Electricity Storage – Comparative Case Studies

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Customer Details

Customer Name:	Ofgem
Customer Address:	9 Millbank LONDON SW1P 3GE
Customer Reference:	10016656
Contact Person:	Deirdre Bell

DNV GL Company Details

DNV GL Legal Entity:	DNV KEMA Ltd
DNV GL Organisation Unit:	DNV GL Energy Advisory, Operational Excellence
DNV GL Address:	5-11 Lavington Street London SE1 0NZ
DNV GL Telephone:	+44 (0) 20 7357 6080
DNV GL org. No.:	EEWGB210
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Contact name:	Matt Freeman; Graeme Sharp; Matthew Rowe; Pedro Ramirez; Thomas Leonard
E-Mail:	matt.freeman@dnvgl.com graeme.sharp@dnvgl.com matthew.rowe@dnvgl.com p.ramirez@dnvgl.com thomas.leonard@dnvgl.com

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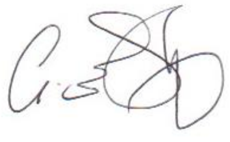
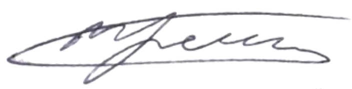
for DNV KEMA Ltd

Prepared by:



Graeme Sharp
Head of Smart Energy Advisory, Operational Excellence

Approved by:



Matt Freeman
Head of Section, Operational Excellence

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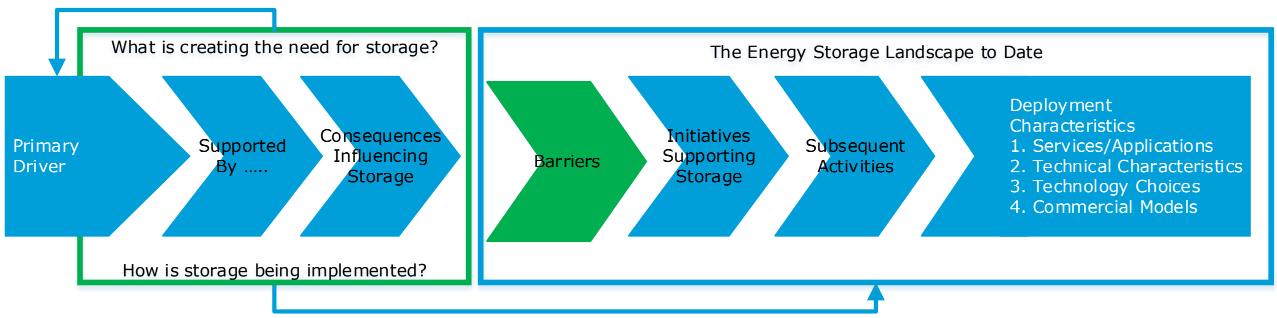
1. Executive Summary

As a result of global developments in technology, energy storage is set to transform the energy market. Many countries are on a path to understanding the role that storage can play in the energy system and adapting policies accordingly. The UK energy market is experiencing significant interest in storage but the potential of battery and other forms of storage to offer services to the system and market participants is some way from being fully realised. This report addresses the following points in three international locations:

- Examples of what services have developed in response to certain signals / incentives that have been given in those countries (e.g. introduction of pay for performance).
- The context as to how storage has been treated generally in those examples for regulatory purposes e.g. definition, licence, ownership structures, rules for charging, etc.
- The relevance of the selected regions to the UK Market.

Three regions were selected and for the following reasons: Ontario, Canada due to the specific introduction of an energy storage licence; PJM (regional transmission organization in the North East of the United States) due to developments of the frequency regulation market, tax incentives and large energy storage pipeline; and Germany due to distinct developments in the domestic storage market.

The findings of the report will be used to consider the insights from these regions' experience and help progress the UK storage agenda. The UK is aiming to enable a level playing field for storage and the wider market, and although there is an understanding of the role storage could play in the future energy system, no incentives, legislation or policy involving energy storage have been implemented - with the exception of funding arrangements leading to a variety of R&D projects. The framework below has been created to conduct an analysis of the information collated from the respective regions.



Key findings show that there are learnings from each of the respective regions. Each region has its own variant behind increasing the need for, and interest in, the deployment of storage. It is however accepted, in each region, that storage can play a pivotal role in the future energy system, and that the primary long term drivers originate in meeting carbon reduction targets and system problems associated with a higher renewable energy penetration in the generation mix. In PJM and Canada, storage is seen as the next step within the energy system transition, both from the perspective of modernising the existing grid and as a new asset that can provide enhanced versions of existing market services. Germany has taken a more targeted approach to developing domestic storage. A summary of the respective locations with the key topics from the framework, including an overview of the current status of the energy storage landscape in the UK is shown below.

	Primary Driver	Supported By	Consequences Influencing Storage	Barriers	Initiatives Supporting Storage	Subsequent Activities	Deployment Characteristics
CANADA	Grid modernizing and increased flexibility to accommodate increasing renewables	- Green Energy and Green Economy Act - Integrated Power System Plan (IPSP) - Long Term Energy Plan (LTEP) - IESO ATR project.	- LTEP 2013 required IESO to include a 50MW storage procurement process - OEB introduced a licence for storage, May 2015	- Difficult to form a business case for energy storage. - no market participant class for storage	- Long term PPA's for storage 4 – 10 years offered by IESO - Licence recognition - Further LTEPs to address storage	- Further market developments required to utilise storage licence - New Markets Entrants	- A variety of storage research and development projects have been deployed, with different technology, sizes, stakeholders and ownership models - A pipeline of over 50 MW of storage planned for construction - Increased network flexibility
GERMANY	- Carbon Emmission Reduction Targets - Increased renewable penetration	- Renewable Incentives - In 2004 the first large-scale feed-in tariff (FIT) scheme was introduced	- Interconnection flexibility at a system level sufficient - Attention on domestic RES plus storage	- High Energy Storage CAPEX Costs and therefore difficult to form business model - Public awareness of domestic energy storage technology	KfW storage subsidy program	Increased interest in domestic storage both from the public and key stakeholders	- 25,000 battery based storage systems were available in Germany by the end of 2015 - With a total installed capacity of 160 MWh (average capacity of 6.5 KWh / battery) - Aggregator market activity
PJM	Promoting energy storage is a priority at the federal level in the U.S.	Acts such as the American Recovery and Reinvestment Act which provided $185 million to 16 energy storage demonstration projects helped support storage development	Increased awareness for energy storage lead to changes in legislation and policy in the U.S. to allow storage to compete fairly in the existing energy markets	Compensation methods for the Frequency Regulation (FR) do not represent the amount of FR being provided by faster-ramping resources such as energy storage	- FERC Order 755 drove the PJM FR market restructuring - A federal investment tax credit for storage was introduced - The capacity market was restructured to enable storage to participate	The amount of frequency regulation accepted into the PJM market is now considered to be too high	- There is over 235 MW of installed grid connected energy storage - Focus is shifting to "behind the meter" RES plus storage and aggregated services provision (including frequency)
UK	- Energy policy focus shifted to the energy security part of the energy trilemma - Carbon Emmission Reduction Targets	Policies promoting Renewable Energy and carbon reduction	- Increase in renewable penetration - Reduction in conventional generation - Increased flexibility / stability required	Many reports highlight the current barriers of energy storage in the UK (See A, B and C below)	- Energy Storage Demonstration projects funded by DECC and Ofgem - Introduction of the Enhanced Frequency Regulation service by National Grid	- External increased interest in the UK Energy Storage Market - Increased awareness of the technology - New business models	- The UK has a variety of storage research and development projects, with different technology, sizes and stakeholders involved - Increased awareness and understanding of the value of system flexibility - National Grid procurement of up to 200MW Enhanced Frequency Response comprising storage

Considerations for the UK market and parallels between the regions studied are drawn out and summarised in Sections 5 and 6. Observations made in this report in relation to considerations for the UK included: Government directed integrated energy plans and specific mandates for storage; incentivised R&D projects to develop the requisite technical and commercial knowledge to advance the prospects for storage for different applications at different system levels; aligning and supporting market arrangements with due consideration to treatment of RES and RES plus storage, including subsidy schemes; consumer awareness of the energy transition agenda and the adoption/acceptance of storage; ensuring the regulatory environment, incentives and subsidies are appropriate, stable and enduring to drive the required amount and nature of storage.

2. Introduction

The UK energy storage market is growing rapidly with key stakeholders in the UK all acknowledging the role that storage could play in the future energy system [1]. DECC is committed to looking into existing political, economic, social and technical barriers to energy storage. The Secretary for State for Energy and Climate Change Amber Rudd recently discussed the role storage can play in increasing security of supply in the UK and stated that, *'we need storage to make renewables viable'* [2] and that, *'locally-generated energy supported by storage, interconnection and demand response, offers the possibility of a radically different model'* [3]. In a recent publication [4], Ofgem recognised the role that energy storage can play in supplying system flexibility.

National Grid (NG) has shown an increased interest in demand side participation. As we are seeing an increase in renewable penetration and a decrease thermal generation, which previously supplied inertia to the system, system balancing requires faster responding frequency response. NG aims to achieve 30-50% of system balancing via demand side measures by 2020 [5], and has recently published Expressions of Interest for both a new Demand Side Response (DSR, [6]) service and an Enhanced Frequency Response (EFR, [7]) service.

Many countries are on their own path in terms of removing barriers, deploying, and understanding the role that energy storage can play in the system. Pumped storage has historically provided energy storage in GB. The potential of battery and other forms of storage to offer services to the system or to smooth intermittent generation has not yet been fully realised in the UK. Energy storage is set to transform the demand side in the UK and as a result of recent global developments, that opportunity is enhanced.

This report has the following structure:

- The remainder of Section 2 will present the Problem Statement and the Regions studied.
- Section 3 introduces the research and analysis framework used to present the research and conduct the analysis in Sections 4 and 5 respectively.
- Section 6 provides a summary and recommendations based on the findings in Sections 4 and 5.

2.1 Problem Statement

In order to investigate the options for integration of energy storage in the UK, Ofgem tasked DNV GL to produce a report to address the following points in three international locations:

- What are the key drivers and barriers for energy storage in the selected locations;
- Does any Policy / Regulation exist for energy storage in the selected regions; and,
- What is the relevance of the selected regions to the UK Market?

The findings of the report will be used to benchmark the UK energy storage landscape against international locations as well as providing insights which may be instructive to regulation of energy storage in the UK.

2.2 Region/Country Selection

The following regions selected as the focus of this report and the reasons behind their selection are as follows;

- Ontario, Canada, due to the specific introduction of an energy storage licence;
- PJM (regional transmission organization in the North East of the United States), due to developments of the frequency regulation market, tax incentives and large energy storage pipeline; and
- Germany, due to distinct developments in the domestic storage market.

3. Methodology

This section introduces the research framework and the analysis framework used in Sections 4 and 5 respectively.

3.1 Research Framework

The research questions described in Table 1 were issued in the form of a questionnaire template for completion by consultants in the respective regions. The responses to these requests were utilised to populate the information provided in Section 3 utilising the same template.

Table 1: Research Framework

Area	Key Question(s)
Market Overview	Historic, current and forecasted total storage capacity. Relevant information to understand the storage market in the country / region e.g. renewable generation penetration, network stability, peak demand, generation mix, etc.
Drivers	What has driven the uptake of energy storage in the selected region? – Political, Economic, Social and Technical.
Barriers	What were the barriers to energy storage uptake, do these barriers still exist and, if not, what process did the country / region went through to remove them?
Incentives	What incentives exist in the area of interest, why were they developed, what has the uptake been and what is the anticipated future development for these incentives?
Policy / Regulatory Perspective	From a regulatory perspective does a definition or storage licence etc. exist? If not, why not and, if so, what was the impact of implementing such regulatory drivers on the incumbent energy storage market? Are any legislative/regulatory changes under consideration at present – if so what and why?
Unexpected or Poor Performance	Are there any examples of unexpected or poor performance in any of the above areas for the selected country / region?
UK Market Relevance	How applicable is the selected area to the UK market, what are the main parallels and divergent comparators between the energy systems from the perspective of energy storage?

3.2 Analysis Framework

The following approach was used to conduct an analysis of the information collated in Section 4. It begins with considering the two primary questions and a range of sub-questions in the form of process steps that can usefully illustrate the experience of the three regions. This is illustrated in Figure 1.

1. **What is creating the need for storage?**
    - What is the primary driver that has revealed the need for storage as the next phase in power systems development?

- How are these primary drivers being supported within the region?
- What are the consequences of these primary drivers that influence the demand for storage?

2. **How is storage being implemented?**
   - Are there any barriers to the implementation of storage?
   - Are there any specific initiatives supporting the implementation of storage?
   - What subsequent activities are apparent in support of storage? (new entrants, etc.)
   - What are the characteristics which influence the way in which storage is deployed?, i.e.:
     - 1. Services/Applications;
     - 2. Technical Characteristics;
     - 3. Technology Choices;
     - 4. Commercial Models.

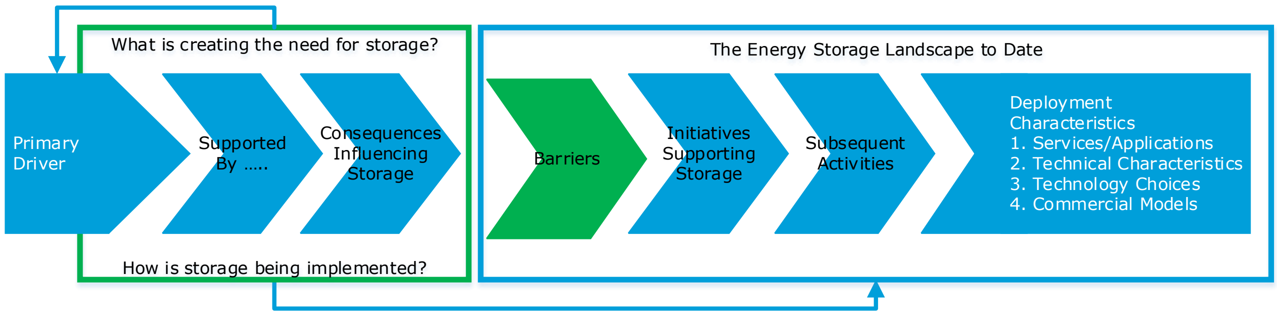


Figure 1: Analysis Framework

This approach is designed to aid comparisons with the UK market conducted in Section 5. This will allow comparison of the relevance of the different experiences: e.g.: whether the demand for storage is emanating from the same primary driver(s) and therefore whether any of the resultant consequences and initiatives provide useful examples for the UK market. Any findings and indicative learnings for UK are considered in Section 5.4, and a summary is provided in Section 6.

4. Research

4.1 Ontario, Canada

Market Overview

Ontario has a total installed generation capacity of 35.2 GW of which 12,301 MW (34.9%) corresponds to renewable resources (140 MW solar PV, 3,234 MW wind, 8,432 MW hydro, and 495 MW of biofuel) [8]. Conventional generation is composed of gas/oil (28.2%) and nuclear (36.8%). In 2015 a system wide peak demand of 22.5 GW was reached in July, and gross electricity consumption was 153.7 TWh (ca. 0.2% lower than in 2014) of which 30% was supplied by renewables [9] [10].

The electricity sector is regulated by the Ontario Energy Board (OEB) and the system is operated by the Independent Electricity System Operator (IESO), which in January 2015 incorporated the Ontario Power Authority (OPA) responsible for ensuring long-term resource adequacy.

Hydro One Networks Inc. (HONI) is the transmission network and largest distribution network owner, along with 75 Local Distribution Companies (LDCs). Ontario Power Generation (OPG) is the main power generation asset owner/operator. OPG owns of the largest hydro storage facility (174 MW Sir Adam Beck Pump Generating Station in Niagara, commissioned in the 50s) and is currently in charge of operating Ontario's nuclear generation fleet. Other electricity generators include municipal utilities and independent power producers (IPPs) contracted by IESO on a long-term basis.

Ontario's electricity market is a power pool for real-time energy with bilateral contracts, power purchase agreements (PPAs) and regulated tariffs. The electricity market is deregulated as per the requirements of the Federal Energy Regulatory Commission (FERC) [11]. This means that the transmission grid is open to private generators to access the electricity market. However, lack of available transmission capacity has been an obstacle to the development of utility-scale renewable generation projects. Historically, utility-scale wind and solar have been procured through provincial programs or tenders (SOC [12], RES I-III [13], RESOP [14], FIT [15], LRP [16]).

In 2003, the energy sector in Ontario was in a critical state, characterized by aging energy infrastructure, shortage of supply and a system that relied on expensive imports and dirty coal. This situation triggered a reaction from the government that in 2004 introduced the Electricity Restructuring Act, which created the OPA, responsible for ensuring an adequate, long-term supply of electricity. In 2007, the OPA introduced the Integrated Power System Plan (IPSP, [17]) which was focused on creating a sustainable energy supply. The government in 2009 introduced the Green Energy and Green Economy Act (GEA, [18]), which triggered the growth in clean and renewable sources of energy. Technological developments, demographics trends, changes in the economy, and the advancements of the renewable energy sector (mainly due to the successful Feed-in-Tariff program) motivated Ontario's government to update its energy plan and introduce its Long-Term Energy Plan (LTEP, [19]) in late 2010, which looked to ensure that Ontario can meet the needs of an evolving economy and shifting electricity demand, while providing affordable electricity.

In 2010, and as a reaction to the Feed-in-Tariff program, IESO launched the Alternative Technologies for Regulation (ATR) pilot project aimed at testing new ways to provide frequency regulation services to Ontario's electricity market and determine if consumers were able to provide some of the required ancillary services [20]. The ATR conducted a competitive procurement that concluded with three contracts, two of which were storage facilities: a 2 MW flywheel storage commissioned in July 2014 (NRStor) [21], and a 4 MW battery storage (RES Canada) commissioned in August 2014 [22].

In December 2013, the Ontario Ministry of Energy released an updated LTEP designed to balance five principles: cost-effectiveness, reliability, clean energy, community engagement and an emphasis on conservation and demand management before building new generation [23]. In this document the government outlined its intention to address the regulatory barriers that limit the ability of energy storage technologies to compete in Ontario's electricity market. In addition, Ontario's Ministry of Energy committed to include storage technologies as follows:

- Commissioning an independent study to establish the value of energy storage's many applications throughout the system;
- Examining the opportunities for net metering and conservation policies to support energy storage; and
- Providing opportunities for storage to be included in large renewable procurements.

Subsequently, Ontario's Ministry of Energy instructed IESO to develop procurement frameworks for large-scale renewables and storage projects [24].[1] To comply with the 2013 LTEP and the Ministry's request, in January 2014, IESO published a storage procurement framework for 50 MW of storage in 2 phases: Phase I for ancillary services to increase grid reliability; and, Phase II for capacity services [25] [26]. The objectives of the storage procurement were

- Maximize learning about the various end-use services that energy storage solutions can provide;
- Explore potential frameworks for competitive procurements, market mechanisms, and the commercial arrangements for energy storage solutions;
- Learn how to effectively and efficiently integrate energy storage resources into the Ontario electricity market, understand its potential roles in the sector and meet system operator needs; and,
- Identify the main regulatory and other barriers preventing energy storage technologies from competing in the energy market.

IESO procured 33.54 MW of storage from five companies during Phase I, which included the utilization of battery technology (18.8 MW), hydrogen storage (2 MW), flywheels (12 MW) and thermal storage (0.74 MW) [27]. The projects are currently under development, the first of which is due for commissioning in late 2016. It is understood that IESO awarded short-term (3 to 4 years) PPAs to those five projects, the rationale being that the PPAs should provide a revenue stream during a transition period until the market rules have been adapted to allow the participation of storage in the electricity market. In the future, new storage facilities will be obliged to obtain a storage licence from the OEB and then an authorization from the IESO in order to operate in the market.

Phase II procurement ended in November 2015 with the award of 10 years PPAs to five companies for nine projects for a total of 16.75 MW of storage [28] [29]. Eight projects are based on two battery technologies: solid battery (4 projects, 8 MW) and flow battery (4 projects, 7 MW); and one project is based on compressed air (1.75 MW).

Currently, no additional storage procurement plans are being contemplated, and the already contracted projects are intended to provide IESO with better understanding of the integration of energy storage into the electricity system and market [30].

Whilst developing the energy storage roadmap Canada identified Ontario '*…as a natural starting place to build our collective vision. It has been recognized that supporting a home for these innovative technologies can*

[1] It should be noted that in late 2015, CanWEA (Canadian Wind Energy Association) replied to the call of the Minister of Energy for potential ways to incorporate storage technologies into the next round of renewables procurements. In the reply, CanWEA discarded in the short term its interest in the co-located renewable plus storage option based on a set of arguments that included: the lack of evidence to support the need of storage for the growth and reliable integration of renewables; the fact that today the levelized cost of energy storage technologies is higher than the levelized cost of wind energy; and, because they do not see a long-term plant and comprehensive energy storage strategy within the broader LTEP process.

provide economic growth, job creation, a stronger competitive advantage and a more affordable supply of clean and reliable electricity' [31].

Drivers

1. Government commitment to address security, affordability and sustainability identified in 2003.
2. Government's commitment to continue investing in renewable generation, and explore flexible options such as storage technologies for increased reliability an.d efficiency of the grid, by applying balanced planning principles in a measured and sustainable way.
3. Government's intention to address the regulatory barriers that limit the ability of energy storage technologies to compete in the electricity market.
4. A $50-million Smart Grid Fund launched in 2011 to help local distribution and Smart Grid companied test and build the technologies to modernize the grid.

Barriers

According to IESO market rules, any stakeholder looking to participate in the electricity market requires an OEB licence [32]. Whilst the OEB introduced a specific licence for energy storage[2] in May 2015, the IESO market rules do not include a participant class for storage yet. Consequently, there are currently no formal processes for storage facilities to apply for an IESO authorization for market participation. As an interim solution, storage facilities have been awarded with either a generator licence[3], or a demand response market participant authorization [35] [36].

A possible barrier cited in the 2013 LTEP is that some storage applications are required to pay certain fees (retail, uplift and Global Adjustment) both at the time of capture and at end use.

Incentives

IESO does not have any capacity mechanisms to compensate storage resources. For this reason IESO signed PPA agreements with the 50 MW energy storage procured as result of the 2013 LTEP. Other than this one-off PPA, there are currently no incentives to deploy storage. However, it is expected that OEB and IESO will establish market rules allowing market participation of electricity storage. It is understood that the next LTEP, expected to be released in 2017 is likely include specific targets for storage.

In October 2015, Energy Minister Bob Chiarelly announced plans for changes to Ontario's wind energy procurement mechanism, and mandatory bundling of new intermittent renewable resources with storage

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[2] OEB Electricity Storage Licence definition: '"*storage facility" means a facility that is connected to a Transmission or Distribution System and is capable of withdrawing electrical energy from the Transmission or Distribution System (i.e. charging), and then storing such energy for a period of time, and then re-injecting only such energy back into the Transmission or Distribution System, minus any losses (i.e. discharging)'* [33].

[3] OEB Electricity Generation Licence definition: '"*generation" facility means a facility for generating electricity or providing ancillary services, other than ancillary services provided by a transmitter or distributor through the operation of a transmission or distribution system and includes any structures, equipment or other things used for that purpose'* [34].

systems is one of the options under consideration [37] [38] (see also footnote 1).

Policy / Regulatory Perspective

In March 2015,[4] OEB established a process to apply for an Electricity Storage Licence[5] [40]. The only apparent distinction between the Storage and Generation Licence is in the "facility" definition. Ownership rules are the same establishing that a licence holder, or an affiliate of the licence holder, cannot own, construct or have any type of participation in the ownership of distribution or transmission assets. Also, the licence does not guarantee any offtake contracts or rates [33].[6] As mentioned earlier, the current electricity market framework does not allow energy storage for market participation directly, and it should be highlighted that the storage licence definition came after Phase I of the storage procurement executed by IESO in July 2014.

Formal indications that the government is committed with a long-term plan to incorporate energy storage in Ontario's power system are:

1. Introduction of the 2013 LTEP.
2. Publication of the Storage Procurement Framework in 2014, and the initial procurement of 50 MW of energy storage; and
3. Introduction of an energy storage license in 2015.

According to the Ontario application process an electricity storage licence *'enables the licensee to generate electricity or provide ancillary services for sale through the IESO-administered markets or directly to another person; purchase electricity or ancillary services in the IESO-administered markets or directly from a generator; and sell electricity or ancillary services through the IESO-administered markets or directly to another person, other than a consumer'* [40].

Unexpected or Poor Performance

It is interesting to note that the creation of a Storage Licence occurred after the procurement of storage systems by IESO, but prior to the acknowledged necessary changes to market rules for the participation of storage.

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[4] Ontario Energy Board Act, 1998, S.O. 1998, Chapter 15, Schedule B, Sections 57 and 60 [39].

[5] One of those exemptions is that a person who owns or operates one or more facilities each with a total name plate capacity of 500 kilowatts or less is exempt from the need to obtain an electricity storage licence.

[6] IESO defines grid energy storage as *'commercially available technology that is connected to the transmission or distribution system and is capable of: absorbing grid energy (charging); storing energy for a period of time; and, injecting energy (discharging) minus reasonable losses back into the grid.'*

4.2 Germany

Market Overview

Germany has a total installed generation capacity of 192 GW of which 83,834 MW (43.6%) corresponds to renewable resources (37,448 MW solar PV, 34,638 MW wind, 6,383 MW biomass, 3,918 MW hydro, and 1,447 MW of other type of renewables) [41]. Peak demand occurs in winter time due to the demand of lighting, water and space heating. In 2014 an annual peak load of 82.7 GW was reached on November. According to preliminary figures, during 2015 the gross electricity consumption was 597 TWh (ca. 0.8% greater than in 2014 [42]), from which 33% was supplied by renewables [43]. Conventional generation corresponds to 56.4% of the total installed generation capacity and is composed of coal (25.6%), gas (14.8%), nuclear (6.3%), and other conventional technologies (9.7%).

The need for energy storage in Germany is closely related to Germany's ambitious energy transition (Energiewende) program [44], which prioritises CO2 emission reductions and the replacement of fossil fuels power plants with renewable resources [45]. By 2050 Germany is committed to 80% greenhouse gas cuts, compared to 1990 levels, and a renewables contribution of at least 80% [46]. The coordinated transmission network development plan for the four German TSOs assumes 24 GW and 66 GW of offshore and onshore wind respectively, and 65 GW of PV by 2033 [47].

The 2000 Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz – EEG) triggered a boom in PV installations [48] [49]. The first large-scale feed-in tariff (FIT) was introduced in 2014 to legally oblige grid operators to pay solar electricity producers a fixed remuneration for a period of 20 years for the electricity injected into the grid. The FIT level changes to account for the different costs of PV installations (rooftop or ground-mounted), the size of the system and system cost reductions over time.[7] The long-term duration of the FIT system provided sustained planning security for investors in PV systems. September 2015 FITs for PV systems ranged from €12.31c/kWh to €8.53c/kWh for small roof-top systems and large utility-scale solar parks respectively and are restricted to a maximum system capacity of 10 MW. However, it should be noted that PV FIT is declining at a faster rate than for any other renewable technology [50]. Over the 25 years to 2014, more than 1.5-million solar power plants with a total capacity of 38 GWp were installed in Germany [51]. The majority of this is solar PV installed on residential rooftops with a capacity not larger than 30 kWp.

As of end 2015, about 25,000 storage systems had been combined with PV behind the meter, either through combined PV-storage investment or through upgrade of existing PV [51]. This translates into a total installed storage capacity of about 160 MWh. The majority of these installations are between 2 and 8 kWh. Forecasts for battery storage capacity by 2033 vary widely and range from 40 to 70 GW. The upper level estimate includes 40 GW in households, 23 GW in small commerce and 5 GW at system level for the provision of ancillary services. This does include a projection of 125 GW associated with electric (EVs). Li-Ion has emerged as the preferred technology for battery based storage system new installations (70%), followed by Lead-Acid [52].

For a number of years there have been new entrants that combine RES into VPPs (Virtual Power Plants). These consortium plants are still limited to distributed generation, but will probably be extended to medium-size storage systems, to increase the benefits for the storage operator or improve the service offering for RES-based electricity supply [53] [54] [55].

German based aggregators are becoming more involved with domestic PV generators. For example Lichtblick is marketing the Tesla *'SchwarmBatterie'* to residential PV owners. These aggregated batteries in turn form part of a grid scale *'swarm storage'* which can be used to supply network ancillary services [56]**.**

[7] Feed-in tariffs are subject to changes, either by regular digression of technology, or by legislative changes.

Drivers

The drivers for energy storage can largely be traced back to the German government policy of reducing CO2 emissions, namely the "Energiewende." The three energy storage building blocks of this policy are electromobility; small (solar PV storage); and large-scale battery systems [57] [58].

Further deployment of residential solar PV is one of the foundations for the development of the small energy storage systems market, and it is expected that the use of residential battery energy storage will allow an increase in average *'own-consumption'* of PV generated electricity from 30% to more than 60% [51].

Small-scale battery storage may increasingly become attractive for other customers in the near future (3 years), provided costs fall and electricity tariffs rise. Given that the expected increase of investments into Li-ion production capacity, economies of scale, etc., battery prices are projected to fall significantly. An IRENA (2015) scenario foresees battery prices of €20c/kWh per battery cycle and PV prices of €10c/kWh also for small-scale users [59] [60] [61]. Tesla, expects to cut overall battery costs by more than 50%, i.e. down to about $120/kWh by 2020 [62] [63]. Some market participants go even further and expect that in 2017 PV-battery combinations will be economically feasible without further promotion.

Despite the decreasing electricity wholesale prices due to the impact of RES, end consumers (especially households and small commerce) face increasing electricity tariffs that are at present around €30c/kWh. These higher tariffs are the result of support mechanisms intended to support TSO costs as they accommodate higher RES penetration. The increased electricity tariffs, combined with storage cost reductions, may cause batteries to become economically feasible as parity is achieved between tariffs and by PV-battery self-supply costs [64].

Due to high levels of interconnectivity, the German system does not appear to require large grid scale connected energy storage for frequency regulation for the foreseeable future. Some large-scale battery demonstration projects are however currently operational. The first large project was a 5 MW lithium-ion unit commissioned in the town of Schwerin in September 2014 to supply primary frequency regulation services. A 1.3 MW lead acid-based battery in Alt Daber, Brandenburg, was successfully prequalified for frequency response by the TSO [51]. It is expected that this market will grow. In the four years leading up to 2016, the weekly weighted average price for primary control power was around €3,200/MW. A battery system participating in this market could recoup capital expenditures at system prices below €1,100/kWh [51].

Barriers

The current tender design for procurement of fast response services has unfavourably high pre-requisites for utility scale storage systems in terms of time availability, etc. Nevertheless, technical pre-conditions have been made more transparent and tailored to allow for participation of batteries.

Problems generated by RES penetration seem to be mostly concentrated at rural and less populated areas and DSOs are mainly interested in understanding the impact of PV-battery and electric vehicles on their systems, but not in the additional value of using those resources for the provision of ancillary services. Additionally, the electricity network regulation still provides adverse incentives to favour traditional infrastructure reinforcement investments. The smart decentralised markets are still a vision and it is unclear how a network operator may combine its regulated business with potential procurement of energy from storage systems.

Analysis of RES penetration and residual load from a system perspective has indicated that storage systems for grid stability management will not be needed until 2035, when RES penetration is predicted to reach 60%

share of the country's generation mix [65]. Other sources of flexibility, such as demand response or RES re-dispatch, are currently more cost effective. RES costs are likely to fall in the future; this means that RES curtailment will also become cheaper, which means that storage will tend to become less attractive as a source of flexibility. There is a decline in prices for services procured by TSOs due to a stable demand and increase in competition in the form of virtual power plants, flexible biogas, emergency power units, etc.

Deployment of storage in combination with large scale RES connections is dis-incentivised as the network operator is enabled to curtail RES generation due to congestion or network stability reasons, and to compensate the RES producers for almost all the loss of energy provision. The economic incentive for increasing RES installation's flexibility through energy storage, to partially shift generation to hours of higher demand/prices, will be also limited as long as the FIT scheme exists and a time-of-use electricity tariff scheme has not been implemented. This is due to the fact that FIT and flat electricity rates do not generate enough revenue so as to compensate the additional costs of storage.

Compliance of PV with/without battery with technical network connection and usage requirements will increasingly become a key requisite for new storage systems. This might however provide for higher complexity for end users and limited scope for combining profitability with technical requirements. Service providers, like utilities, might step in and provide service offerings similar to those that are currently being deployed/developed for PV-only-systems including contracting and leasing models, installation service, connection to other systems, PV/storage optimization including forecasting and tailoring to demand. They might provide these services at much lower costs and provide an added-value to end consumers/storage owners (users).

Based on remote control/optimization of storage systems, the utility might offer additional network services. At present and in the medium-term, the focus will be on complying with network connection requirements determined by the local DSO and regulation. For example, the large utility MVV cooperates with storage manufacturer Ads-tec in a 116 kWh Li-ion pilot project which provides storage services to 14 households and 4 small commerce/industry sites nearby [66].

The large scale roll-out of batteries has raised some safety concerns, with some reports of house-fires caused by uncertified installations. This problem is however largely perceived to be the result of inexpert installers being employed due to the high demand [67].

Incentives

The German low carbon agenda has been strongly supported in incentivising the development of distributed RES, and subsequent adoption of small scale energy storage systems. Approximately half of all battery installations were a result of the state loans and repayment subsidies for energy storage batteries in grid-connected solar PV systems. The other half was deployed without the support of the state programme.

State support program for storage (*'KfW-storage subsidy program'*), takes the form of low-interest loans and investment grants for PV-battery systems. The level of support provided is subject to the size of the PV system and the cost of the storage system, as in the case of the FIT system for solar PV. Whilst the deployment of small battery storage systems is being supported by a dedicated state investment promotion, at a utility-level, no incentives are currently in place and only pilot projects are under development.

Those which did not take advantage of state subsidies were in some cases not eligible, or were unwilling to be bound to the conditions of the subsidy [68]. Monitoring of these unsubsidised users, showed a range of reasons for installing storage:

- Hedging against increasing household electricity tariff increases.
- Pro-active contribution to the energy transition.
- Being front-runners and attracted by new technologies.
- Ease of project implementation based on services relished or engaged, e.g. feasibility consultancy, sales, procurement, installation by manufacturers, public authorities, craftsmen, wholesaler, etc.
- Independence and reliability of supply.

The first phase of the official storage promotion scheme from 2012-2015 provided a total budget of €60m and resulted in ca. 19,000 battery projects. This promotion took the form of:

- Low-interest loan by the state-controlled bank KfW.
- Rebate on the repayment instalment through state funds up to 30% of the installation costs that are eligible for the programme.
- Repayment time and interest rate fixed for 20 years.
- Promotion covers the battery only.
- Promotion refers to a specific share of normed specific battery investment costs:
    - Normed specific battery investment costs are defined as the costs of the battery system including installation divided by the kWp (PV).
    - Promotion will be given only up to that share, irrespective of the actual costs of the battery installation.

The PV system may not feed more than 60% of its installed capacity into the grid. This provision is intended to promote grid-optimal PV feed-in coupled with battery system charging.

The second phase of the official storage promotion scheme runs from 2016 to 2018 provides for a total budget of €30m and takes the following forms of promotion:

- The promotion will be limited to a share of 25% of normed specific battery investment costs in 2016 and will decrease to 10% by Q2 2018.
- Normed specific battery investment costs (set to €2,000/kWp for battery systems installed at the same time as the PV, and €2,000 for *'upgrade'* of existing PV schemes by new battery) may also be adjusted later.

Requirements have been set as follows:

- Minimum operation time of 5 years.
- Feed-in into the grid will be permanently set to max. 50% of the installed PV power for the entire PV lifetime.
- 10-year guarantee by manufacturer for the residual equipment value.

The phase out of the 20-year guaranteed FIT for old PV installations is expected to boost the household energy storage market due to PV plant retrofit, offering a battery market potential in the GW range [69]. By 2033, more than one million PV systems could be potential customers for retrofit batteries [70]. Eligible parties include new projects and *'re-powering'* of existing PV installations, if the PV is older than 6 months; requirements include:

- Connection to the distribution network.
- One, new storage device per PV, including a max. PV size of 30 kW.
- Feed-in into the grid will be permanently set to max. 60% of the installed PV power for the entire PV lifetime (irrespective when the battery lifetime ends).
- Inverter (PV, battery) allows for remote control and parametrisation for dynamic (e.g. (re-)active power supply), but actual use of remote control will be subject to the owner's consent.
- Quality: 7-year guarantee by manufacturer (refunding the residual value of the battery in case the battery breaks down or performs significantly below usual values during the 7-year period after commissioning).

The electrification of the transport sector, specifically electric vehicles, is being promoted through tax and promotional incentives. Federal government also supports R&D into energy storage, hydrogen, fuel cell, as well as electric vehicles [71].

Policy / Regulatory Perspective

There is no storage licence definition in place, nor any indications of such being developed in the short term.

The German energy regulator, the Federal Network Agency (Bundesnetzagentur), has made changes to the control power market in order to allow VPPs to participate. The regulations allow the pooling of facilities to provide services within each of Germany's four transmission control areas. The pool of facilities may be swapped every quarter of an hour. In this way a VPP operator can reassemble its pool in order to meet changing technical restrictions and conditions.

4.3 PJM

Market Overview

PJM manages the high-voltage electric system across 13 states and the District of Columbia [72]. The system has 7,491 MW wind, 667 MW solar, and 6,613 MW hydro in service. Summer peak load in 2015 was 150,295 MW and winter peak was 130,243 MW. In 2015, wind and solar accounted for 2.1% and 0.7% of energy produced in the PJM area. Coal, nuclear and gas form a significant part of the total generation mix providing 30%, 36% and 22% respectively. Note, renewables targets are set at the state level and tracked via the database of State Incentives for Renewables and Efficiency [73].

Grid connected energy storage in the PJM region has grown from 1 MW 5 years ago to 235 MW total installed capacity in 2015. Figure 2 shows the historical and projected energy storage capacity from the PJM energy storage queue [74], the figure shows that the growth trend is expected to continue to the end of 2019 where the total cumulative installed capacity under construction is 706 MW. Historical capacity is listed as storage in service by the end of the given year, and capacity under construction or under review is listed by their projected online dates. It should be noted that some capacity projected to come online in 2014/2015 has been delayed and not all sites under review may actually be delivered in-service.

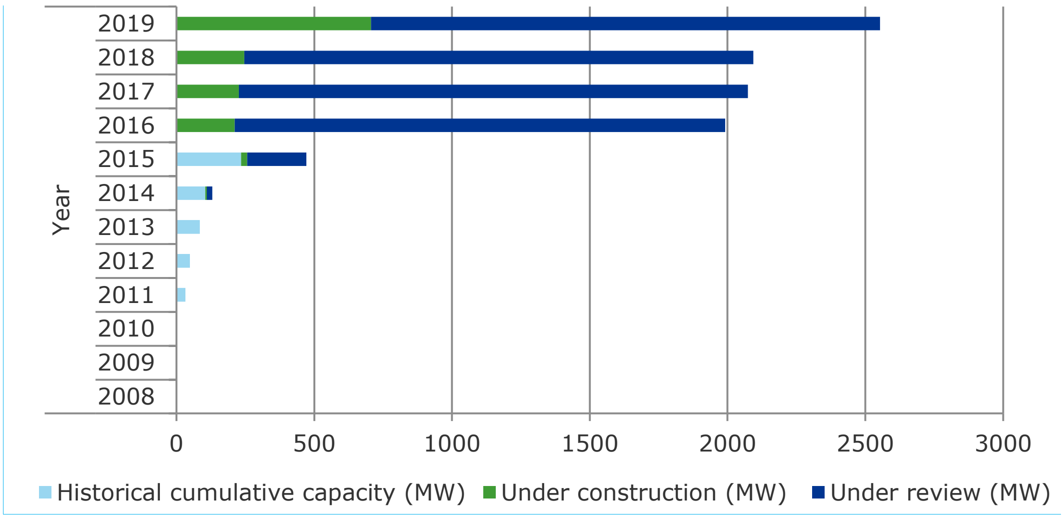

Figure 2: Historical and Projects Energy Storage Capacity from the PJM Queue

For several years a 1 MW array of lithium-ion batteries, owned by AES Energy Storage provided regulation service in the PJM market, and this was supplemented by a further AES 2 MW battery facility. A much larger battery facility, 64 MW AES Laurel Mountain in West Virginia went into operation in 2011 in conjunction with a 98 MW wind farm. The battery facility responds to PJM requests to regulate frequency and is capable of changing its output in less than one second. The primary role of storage that has been constructed and is in the pipeline within the PJM region is for frequency regulation.

The majority of non-pumped hydro storage in PJM takes the form of batteries. The sole flywheel project is a 20 MW Beacon flywheel facility providing regulation services that went online in 2013 in Pennsylvania.

In terms of the business models it is primarily third parties that own storage systems in the PJM area which are mostly grid-connected (with some, especially the older projects, co-located with generation). The primary function of these devices is to provide frequency regulation services in PJM's wholesale market.

In addition to grid-connected energy storage, as of January 2016 there was around 5 MW of batteries participating in the frequency regulation market as demand response (and about 10 MW of water heaters as demand response/regulation) which are not included in the PJM energy storage queue.

PJM has acknowledged a few pilot behind the meter storage projects and is likely to overhaul its rules for behind the meter storage access by late in 2016 in order to facilitate the participation of demand-side resources in the regulation markets.

A recent study has shown that the PJM system, with adequate transmission expansion (up to $13.7 billion) and additional regulation reserves (up to an additional 1,500 MW), would not have any significant reliability issues operating with up to 30% of its energy provided by wind and solar generation [75].

Drivers

FERC, the Federal Energy Regulatory Commission, stated that '.. *current compensation methods for regulation service in Regional Transmission Operator (RTO) and Independent System Operator (ISO) markets fail to acknowledge the inherently greater amount of frequency regulation service being provided by faster-ramping resources'* [76].

This resulted in FERC Order 755, issued in October 2011. This *'.. requires RTOs and ISOs to compensate frequency regulation resources based on the actual service provided, including a capacity payment that includes the marginal unit's opportunity costs and a payment for performance that reflects the quantity of frequency regulation service accurately provided by a resource following the dispatch signal'* [76]. The primary aim of FERC introducing the order was to ensure that technologies that could perform better than expected, and of which benefited the energy system by doing so, would be remunerated correctly. Due to existing system issues, the speed in which a technology could respond to a frequency signal, when providing frequency regulation, was seen as a key area. Though FERC introduced the order it was the role of the system operators to introduce the relevant market changes to achieve the desired result stated in the order.

Barriers

A main barrier for energy storage in PJM has been in its commercialisation. Project developers have struggled to convince financiers who tend to have lower risk tolerance than project developers, who may want to get into the market for strategic reasons. A primary reason for this is the lack of performance and history that the vendors/project developers can cite, particularly for more complex applications or new battery chemistries - that have largely uncharacterized degradation profiles.

However, the situation is improving and the industry has successfully established its value proposition in the regulation market, helped significantly by FERC Order 755 that removed the old, undifferentiated market.

An additional barrier is the costly and time-consuming PJM interconnection queue process - although this is not unique to storage. The interconnection queue covers the process from which the connection application is received by PJM to the point in which the system is in service. Note, storage is treated as generation and must sit in the generation queue. However, this is especially burdensome for smaller storage devices, since (1) second utility service lines must be installed and (2) costly measurement and verification processes are necessary if the storage system is to provide any service to the end-user facility other than PJM market services. In the case of (2) PJM requires a mixed wholesale and retail tariff to be applied to the battery storage system where power charged by the battery is charged at full retail value and power discharged from the battery is credited at wholesale locational marginal pricing (LMP).

Small storage facilities may elect to enter the PJM market as demand response providers rather than go through the normal queue process, however this subjects them to strict demand response rules [77]. As discussed below, FERC Order 745 stipulates that demand response resources which participate in wholesale markets must be compensated for the service they provide at the wholesale energy price.

Incentives

A federal investment tax credit (ITC) of 30% for storage facilities that are paired with wind/solar plants was introduced in 2013, but it is not available to standalone storage or if the percent of electricity stored by the battery from renewables falls below 75%. There are currently no clear accounting or auditing rules specified to show that at least 75% of the energy in the storage system is from renewables. The applicant currently fills out a form to apply for the credit but don't have to provide any data. Large scale storage owners have been noted to be keeping data in case they are audited. This is a significant issue in terms of confirming the performance of the ITC for storage. At the end of 2015, the ITC was extended for 5 years. The tax credit applies to grid-scale renewables all the way down to small residential behind the meter installations and has led to an increase in combining solar and storage.

Individual states within the PJM region have storage incentives [78]. For example:

- The New Jersey Board of Public Utilities, under its Clean Energy Program, awarded incentives to 13 battery storage projects: ca.9 MW in aggregate and totalling $2.9m in incentives as part of its Fiscal Year 2015 Renewable Electric Storage Incentive Solicitation. An additional $6.0m has been allocated for battery storage projects under this program for Fiscal Year 2016. All battery systems need to be co-located with customer-sited solar.
- The Maryland Energy Administration (MEA) under its Game Changers Grant Program has awarded funding to battery storage projects at residential homes with solar to participate in the PJM Frequency Regulation market. This is an active project with Wholesale Market Participation Agreements in place for 20 homes totalling 100 kW in aggregate. The MEA recently closed another Grant Solicitation specific to battery storage for behind the meter applications.

The redesign of the frequency regulation market and the restructuring of the capacity market to allow storage (both explained below in further detail) have also incentivised storage participation. It would appear that storage in PJM is moving to applications combined with renewables as opposed to the single, large transmission-connected deployments and future storage deployment is expected to be considerably more distributed - most notably as PJM is currently in the process of changing and introducing rules for participation for behind the meter storage in the frequency regulation market.

Policy / Regulatory Perspective

In response to FERC Order 755 of 2011, PJM restructured its frequency regulation market to consist of two different services:

- RegA: Traditional frequency regulation resource. Providers include fossil generation (oil and gas steam, oil and gas CF, gas CC, small engines), behind-the-meter water heaters/batteries/PHEV, and demand response (variable speed pumps, ceramic storage, various utility curtailment programs/fast demand response).
- RegD: Fast-moving regulation resource that may not be able to sustain their power output level (D stands for "dynamic.") RegD was designed specifically for energy storage devices with limited storage capabilities; the target is for the RegD signal to be energy neutral over a 15-minute period. Providers include batteries, flywheels, reciprocating engines and fast-ramping gas, and (limited) hydroelectric.

In July 2015, FERC approved a restructuring of PJM's capacity market, enabling non-hydro storage resources to participate for the first time. The motivation was a combination of poor past performance and changing resource mix. The new rules introduce reliability-based capacity payments, and allow for storage, intermittent resources, energy efficiency, and demand response to submit capacity offers based on their average expected output during peak hours. The first auction for the new capacity market was in August 2015, for delivery in 2018/2019. There is however not significant activity taking place around storage in this market, this is primarily due to the misaligned technology specifications and auction price point.

PJM defines an energy storage resource as follows: '*"Energy Storage Resource" shall mean flywheel or battery storage facility solely used for short term storage and injection of energy at a later time to participate in the PJM energy or Ancillary Services markets as a Market Seller'* [78].

PJM is currently in the process of changing rules for behind-the-meter participation in the frequency regulation market, which will impact PV+storage resources as well as standalone storage. This process has been initiated and expected to take until Q4 2016. Changes will potentially impact participation rules / qualifications, operation requirements, and revenue structure.

In January 2016, the US Supreme Court upheld FERC Order 745, which stipulates that demand response resources that participate in wholesale markets must be compensated for the service they provide at the wholesale energy price. The order had been challenged by a lower court, which found that regulating DR was outside of FERC's jurisdiction. The court ruled to overturn FERC 745 on the grounds that it went too far in encroaching on the states' jurisdiction to regulate retail electricity markets. The Supreme Court decision helps remove barriers to market participation for demand-response resources including storage facilities acting as capacity.

Unexpected or Poor Performance

The RegD market design is having unintended consequences, as the amount of RegD accepted into the PJM market can current be too high. Since the RegD signal is meant to be energy neutral in 15-minute intervals, too much RegD procurement can compromise system controllability when excursions last longer than 15 minutes [79]. In order to develop an optimal mix of system services to achieve reliable system performance PJ&M require a variety of services, too much RegD can see diminishing returns in terms of the technical and economic performance of the system. PJM has commissioned a task force to explore solutions to the market and operational issues associated with the current RegD definition [80].

The lack of procedures and auditing rules around the investment tax credit (ITC) has led to a poor transparency in how the combined storage and renewable systems are performing. At least 75% of the energy in the storage system needs to be from renewables to achieve the 30% ITC though there is a lack of clarity around how this monitored and reviewed.

5. Identification of Lessons Learnt and Relevance to the UK Market

This section considers key lessons learnt from the research presented in the previous chapter. The analysis framework is shown in Figure 3 and a summary of the respective locations with the key topics from the framework, including an overview of the current status of the energy storage landscape in the UK is shown in Figure 4 at the end of this section. The following sections provide summarised commentary for each of the respective locations.

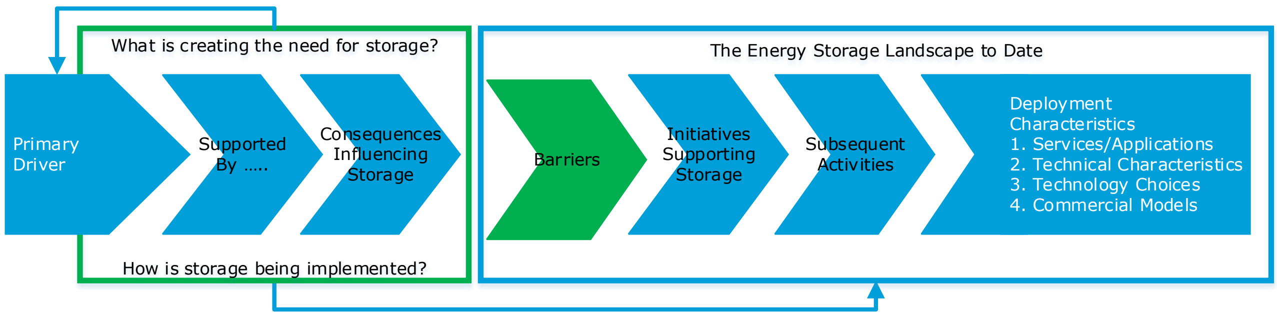

Figure 3: Analysis Framework for PJM, Canada (Ontario), Germany and the UK

5.1 Ontario, Canada

Renewables represent a high proportion of installed capacity (35%) but greater than 53% of peak demand. Two thirds of this capacity is hydro-electric and therefore less intermittent than wind/solar. However, the demand characteristics and high percentage of nuclear generation means that balancing and transmission constraints restrict higher penetration and utilisation of renewables on the grid.

In 2003, Government recognised the critical nature of the electricity system in terms of reliability, affordability and sustainability and took direct action to address the situation through the Integrated Power System Plan 2007; Green Energy and Green Economy Act 2009; and a Feed in Tariff programme. In order to modernize the existing grid and to provide additional flexibility to accommodate more renewables, Ontario's Ministry of Energy introduced their Long Term Energy Plan (LTEP) in 2010, and IESO initiated the Alternative Technologies for Regulation (ATR) project.

The LTEP was updated in 2013 to further address primary aims in the energy market and included specific actions for 50MW storage that IESO facilitated through PPAs as a supporting financial commitment for projects that would allow continued development and understanding of energy storage technologies and applications.

The Ontario Energy Board (OEB) introduced a storage licence in May 2015 that contains a definition of storage, but comprises the same obligations as the generation licence. This storage licence was created after the 50MW IESO projects initiated – that operate under the generation licence - but ahead of any market changes that require the use of the licence. The IESO market rules do not currently include a participant class for storage, and as such, there are currently no formal processes for storage facilities to apply for an IESO authorization for market participation. However, a further LTEP due in 2017 is expected to comprise further storage commitments and market developments; and changes to wind energy procurement mechanism also likely to encourage storage.

The storage licence to date has had little impact on the level of storage installed and the business models found supporting storage in Ontario, and the licence has not been seen as the catalyst for storage in Ontario. However, the next storage facilities procured will need to obtain a licence from the OEB and also authorization from the IESO.

5.2 Germany

The German Government program "Energiewende" is the key driver for energy transition. Germany has committed to reducing greenhouse gas emissions by at least 80% by 2050; is in the process of phasing out its entire nuclear generation fleet by 2023; and aims to increase RES energy contribution to at least 80% by 2050. Such a large increase in renewable energy will require an increase in system flexibility. Whilst Germany is considering system level storage as one of the potential solutions, there is less apparent urgency due interconnections with neighbouring countries that is seen as sufficient to support 60% RES penetration expected in 2035.

The 2000 RES Act created an environment for increasing renewables. PV is encouraged through a stable and progressive FiTs regime, and there is a specific storage subsidy program to drive storage combined with domestic PV as a solution to reduce customer bills.

The KfW storage subsidy program supports the initial CAPEX of a domestic storage system, with parallels to how renewables subsidies have helped drive down the cost of the respective technologies as well as raising public awareness. The incentive program has been considered a success with the first phase oversubscribed and subsequently extended in order to allow more domestic properties to participate. However, interest in residential storage has been such that around 50% of installations did not take advantage of the funding scheme. Renewables represent high proportion of installed capacity (44% (83.8GW/192GW)) and >50% of that is solar, largely on residential properties.

A further phase of incentive funding is proposed for 2016-18, and it is observed that as PV installations near the end of their 20 year FIT then storage may provide a logical extension to maintain consumer value. This is combined with expected continued falls in prices for energy storage, and broader consumer acceptance.

It is also notable that aggregators activity is emerging - for example Lichtblick is marketing the Tesla *'SchwarmBatterie'* to residential PV owners to form part of a grid scale *'swarm storage'* to supply network ancillary services.

It has been mooted that savings in consumer bills may be achieved by reducing network distribution charges due to the deferral of the amount of demand and generation on the system by increasing self-consumption. However, it is also valid to observe that sunk asset costs spread over less consumption will be a balancing consideration in this debate.

The encouragement of RES is also apparent in payments made for network connected generation that is curtailed off due to system constraints. Whilst, this payment in itself could be seen to reduce the value of co-located storage to the generator, it may increase value to the DNO to reduce their curtailment payments.

With reference to the last two points above, it is worth noting the observation that the regulatory regime still favours traditional reinforcement over alternate solution options.

5.3 PJM

There is 14.8 GW of installed renewable capacity in PJM representing less than 10% of the peak system demand of 150 GW in summer. Within PJM is should be noted that renewables targets are set at the state level and although there is no overall target, PJM is however planning ahead to RES penetration levels of 30% and higher.

Promoting energy storage is considered a priority at the federal level in the U.S. and as a result market and policy changes in regions such as California, PJM and New York have all shown significant progress in driving forward energy storage.

There are two apparent market features driving storage – the first is grid connected frequency market services and secondly a demand response market featuring storage predominantly combined with renewable generation. The market for energy storage has been enhanced by (i) regulatory directives (FERC Order 755); (ii) a federal investment tax credit and individual state incentives; and (iii) changes to the PJM Capacity market to allow storage to participate.

Although the aforementioned features, have driven over 235 MW of grid-connected storage in the PJM region it is expected that PJM is moving to combined RES/storage applications as opposed to the single, large transmission-connected deployments. It is notable that the RegD service created for fast responding technologies such as storage has at times seen amounts accepted that have led to concern over system stability. This may raise issues for the 706MW of storage devices in the current connection queue.

A 30% Federal Investment Tax Credit (ITC) was introduced in 2013 for storage twinned with solar/wind where the storage is subject to 75% of the electrical charging being required from a renewable source. The ITC was extended by 5 years in 2015, and it can be viewed that PJM is driving the move to a more distributed storage landscape through changing rules for behind the meter participation in the frequency regulation market.

The rule change process has been initiated and is expected to take until Q4 2016 to complete. Changes will potentially impact participation rules/qualifications, operation requirements, and revenue structure, and may consider the current situation where smaller storage devices charge at retail price and get paid for discharge at Wholesale LMP, resulting in some opting to participate as demand response providers for frequency services instead. In fact single-application facilities, primarily standalone grid connected systems, may be undercut in the future by distributed behind the meter storage / other resource aggregators (e.g. Tesla, Solar City, Sun Edison) who are positioning themselves to maximize value by offering combined services such as intermittency management/frequency regulation/contingency reserves, that are supported by various state initiatives.

5.4 Relevance to the UK Market

Each region studied has their own variant on a primary driver behind increasing the need for, and interest in, the deployment of storage. It is however apparent in each region that storage can play a pivotal role in the future energy system, and the primary long term drivers originate in meeting carbon reduction targets and system problems associated with a higher renewable energy penetration in the generation mix. Observations were also made in relation to the anticipated wider economic benefits of being at the forefront of storage developments.

The UK is aiming to enable a level playing field within storage and the wider market and although there is an understanding of the role storage could play in the future energy system, no incentives, legislation or policies involving energy storage have been implemented to date.

PJM and Canada have both taken a top down approach to energy storage development which has mandated that specific stakeholders (PJM and IESO) change existing value propositions and services to enable fast responding technologies including storage to participate fairly in the existing market. In the UK, without this top down direction, National Grid has been proactive in introducing a new market service due to technical system requirements, Enhanced Frequency Response, for which electrical storage will be a key contributor.

The UK has variously funded energy storage demonstration projects with an array of technologies and points of network connection. Such funding for storage projects is evident in the regions studied with alternative forms of encouragement or financial incentives – LTEP and IESO PPAs in Ontario and FERC Order 755 and the RegD service in PJM. This can be compared with the various Government and regulatory funding (LCNF) for storage R&D projects in the UK.

It could be regarded that such R&D for grid connected storage projects have served their significant purpose, and it is believed that towards the end of 2016 that storage will begin to be deployed in the energy system in the UK with commercially attractive business models in place – not least through the National Grid EFR tender.

An observation in relation to this development is the position PJM find themselves in with regard to potentially excess amounts of RegD service. Clearly, the specification, procurement and correct operation of the technical and commercial aspects of such arrangements will be important to the respective success of all parties involved.

Despite an aggressive renewables energy agenda, Germany has sufficient system flexibility to cater for 60% renewables penetration due to the interconnection capacity. Whilst this differs to the UK energy system, the greater interconnection of Europe and the UK is a consideration.

Possibly as a consequence of system level stability, Germany has identified domestic storage as a game changer similar to domestic PV. This has seen encouragement and high penetration of PV through a structured and progressive FIT; and now through the kfW storage subsidy scheme to help realise further benefits of the installed and continued expansion of PV. It is also of note that around 50% of domestic storage installations do not receive the funding but are installed on the basis of consumer interest and expectation of savings in other areas brought about by an increasing awareness of storage potential.

There is already UK interest from developers in promoting storage installations with existing PV installations, and the experience in Germany gives clear indication of the potential of well-structured schemes, as well as a general increase in customer awareness. The possible influence of smart meters and Time of Use tariffs in the UK for raising the potential benefits of storage and wider consumer interest in a wider energy agenda may be worthy of consideration.

In Ontario, the introduction of a storage licence has not, to date, been considered a game charger. This could be regarded more as a preparatory step and recognition for the need for such a licence without the requisite market framework in which it would sit. As it stands, it replicates the generation licence with only a change to define storage. There are benefits and detriments, as currently being discussed in the UK, to introducing a storage licence. However it is apparent from the evidence in Ontario that the correct policy, regulation and processes are put in place to ensure a licence is utilised by the existing stakeholders. It is perhaps worthy of consideration that any initiative to discuss and/or consult on a storage licence in the UK could act as a catalyst for the necessary wider discussions on the technical, regulatory, commercial and market issues for storage.

In Germany, it was observed that there may be potential unintended or conflicting consequences for storage, in some of the regulatory arrangements. DNO payments to RES for constrained off generation disincentives the generator to invest in storage but may encourage the DNO to consider storage to avoid such constraint payments. Also, whilst increased “self-consumption” by customers may reduce their energy and network system payments, the fixed costs of networks will still have to be recovered from fewer customers/less units. Both these should be considered in a regulatory environment that favours traditional reinforcement.

There is evidence of initiatives to drive “behind the meter” distributed storage, primarily with RES, and acknowledgement of the potential this offers for aggregated market services including frequency response services. Germany and PJM are already seeing third party entrants (aggregators) seeking to exploit the growth in storage and developing market features against which such services can be exploited.

There are parallels between barriers which have been identified in the UK and those across the regions studied. Similar to the UK a significant barrier for investors, developers and domestic customers interested in storage is the lack of longer term contracts and a commercially attractive business case. To support the business case and investment interest, CAPEX support was introduced in Germany; Long term PPAs in Canada; and in PJM CAPEX support via the federal tax incentives and market support by ensuring technologies are being paid for the actual service they are delivering and benefit they are providing to the system.

Storage offers a range of services to the market, often mutually exclusive, and there may still be some way to go in realising all those services to make the technology sufficiently attractive to meet the aspirations of the low carbon agenda. However, with respect to that point, it is of course necessary to know the ideal amount, location and use of storage.

In summary, there are a number of features that offer useful insight for the UK, and Ofgem should be mindful of the need for a level playing field and possible unintended consequences, whilst supporting a stable framework for parties seeking to participate and/or invest in the market. Continuing to follow these and other regions will provide insight to the levels of adoption and success, or otherwise, of the ongoing market developments.

	Primary Driver	Supported By	Consequences Influencing Storage	Barriers	Initiatives Supporting Storage	Subsequent Activities	Deployment Characteristics
CANADA	Grid modernizing and increased flexibility to accommodate increasing renewables	- Green Energy and Green Economy Act - Integrated Power System Plan (IPSP) - Long Term Energy Plan (LTEP) - IESO ATR project.	- LTEP 2013 required IESO to include a 50MW storage procurement process - OEB introduced a licence for storage, May 2015	- Difficult to form a business case for energy storage. - no market participant class for storage	- Long term PPA's for storage 4 – 10 years offered by IESO - Licence recognition - Further LTEPs to address storage	- Further market developments required to utilise storage licence - New Markets Entrants	- A variety of storage research and development projects have been deployed, with different technology, sizes, stakeholders and ownership models - A pipeline of over 50 MW of storage planned for construction - Increased network flexibility
GERMANY	- Carbon Emmission Reduction Targets - Increased renewable penetration	- Renewable Incentives - In 2004 the first large-scale feed-in tariff (FIT) scheme was introduced	- Interconnection flexibility at a system level sufficient - Attention on domestic RES plus storage	- High Energy Storage CAPEX Costs and therefore difficult to form business model - Public awareness of domestic energy storage technology	KfW storage subsidy program	Increased interest in domestic storage both from the public and key stakeholders	- 25,000 battery based storage systems were available in Germany by the end of 2015 - With a total installed capacity of 160 MWh (average capacity of 6.5 KWh / battery) - Aggregator market activity
PJM	Promoting energy storage is a priority at the federal level in the U.S.	Acts such as the American Recovery and Reinvestment Act which provided $185 million to 16 energy storage demonstration projects helped support storage development	Increased awareness for energy storage lead to changes in legislation and policy in the U.S. to allow storage to compete fairly in the existing energy markets	Compensation methods for the Frequency Regulation (FR) do not represent the amount of FR being provided by faster-ramping resources such as energy storage	- FERC Order 755 drove the PJM FR market restructuring - A federal investment tax credit for storage was introduced - The capacity market was restructured to enable storage to participate	The amount of frequency regulation accepted into the PJM market is now considered to be too high	- There is over 235 MW of installed grid connected energy storage - Focus is shifting to "behind the meter" RES plus storage and aggregated services provision (including frequency)
UK	- Energy policy focus shifted to the energy security part of the energy trilemma - Carbon Emmission Reduction Targets	Policies promoting Renewable Energy and carbon reduction	- Increase in renewable penetration - Reduction in conventional generation - Increased flexibility / stability required	Many reports highlight the current barriers of energy storage in the UK (See A, B and C below)	- Energy Storage Demonstration projects funded by DECC and Ofgem - Introduction of the Enhanced Frequency Regulation service by National Grid	- External increased interest in the UK Energy Storage Market - Increased awareness of the technology - New business models	- The UK has a variety of storage research and development projects, with different technology, sizes and stakeholders involved - Increased awareness and understanding of the value of system flexibility - National Grid procurement of up to 200MW Enhanced Frequency Response comprising storage

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Figure 4: Analysis Framework for PJM, Canada (Ontario), Germany and the UK

6. Summary

Each region has varying drivers for energy storage deployment and differing approaches to understanding the role that energy storage can play, removing barriers, and incentivising and targeting deployment.

The Canadian Government took direct action to address energy industry concerns, and with increasing renewables penetration on the agenda, the authorities in Ontario introduced direct actions for storage and the ongoing development of market arrangements to accommodate further storage deployments.

In the USA, storage has been mandated from the highest political level. This has the overarching aim that storage will be well integrated and understood as networks and markets begin to operate in ways they were not originally designed for, when higher penetrations of renewables and changes to demand patterns and behaviours become apparent.

In Germany, the system flexibility though interconnectors to support the integration of renewables, will have contributed to less attention on grid connected storage. The incentive in Germany to support domestic storage installations, and resultant uptake, will help drive down the cost of domestic storage, progress the maturity of the industry, and in the longer term help to bring down the cost of the energy to the bill payer.

In all regions, the incentives and changes to markets and policy have been implemented to allow storage to compete fairly within the energy system and has raised the profile of, and level of deployed storage. General trends identified across all regions are the transition to a more smart and flexible energy system with an incumbent market that allows all technologies to compete on an equal playing field, as well as designing and implementing policy and incentives now that will support the future of storage in the region. Renewables combined with storage are also stated, most notably, in Germany and PJM.

Observations made in this report in relation to considerations for the UK included:

- Government directed integrated energy plans and specific mandates for storage
- Incentivised R&D projects to develop the requisite technical and commercial knowledge to advance the prospects for storage for different applications at different system levels
- Aligning and supporting market arrangements with due consideration to treatment of RES and RES plus storage, including subsidy schemes
- Consumer awareness of the energy transition agenda and the adoption/acceptance of storage
- Ensuring the regulatory environment and incentives are appropriate, stable and enduring to drive the required amount and nature of storage

Taking the last point above requires a clear view of the role and location (grid-connected to domestic "behind the meter") for storage and the expected or resultant volumes to allow suitable policies and market arrangements to form. This requires consideration of the development path for renewables and the electrification of heat and transport, and the role that different storage technologies at different locations can provide.

Based on the research, analysis and findings, Ofgem may wish to consider which drivers, incentives, policy and legislation seen across the regions may support a positive transition for energy storage in the UK. It would also be advisable to follow the ongoing market developments within the regions considered, and possibly others.

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