local grid operators installing (or mandating) semi-detachable PV resources in order to manage location specific constraints. REV in NY facilitates elements of 'ancillary services' at the distribution level which allow operators to contract for energy services at location-specific points.

Functional area	Candidate Requirement / Function area	Ireland	Germany	US
2. Operational Planning	9. Involve operational stakeholders in operational planning	No evidence of plans as envisaged by this function being made available and communicated other than what already takes place at the transmission level. Not yet developed for microgrids and community energy systems.	Similar to that in Ireland. Focus at present is on transmission and established ancillary services.	CA's mandate for the large distribution companies to consult on and publish their DRPs for the benefit of other industry participants is consistent with this identified function. In southern CA, SDG&E have implemented forms of demand control to distributed PV where connected to overloaded/constrained networks. This is being formalised into operation control procedures.
3. Real Time and Balancing	10. Confirm operational plan ready for real time execution	In place for large scale and transmission connected renewables, not yet extended to community energy systems and private networks.	Not currently in place though investigation work is underway to understand the requirements and whether it will be required (formal DSO). At present aggregators aggregate distribution connected flexible resources and make available to the balancing market.	NY implementing a new model to incorporate distributed resources to assist planning. These are likely to be characterised and their availability and services offered to the distribution system operator and other 3rd parties via peer-to-peer (P2P).
	11. Execute operational plan	No functionality plans at present for the distribution networks to incorporate despatch plans as, at present, the generation despatch is currently controlled by the system operator. It is acknowledged as an area for future consideration should there be widespread connection of generation on the LV network. Aggregators are active in the transmission market.	As above, currently aggregated and provided to the transmission level balancing market. No balancing market exists purely for distribution systems. 'DSO 2.0' concept being developed which initially appears to be similar to REV and would create new active system operations at MV and LV.	NY REV creates a platform to enable this function to take place, though unclear if it will be to this extent. The interface between NYISO and NY DSOs (DSPs) is being further developed. It is expected that the new market design and implementation will deliver low cost balancing. CA considering the same.
	12. Monitor and control demand/generation.	A possible requirement for the future should active network management be deployed. Not envisaged in the near future.	Beginning to consider whether all DG needs real-time output measurement, though renewables have priority. This functionality is expected as active network management technologies are deployed on LV networks.	Some cities in CA implementing active network management at low voltage levels where there is (or expected to be) constraints on networks, though not currently a comprehensive network wide function as penetration of DG and DERs not yet widespread enough.
	13. Respond to exceptional events	Not covered	Not covered	Not covered

Functional area	Candidate Requirement / Function area	Ireland	Germany	US
4. Markets and Settlement	14. Distribute settlement information	A national smart meter programme has been underway since 2012, similar to that in the UK. The intention is to begin a rollout programme in 2018 subject to confirmation of a positive business case later in 2016. It is envisaged that the data will be read by the network companies and then passed to the relevant supplier for billing and use with the customer. Addressing privacy and protection is part of the current project phase in designing system wide solutions to data handling.	Germany has made a distinction between smart and intelligent meters. The former is only required for consumers with annual consumption over 6,000 kWhs and it only has to have communications capability. Intelligent meters have no communications functionality, just IHD. Data will be collected by each DSO. Data interoperability accepted as being high priority, along with data security. Standards committee DKE leading industry consortium to define 'smartgrid' and data standards and interoperability.	Smart meters not an explicit requirement in NY, though expected to see widespread deployment as they are a key enabler of the REV changes. The major utilities are submitting rate plans to begin deployment. They are actively being deployed in CA. CA is seeing widespread deployment of smart meters with the utilities having responsibility to collect and share meter data. Data interoperability well understood and actively being developed. Seen as ongoing, REV introduces some market based standardisation while the sector continues to develop broader standards (with national bodies).
	15. Structure market	It is expected that ToU tariffs will be become the default sometime after 2020. Once smart meters are installed suppliers will have the obligation to offer ToU tariffs to all their customers.	Studies have been carried out into the effects of residential ToU on the energy system. As yet there are no plans to implement ToU tariffs.	In CA, ToU tariffs are an option in some places, however a recent order from the commission means that they will be the default rates by 2019 for residential customers. In NY some utilities offer voluntary ToU, while others only make available to very large residential (and C&I). Take up at residential level is very low.
	16. Engage customers	There are limited formal functions to promote or encourage community energy type schemes at the moment though it is envisaged they will become a greater part of the energy system in the future.	Some large community energy type systems are in place (Aerial Networks). It is expected that these will grow in the future though functionality to enable this is still at the concept and development stage (outside of the already established FiT type schemes). The energy transition encourages community ownership, primarily through commercial and legal changes.	In NY, REV is seen as a key enabler to more active engagement with customers and communities, allowing them to play a greater part in the future energy system. This is core to the market and regulatory design which is still in development. For example peer-to-peer trading will facilitated through the new market platform.

Appendix 2 – References, Acronyms and Abbreviations

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30 Smart Grid Interoperability Panel (http://www.sgip.org/)

Acronyms and Abbreviations

AC	Alternating Current
CAISO	California Independent System Operator
CEC	California Energy Commission
CHP	Combined Heat and Power
ConEd	Consolidated Edison
CPUC	California Public Utilities Commission
DC	Direct Current
DER	Distributed Energy Resources
DMS	Distribution Management System
DoE	Department of Energy (US)
DPS	Department of Public Services (NY)
DRP	Distribution Resource Plan
DSR	Demand Side Response
DS3	Delivering a Secure Sustainable Electricity System (Ireland programme)
DSO	Distribution System Operator
DSP	Distribution System Platform
ENTSO-E	European Network of Transmission System Operators
EPRI	Electric Power Research Institute
ERCOT	Electric Reliability Council of Texas (Texas ISO)
ESB	Electricity Supply Board
EV	Electric Vehicle
FERC	Federal Energy Regulatory Commission
GHG	Green House Gases
GMS	Grid Management System
GW	Gigawatt
HVAC	Heating, Ventilation and Air Conditioning
HVDC	High Voltage Direct Current
IHD	In Home Display
IOU	Investor Owned Utility
IPP	Independent Power Producer
ISO	Independent System Operator
ISO-NE	ISO – New England
IT	Information Technology
KEPCO	Korea Electric Power Corporation
kWh	Kilowatt-hour
MV	Medium Voltage
MW	Megawatt
NERC	North American Electricity Reliability Corporation
NIE	Northern Ireland Electricity
NIST	National Institute of Standards and Technology
NYISO	New York Independent System Operator
OT	Operations Technology
PG&E	Pacific Gas & Electric
PNNL	Pacific Northwest National Laboratory
PSC	Public Services Commission
PHEV	Plug-In Hybrid Electric Vehicle
PV	Photovoltaic

REV	Reforming the Energy Vision (New York regulatory framework)
RFP	Request For Proposal
ROCOF	Rate Of Change Of Frequency
RPS	Renewable Portfolio Standard
SCADA	System Control and Data Acquisition
SCE	Southern Californian Edison
SDG&E	San Diego Gas & Electric
SEMO	Single Electricity Market Operator (Republic of Ireland and Northern Ireland)
SGIP	Smart Grid Interoperability Panel
SO	System Operator
SONI	System Operator Northern Ireland
TO	Transmission Owner
ToU	Time of Use
V2G	Vehicle to Grid
VSC	Voltage Source Converter

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Future Power System Architecture

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