Workshop Proceedings

The Transformative Power of Storage:

Developing IRENA's Electricity Storage Roadmap

Final Version

Dusseldorf, 27 March 2014

Participants of the IRENA Energy Storage Policy and Regulation Workshop on 27 March.
The workshop took place during the 3rd Energy Storage - International Conference and Exhibition for the Storage of Renewable Energies.

1. Introduction

The International Renewable Energy Agency (IRENA) organised an "International Energy Storage Policy and Regulation Workshop" on 27 March 2014 in Dusseldorf, Germany. The workshop took place alongside the 3rd Energy Storage - International Conference and Exhibition for the Storage of Renewable Energies that took place from 25-27 March in Dusseldorf.

The aim of this workshop was to identify the key energy storage technologies and applications to support the accelerated deployment of renewables, and to identify what applications, best practices and lessons should be highlighted in IRENA's global technology roadmap for electricity storage. Workshop participants consisted of representatives from 13 IRENA countries, industry representatives, academia, and other relevant stakeholders. 45 people participated in the workshop.

1.1 Structure of the workshop

The workshop was opened by IRENA's Deputy Director General Frank Wouters. Subsequently, the Director of IRENA Innovation and Technology Centre (IITC) Dolf Gielen presented IRENA's roadmap towards a doubling of the renewable energy share by 2030 (REmap 2030), and IRENA's activities on energy storage so far. IRENA's activities include:

- Electricity Storage and Renewables for Island Power: A Guide for Decision Makers (May, 2012);
- IRENA and IEA-ETSAP Electricity Storage Technology brief (April, 2012);
- Smart Grids and Renewables: A Guide to Effective Deployment (November, 2013);
- IRENA's grid stability studies for islands;
- Storage discussions during IRENA's 2nd International Off-grid Renewable Energy Conference and Exhibition (IOREC, 16-17 June 2014).

The introduction presentations were followed by a panel discussion with inputs from five experts. The list of experts and their respective topics can be found in Table 1.

Table 1. List of experts in panel discussion

Expert	Organisation	Topic
Franck Al Shakarchi	French Atomic Energy and Alternative Energies Commission, France	Electricity storage: requirements, experimental results and tools
Allan Schroeder Pedersen	Technical University of Denmark; Energinet, Denmark	European Energy Storage Technology Development, Roadmap towards 2030
Luigi Mazzocchi	Ricerca sul Sistema Energetico - RSE SpA, Italy	Cost-Benefit of Electricity Storage
Andreas Zucker	Joint Research Centre, Petten European Commission	Valuing Electricity Storage in Markets
Tetsuji Tomita	The Institute of Energy Economics, Japan	Policies and Regulations for Electricity Storage in Japan

The workshop concluded with four roundtables. Each roundtable was organised around specific application area for electricity storage for renewables. The reason for grouping the roundtables around application areas is that government policies for different application areas are likely to differ (see Table 2). Therefore, best practices and international cooperation activities are likely to depend on the different national policies that policy makers consider.

Table 2. Topics of roundtables

Roundtable	Application	Time frame
Storage for grid stability	Voltage support	Millisec-sec
	Frequency regulation	Minute
Storage for dispatchability	Load following	<15min
	Demand shifting/peak reduction	<15min
	Ramp rate control	<15min
	Spinning Reserve	<15min
	Black start	<1hour
Long-term storage for renewables	Congestion relief	>1hour
	Investment deferral	>1hour
	Self-consumption	>1hour
	Daily/Seasonal	>1hour
Storage for off-grid solutions	Portable	
	Single Building	
	Mini-grids	

In each of the round tables, the participants addressed the following five questions:

- ***Which location (generation, transmission, distribution, consumers)*** *will be most relevant for storage deployment?*
- *Which* ***technology developments*** *in storage are needed to facilitate renewable energy grid integration?*
- *What will be the* ***key drivers for commercialization*** *of electricity storage technologies for renewables deployment?*
- *Which* ***policies and regulations*** *for electricity storage are needed to support the accelerated deployment of renewables?*
- *Based on the answer above, what are the three key areas where IRENA members can support the electricity storage for renewables through* ***international cooperation*** *activities?*

These proceedings will first provide the background for IRENA's activities in electricity storage (section 2), followed with a discussion from the insights of the expert panel (section 3). Section four will discuss the insights of the four roundtables, and the conclusions of each of the discussions. The final section will provide the conclusions from the workshop for IRENA's electricity storage roadmap.

2. IRENA and energy storage

In January 2014, IRENA launched its global renewable energy roadmap towards 2030 (REmap 2030). This roadmap identifies a number of pathways to double the share of renewable energy in the period from 2010 to 2030. The roadmap is based on an in-depth analysis of existing national renewable energy plans and additional renewable energy options in 26 countries across the globe. Together, these 26 countries account for 75 percent of global energy consumption.

The results suggest that existing national renewable energy plans would increase the RE share from 18 percent in 2010 to 21 percent in 2030. However, there are a large number of additional renewable energy options that can be pursued within these countries to achieve a RE share of around 36 percent. The power sector is one of the sectors where the growth of renewables will be largest reaching around 44 percent of power generation in 2030 (IRENA, 2014).

The largest growth for renewable power generation will be from wind energy and photovoltaics. Governments expect the installed capacity from wind power to triple from 318 GW today (GWEC 2014) to 1000 GW in 2030, and to quadruple for solar PV with 141 GW today (BNEF, 2014) and 400 GW in 2030. However, the analysis of additional RE options suggest that there is a substantial potential to grow these two sources even further, up to 1600 GW for wind and 1250 GW for solar PV (IRENA, 2014).

Both wind and solar PV are so-called variable renewable energy sources (vRE), which means that they will only be able to produce electricity when the wind is blowing or the sun is shining. This is different from conventional technologies like nuclear power or fossil fuel power generation which produce electricity continuously or can be switched on upon demand.

At the global level, the share of vREs is still very small – only 2.5% of electricity production came from wind and solar PV in 2012. In most cases, grid operators can handle vRE shares up to 45% of annual production without significantly increasing the power system costs in the long run (IEA 2014a). For example, pumped hydro has been used for many years in most countries to support load shifting from electricity production at night time to support peak hours during daytime. However, for some countries the variable nature of wind and solar PV is already creating a new paradigm for managing and operating grids. In the month of December 2013, for example, Denmark produced 55% of all electricity generation from wind power.

Another characteristics of wind and solar PV is that they are modular – their size can be tailored and expanded as demand for electricity grows. Producing electricity close to demand centres means reduced need for costly transmission lines and it can provide electricity for small islands, remote locations, and for local communities on the spot. On the other hand, in some cases the wind and solar resources are far away from demand centres, and additional transmission lines are needed to connect wind turbines in windy locations across demand centres a country.

Combined, these two characteristics – variability and modularity – create new technical opportunities and challenges for planning and operating the future power system. For emerging economies – where around 80% of the estimated 10 billion dollar of grid investments will take place – wind and solar PV provide new means to accommodate the rapidly growing demand for electricity. For isolated states, it will even allow leapfrogging to new grid systems that are more decentralised, more variable, and run without marginal costs. Regardless of the pathway, it is clear that electricity storage will open up new opportunities and challenges.

2.1 Context, scope and timeline

IRENA is developing two separate roadmaps to examine the consequences of the rapid growth of variable renewables onto the grid infrastructure. The first technology roadmap will examine different strategies for renewable energy grid integration. In this roadmap, energy storage is only one of many options for the integration of renewables. Other options that will be discussed in this roadmap include the development and strengthening of grids and interconnectors, demand side management, and the use of dispatchable power plants and markets to balance supply and demand.

The second technology roadmap – and the focus of this workshop - will look specifically at electricity storage, because the recent advances in this technology are creating possibilities for a new paradigm of operating, managing, and building grid infrastructure. The current deployment of electricity storage technologies remains limited. Only 150 GW of electricity storage capacity is installed, compared to 5500 GW of installed electricity generation. Furthermore, more than 99% of this storage capacity is pumped hydro (140 GW). Other storage technologies are compressed air (CAES), batteries (lead-acid, NaS, Li-ion, NiCd, redox-flow), and flywheels (IEA, 2014b). Except for the use of lead-acid batteries, most electricity storage technologies are at a pilot scale.

In the last two years, IRENA has already developed a number of analyses for specific electricity storage markets. IRENA's electricity storage technology brief provides an overview of the different electricity storage technologies (IRENA-IEA-ETSAP, 2012a). For islands, IRENA has developed a guide for decision-makers that outlines possible strategies for electricity storage (IRENA, 2012b). For off-grid applications, IRENA organises the bi-annual International Off-Grid Renewable Energy Conference and Exhibition (IOREC) featuring storage solutions.

Building on these projects, the objective of IRENA's roadmap is to identify international cooperation opportunities for electricity storage to achieve a doubling of the share of renewables in the global energy mix, as outlined in IRENA's global renewable energy roadmap (IRENA, 2014). This roadmap includes both accelerated deployment of renewable energy options as well as energy efficiency improvements.

The roadmap will specifically focus on the role of electricity storage. The roadmap recognises that thermal applications for integrating variable renewable energy into the systems will be an important and in many cases the cheapest options for coping with variable renewables. For example, residential electric boilers are already used effectively to reduce peak capacity in France, combined heat and power (CHP) plants can be used to provide a more flexible generation mix, longer-term thermal storage facilities can provide seasonal flexibility, and thermal cooling technologies can free other generation sources to provide balancing services. However, the scope of this roadmap will be on electricity storage technologies that are immediately reversible, so can be used to both store and supply electricity when needed.

The geographical scope of IRENA's roadmap is global. IRENA recognises that there are already a large number of roadmaps on electricity storage available, including the recent development of the Energy Storage Roadmap of the International Energy Agency (IEA, 2014b). Most roadmaps focus on a specific geographical area, on specific milestones for technology deployment (costs, efficiency, capacity), or on research, development and demonstration priorities for storage deployment. Therefore, the specific aim of IRENA's roadmap is to focus on the identification of international cooperation opportunities for electricity storage for renewables across both developed and developing countries. In this context, deployment opportunities for electricity storage for renewables in developing countries and islands will receive special attention. Another area that will be of interest to IRENA members is electricity storage for self-consumption of renewable power generation. This is of particular interest in both developed economies with high electricity prices as well as emerging economies were reliable and uninterrupted electricity generation is required.

The intention is to present a draft roadmap report within a year. This roadmap will be critical in identifying how countries can benefit from this emerging paradigm.

3. Insights from the expert panel

The input statements of the five expert panels covered the whole range of activities, starting from technology development, to economic evaluations, and to policies. The presentations are available online at: www.irena.org/menu/index.aspx?mnu=Subcat&PriMenuID=30&CatID=79&SubcatID=411.

Franck Al Shakarchi - Electricity storage: requirements, experimental results and tools

Mr. Shakarchi presented the work of the French Atomic Energy and Alternative Energies Commission (CEA). The CEA is currently involved in doing benchmarking analysis for different storage technologies, modelling of storage, design of energy management systems, and system testing with grid simulators. Mr. Al Shakarchi identified three areas where storage can play a role: 1) support for transmission system operators to control power fluctuations and support frequency, 2) voltage control in distribution networks, and 3) self-consumption. He also presented three cases in which policy makers have developed regulation for power fluctuations that are supporting storage deployment. The first case is the PREPA request for proposals in Puerto Rico, which expects power producers to smooth their production and provide primary frequency control. The second case is the feed in tariff for wind power in the French islands, which requires 30 minutes production forecasts with limited variation in real production. The third case is the request for proposals for solar PV systems in the French islands, which require forecasting and trapezoidal production pattern with specific ramp-up and ramp-down rates. Furthermore, Mr. Al Shakarchi presented a number of storage projects in the French islands where generation costs at peak production are around 60ct€/kWh. The projects include a vanadium redox flow battery, a Zebra (Sodium Nickel Chloride) battery, the IPERD project for low voltage network support, and the SOLION project for PV self-consumption.

Allan Schrøder Pedersen - European Energy Storage Technology Development, Roadmap towards 2030.

Mr. Schrøder Pedersen presented the result of the European EERA/EASE technology roadmap on energy storage, which includes chemical, electrochemical, mechanical, thermal and electrical energy storage. Based on this roadmap, Mr. Pedersen also developed a Danish roadmap with RD&D recommendations for energy storage. An important starting point for this roadmap is Energinet's vision of a fossil free Denmark in 2050. In this context, the conversion of excess and cheap electricity into hydrogen – creating a synergy with the current biomass and gas infrastructure – will be an important option. Furthermore, thermal solutions – like Pit, Borehole, or aquifer thermal storage - will be one of the cheaper options to provide short- and long-term energy storage. The fundamental question for battery will be if the energy density can be improved. Furthermore, improved battery technologies will need to be tested in renewable energy environment.

Luigi Mazzocchi - Cost-Benefit of Electricity Storage.

Mr. Mazzocchi presented the work of Ricerca sul Sistema Energetico - RSE SpA, which is a subsidiary of GSE. He provided an overview of existing energy storage projects in Europe, which shows that most projects take place using electrochemical storage devices applied at the distribution and end-user level. Also from a budgetary perspective, most funding goes to electrochemical storage devices, especially applications in transmission grids. RSE SpA has analysed the costs and benefit for mainly battery storage applications in Italy. The results show that battery applications for primary reserve in the transmission grid and for the recovery of wind energy losses are uneconomical with the current technology status. Storage can provide additional and economic benefits for PV plants that would require to provide primary reserve (assumed to be 1.5% nominal power). Furthermore, energy storage for residential PV deployment is at the moment still uneconomical for most users, but storage system cost reductions in the order of 10 to 35% could make the economic positive for around 40% of the residential users with systems in the range of 2.5-4.5 kWh/day. In conclusion, Mr. Mazzocchi argued that electrochemical storage is still relative expensive for grid-connected applications, and that continued R&D, production innovation and demonstration projects are needed to achieve cost reductions targets in the next five to ten years. In the mid-long term, battery storage systems will become a key technology for a decarbonised electrical system.

Andreas Zucker - Valuing Electricity Storage in Markets.

Mr. Zucker presented the results of a recent Joint Research Centre (JRC) publication that evaluated a number of valuation methods for storage in electricity markets (Zucker et al., 2013). He pointed out that there are two different ways of valuing storage: from an investors' perspective to assess the profitability, and from a systems perspective to assess the benefits. The results show that the engineering studies show a wide variety in estimated margins required for profitability – ranging from 10-90 euros/kW. Only a few studies explore the profitability of providing both daily (through arbitrage) and real time (through reserve markets) flexibility. The assumed capital costs (ranging from 300 to 1000 euros/kW) and the assumed discount factor (ranging from 6 to 10 %) are important factors. System benefits of storage are along the entire value chain, in both regulated and deregulated parts of the electricity system. An overview of existing studies suggests that the value differs across the value chain, and that more systematic studies are needed to understand how storage can be used for multiple purposes simultaneously.

Tetsuji Tomita - Policies and Regulations for Electricity Storage in Japan.

Mr. Tomita presented existing policies and regulation for electricity storage in Japan. Japan's interest in electricity storage stems from limited opportunities to construct new pumped hydro stations beyond the 26 GW used for load levelling and reliability/quality improvements. Although the exact mix of nuclear, renewables and fossil fuels is not specified in the latest new Basic Energy Plan (released 25th February 2014), grid enhancement for renewables deployment will be one of the priority issues. In 2012, the Japanese established a Storage Battery Strategy Project Team in the Ministry of Economy, Trade, and Industry (METI) to formulate and implement integrated strategic policies for storage batteries, including a certification system. The strategy assumes that the storage battery market will consist for 35% out of large scale batteries for storage applications, 25% out of residential or industrial use applications, and 40% out of vehicle use. In 2013, the New Energy and Industrial Technology Development Organization (NEDO) released an updated technology roadmap for stationary batteries with targets for both grid and demand side applications in terms of life span and costs. Major challenges are cost reduction, enhanced safety, discharge/charge efficiency, durability, recycle technology, and resource restrictions. The Japanese government has established a number of major subsidy programmes for 2012-2013, provides guidelines to secure electrical quality, and has simplified procedures to promote battery deployment. Examples of electricity storage projects for renewables are the Wakkani Mega Solar Project, the Miyakojima Remote Island Microgrids, a large-scale battery energy storage system by Tohuku Electric power Co. Inc., and a multi-purpose grid storage project with Hokkaido Electric Power Co. Inc.

The expert panel was followed by a discussion on the following issues:

Capacity markets

The performance and costs of energy storage technologies have improved rapidly, but technology development is only one part of the equation. The other part of the equation is how storage will be renumerated. A number of countries are looking at market mechanisms to support a more flexible energy system, including efforts to support capacity markets. The definition and scope of 'capacity markets', however, is not clear yet and differs per region. The UK has created a Capacity Market with auctions providing a predictable revenue stream to capacity providers in return for providing reliable reserves when needed, whilst in the US the regional transmission organisation PJM has a 3 year forward capacity market (Known as Reliability Pricing Model or RPM). More research and scenario analysis is needed on how the different designs for capacity markets affect the development of the energy storage market. The roadmap will need to consider the importance of the interplay between technological developments and market developments.

Storage for developing countries

There are a number of initiatives to support electricity storage technologies in developed countries and islands. For developing countries, there are a number of additional issues that need to be considered:

A. Resource assessment are still lacking, especially in developing countries, which is preventing the growth of renewables and is hampering planning;
B. Developing countries are attracting investment streams into their electricity systems to replace, upgrade, and expand the existing grid. To ensure universal access, more focus is needed on the role that storage can play in distributed systems. To promote energy access, the economics of micro grids with RE and storage need to be sorted out as soon as possible.
C. Interconnection between adjacent countries can be useful for them to complement each other, but there are a number of political barriers that are hampering this process. The interplay between interconnections on the one hand, and storage on the other hand should be examined.

Standardisation and technical regulation

For the creation of energy storage markets, it is important to agree to a minimum level of standardisation and technical regulations. For example, in most cases existing grid codes are insufficient to account for the variable and decentralised nature of renewables. However, technical specifications often depend on the specific situation in which variable renewables and storage are deployed. This is particularly relevant for small-scale systems where fluctuations can have significant effects on the entire grid. For example, in most cases regulations requireing a 30 minute forecast from vRE sources with other flexibility options would be sufficient to operate the system.

4. Roundtable results

The roundtable took 1.5 hours, and workshop participants were free to choose one of the four roundtables. Each roundtable consisted of around 8-10 workshop participants. The discussion was subsequently summarised according to the five questions outlined at the start of the workshop. At the end of the discussion, the groups presented back to the workshop.

4.1 Storage for grid stability

This roundtable examined electricity storage for supporting voltage and frequency control for renewables integration.

Which location (generation, transmission, distribution, consumers) ***will be most relevant for storage deployment?***
Storage technologies for grid stability, particularly for frequency control, can be located anywhere in the electricity system (from generation to consumer). In larger T&D systems, frequency control services can be created. Voltage and reactive power support is more localised (depends on where you need voltage support) and requires also power-electronics on the generation side. Therefore, more complex to have a market for reactive power or voltage support services. For both new and existing grids, storage should be seen as an integral grid element, and the grid should be design or modify considering the storage component from the beginning. Also, storage should not be designed for grid stability only, but storage should serve different purposes as stability + assured reliability + dispatch management + seasonality + others The location of storage systems also depends on who should pay for storage for grid stability. Today, stability is normally a responsibility of (investment from) the TSO. However some participants considered that in the future responsibility and cost might be transferred to the RE generator, while others consider that may continue to be TSO's responsibility. Some participants did not think that the distribution of obligations is the important issue, but that the real issue is having a market that allows the responsible party to access ancillary services from the generator or any other market actor.
Which ***technology developments*** *in storage are needed to facilitate renewable energy grid integration?*
Technologies already exist (at different levels: from R&D to commercial). Therefore, no urgent need for brand new technologies. Pump hydro will continue to grow, and Li-ion continues to be a very promising technology. Electric vehicles (EV) will help to bring technology cost down (e.g. Li-ion batteries) enabling the transition from mobile applications to future stationary applications.

technologies as Li-ion batteries. Thermal energy storage will be a relevant technology for demand side management.

Instead, there is a need for more R&D to improve and reduce cost of existing and emerging technologies, as well as more demonstration projects for specific applications. Also, there is need for R&D at system level, not at component level. For example, integration of different storage technologies in one electricity systems. Fly wheels still have scalability and safety issues and super capacitors and SMES can be feasible in combination with other. For second-life applications of batteries, system level R&D is needed as well as collection of lessons learnt from available experience

Standardization and testing are relevant, but at the moment some technologies are developing so fast that standardization cannot be done yet for those.

*What will be the **key drivers for commercialization** of electricity storage technologies for renewables deployment?*

- Very important to facilitate the creation of markets for ancillary services
- Establishment of grid standards/codes which include grid stability requirements for generators
- Frequency control services seem to already be a profitable business
- Regulations and policies that free the market for ancillary services
- Request RE generators to assure grid stability by establishing technical standards/codes for RE penetration levels. Then let the generator to use the market to find grid stability service providers

*Which **policies and regulations** for electricity storage are needed to support the accelerated deployment of renewables?*

- Facilitate market for ancillary services
- Pricing grid stability services (incentives). For example: FiT for Wind generation + Battery as implemented in French islands
- Mandates for grid stability requirements for RE generators
- Long-term stability in policies

*Based on the answer in section 3, what are the three key areas where IRENA members can support the electricity storage for renewables through **international cooperation** activities?*

1. Capacity building for regulators on the latest technology developments and market incentives (and market tools) for electricity storage.
2. Sharing experiences and case studies – no need for demo projects everywhere
3. Technical collaboration – Including R&D programmes, sharing test results and benchmarking
4. Facilitate clustering small markets to create economy of scale; e.g. many small islands in one region requiring storage systems -> cluster them to leverage on scale
5. Discuss opportunities for integration of ancillary markets
6. Harmonization of international standards

Additional comments

Some participants considered that*:*

- IRENA's roadmap should focus on priorities for accelerating the deployment of storage technologies, instead of focusing on international cooperation. For example, IRENA may highlight that the first step for the acceleration of electricity storage deployment is to develop appropriate regulations for RE grid integration (including storage as a grid element). In terms of technology, the priorities should be demonstration and improvement of technologies for short-term storage. Mid and long-term storage will follow, but is more closely linked to the developments in other solutions, such as other system flexibility options or weather forecasting.
- There is no need to differentiate storage solutions based on different applications (e.g. only grid stability), as storage projects are viable when they provide services to different applications (e.g. grid stability + transmission congestion + DSM).
- IRENA should also provide guidance on how to mitigate technical risk for storage projects, making them bankable. For example providing loan guarantee.
- IRENA should continue organizing forums that enabling sharing experiences in different regions

4.2 Storage for dispatchability

This roundtable discussed a number of electricity storage applications to ensure that variable renewable generation matches demand. This includes load following and demand/peak shifting, ramp rate control, and the providing spinning reserve and support black starts.

***Which location (generation, transmission, distribution, consumers)** will be most relevant for storage deployment?*
Electricity storage for dispatchability can be applied across the entire electricity value chain. However, it is commercially easier to apply electricity storage at a generation level. For distributed RE power generation, electricity storage for dispatchability can also be applied at the consumer level. In that case consumers should be regarded as generators. This would also be the case for EVs is easier at consumer level. Having a time-of-supply variable feed-in tariff can promote generation-side storage.
*Which **technology developments** in storage are needed to facilitate renewable energy grid integration?*
The emerging market for Electric Vehicles is seen as an important application area for electricity storage for dispatchability. The electrification of the transport sector will result in growing electricity demand, and batteries for EVs need to be designed to be able to be used for stationary applications at the end of their "mobile life". From this perspective, batteries and supercapacitors in the context

growing EVs market will be key. At the same time, smart charging of EVs will be key, as it can provide peak shaving and demand shifting.

For developing countries, technological improvements should be on stationary applications: reliability improvements in power grids are still necessary. Safety, clean chemical compounds, recyclability (decommissioning cost) are also very important in developing countries context.

For large-scale grid-connected systems, technology developments for robust, scalable and cheaper software will facilitate integration of storage, as well as cheaper and easier smart metering and grid interaction: cheaper, more flexible and robust smart grids components. In this context, technology developments to reduce the costs of interconnection will an important measure to evaluate the development of storage technologies. Similarly, improved thermal energy storage and materials and improved heat pumps efficiency and flexibility are needed.

Technology development, and cost reductions for electricity storage technologies, need to be accompanied by developments of a consistent modelling framework to look at cost effectiveness.

*What will be the **key drivers for commercialization** of electricity storage technologies for renewables deployment?*

- There is a need for methodologies that attribute value to storage and methods to price dispatchability in order to create a market.
- Subsequently, procuring and contracting mechanisms for storage are needed that can result in bankable solutions for financial institutions.
- Interaction with non-energy markets, especially the transport sector, will be an important driver for energy storage for dispatchability.
- Removing technical barriers, for example through software communication, can accelerate deployment.
- Regulatory certainty for utilities that they will recover cost.
- Need to certify technologies for primary, secondary and tertiary reserve. So far only pumped hydro and gas are allowed to provide that in Europe, although this is changing.
- Demand for reliability can be an important driver (i.e.UPS backup, improve unreliable grids).

*Which **policies and regulations** for electricity storage are needed to support the accelerated deployment of renewables?*

- Need to create consensus on the valuation methodology.
- Technology-neutral policies.
- Savings from introduction of variable renewables can be partly used to invest in storage. Easier in terms of consensus is to have the burden on generators rather than recovering the cost and having TSO to have transmission-connected storage.

• Regulators requesting all stakeholders to work together to come up with a consensus on how to best deploy storage. • Higher dispatching priority for generators with some predictability on output due to storage.
Based on the answer in section 3, what are the three key areas where IRENA members can support the electricity storage for renewables through ***international cooperation*** *activities?*
1. Platform for creating consensus on valuation methodologies and modelling frameworks, and review of modelling tools available. Assisting countries in developing their strategy for RE deployment, including looking explicitly at the role of storage. 2. Sharing of experiences among countries on: 1) successful policies 2) processes to come up with a consensus on regulation, including on procurement and contracting mechanisms, and merit order for defining policy success (i.e. amount of VRE integrated per unit of storage, or investment) 3. Advocacy on making funding schemes for R&D more accessible and open for all countries.

4.3 Longer-term storage for renewables

This roundtable explored applications of electricity storage for longer-term storage (>1hour) of renewable power, such as daily/seasonal load shifting, congestion relief and investment deferral, and self-consumption.

Which location (generation, transmission, distribution, consumers) *will be most relevant for storage deployment?*
The three applications take place at different locations across the electricity value chain. Storage for self-consumption is installed on the consumer side. However, this has its own set of issues related to profitability for consumers (retail v/s wholesale prices), business models for distribution utilities, and tariffs for grid connection, self-consumption and grid feed-in. Business case for self-consumption based on policies which are not certain to be in place for a long time can be detrimental to deployment. Congestion relief and investment deferral can be done on the level of transmission and distribution networks, but will only have its place in large interconnected networks. For smaller networks, storage is only a temporary solution until the resources are in place to strengthen the grid. However, in most cases it is better to speed up grid expansion rather than to defer it. Storage for congestion relief or investment deferral is only a long-term solution if land use, administrative or permission constraints obstruct development of additional transmission or distribution network infrastructure. Daily and seasonal storage can be useful on the generation side. This depends a lot on the demand profile. In cases like Australia and Saudi Arabia with inflexible generation and summer

peaks due to cooling loads, the peaking plants run for as short a time as a few hours per year. Storage could be a better solution in such cases. In general, roundtable participants agreed that load shifting and self-consumption would be the two most important applications of electricity storage for renewables.
Which ***technology developments*** *in storage are needed to facilitate renewable energy grid integration?*
For daily load shifting, cost reductions in lead acid and lithium ion batteries will determine their usage to a large extent. Once prices reach a level where it becomes economical to have storage for self-consumption, they can become entrenched, unless there is some other unforeseen technological breakthrough. In the longer term, we need to focus on CAES and power-to-gas technologies. These can provide long-term storage and have much longer lifetimes, which would be important to compete with conventional peak generation. CAES needs to get more attention in the shorter term, although it is constrained by geological requirements and authorization difficulties. For bigger applications on the demand side (or aggregated storage for a number of consumers), NaS and flow batteries need to be developed further. Also, improvements through advanced lead-acid technology developments should not be underestimated. Finally, improved safety aspects will be an important determinant for technology development for self-consumption.
What will be the ***key drivers for commercialization*** *of electricity storage technologies for renewables deployment?*
• For load shifting applications, storage is expected to play a big role in countries with less flexible power systems, particularly with large share of generation from technologies like coal and nuclear. • Demand profile (e.g. cooling requirements in the Middle East versus heating requirements in Nordic countries) will be more important determinants for storage applications than the rate of electricity growth in different countries. • The need for flexibility in power systems could become a key driver for deployment of storage. This, coupled with daily/seasonal demand peaks could create favourable conditions for energy storage. • GHG emission reduction targets could also create a case for storage to be preferred over peak generation. • Difficulties in grid extension or upgrading in certain contexts can favour energy storage to be used as a solution. • For self-consumption, the difference between electricity wholesale and retail prices can act as a driver for storage applications. Existing electricity rate structures may be an important drivers for storage for self-consumption. For example, the tiered rates in California make it attractive for households to reduce consumption to fall in a lower rate category. • The electricity rates paid by small- and medium-sized enterprises may also become an important determinant for self-consumption in economic clusters.

*Which **policies and regulations** for electricity storage are needed to support the accelerated deployment of renewables?*
• For load shifting, incentives for flexibility are needed, rather than measures directed at specific technologies such as gas power plants or batteries. Well-functioning secondary and tertiary control markets can help support this. • Nodal pricing and capacity markets can help incentivize storage for deployment of renewables, and can help relieve congestion as well. • Stable electricity price structures are needed to reduce uncertainty and create case for investment in storage, especially for self-consumption.
*Based on the answer in section 3, what are the three key areas where IRENA members can support the electricity storage for renewables through **international cooperation** activities?*
1. Technology and knowledge transfer – This includes expert discussions, sharing of know-how, sharing of experience from pilot projects and case studies to learn and determine applicability of projects in similar conditions elsewhere. 2. Data collection and standardization – The lack of data from storage projects and standard ways to evaluate their characteristics prevents comparisons and application of technologies from one context to the other. 3. Roadmap – The document should be a continuous process to evaluate the state of the technology and encourage dialog between stakeholders from different regions.

4.4 Storage for off-grid solutions

This roundtable discussed electricity storage applications for renewable energy deployment in portable devices (e.g. solar lanterns), for single-building applications (e.g. solar home systems), and for mini-grid applications, including islands. The role of electricity storage may differ depending on the applications.

***Which location (generation, transmission, distribution, consumers)** will be most relevant for storage deployment?*
Storage technologies should be used at all levels from generation, transmission, distribution to the consumer level to enable the integration of higher share of RE. On many islands the transmission level does not exist, which is why especially on islands settings it is technically and economically easier to apply the electricity storage close to the generation facilities. Storage options on the consumer end - like batteries at household level - are currently still very expensive and not considered a long-term economic solution for renewables-based off-grid-systems.

*Which **technology developments** in storage are needed to facilitate renewable energy grid integration?*
The lists of existing technologies discussed in IRENA's electricity storage technology brief (April, 2012) is comprehensive, many of the technologies are already commercially available. Pump heat electricity storage was identified as a missing technology on the list. Before using storage options it would be important to make use of demand response and load shedding opportunities. Especially islands have a big potential on cooling facilities (for example, refrigerating storage houses for fish). Cooling facilities have a flexibility potential that should be used for system balancing. Energy storage should be a broadly deployable asset for enhancing renewable penetration – specifically to enable storage deployment at high levels of new renewable generation. For levels with RE penetration rates around 10 – 15% renewable energy forecasting and smart inverters are the first choice.
*What will be the **key drivers for commercialization** of electricity storage technologies for renewables deployment?*
• For off-grid solutions (including islands and rural electrification), energy storage is already near commercial viability in augmenting power management and frequency regulation techniques. • Energy storage is a building block for a fossil-free energy supply which is a key driver for the commercialization. • The necessary storage technologies exists and everybody understands the benefits of this technology but there are no funds available for storage capacities. • Big challenge is that storage capacity costs to ensure a reliable integration of renewable energy resources into the grid are high. The CAPEX for RE sources is already considered as high. To combine renewable energies with storage capacities is seen as an additional CAPEX increase related to renewables. Also the funding of renewables in combination with storage requires long term guarantees which cannot be given by many countries. The loan guarantees from many Small Island Developing States (SIDS) or other developing countries are not accepted by multi-lateral banks,, development banks or private banks. Since off-grid systems and island systems are amongst the biggest areas for commercial growth of storage technologies the lack of accepted loan guarantees is a relevant barrier for the commercialization of storage technologies.
*Which **policies and regulations** for electricity storage are needed to support the accelerated deployment of renewables?*
• Currently there are no business models related to storage because flexibility does not have a price in many energy systems. Policies are necessary to unleash the potential of existing electricity storage technologies by creating a value for flexibility capacities. • Facilitate markets and create policies which give incentives to the deployment of storage capacities. Capacity and flexibility markets are needs that create space for new business models.

• Meeting the mentioned challenges requires coordination from all stakeholders related to combined use of renewable energies and storage capacities. • Standards for off-grid and mini-grid solutions are key for the establishment of sustainable quality infrastructure for renewable energies.
Based on the answer in section 3, what are the three key areas where IRENA members can support the electricity storage for renewables through ***international cooperation*** *activities?*
1. Light house projects for funding institutions: Support of funding institutions is critical. Pilot projects and case studies like the project on French islands (DOM/TOM) are necessary. The success stories need to be shared with funding institutions to convince them to finance storage projects. 2. Sharing of experience between countries regarding: successful policies, regulation, business models and experiences with certain standards is a key task for IRENA. 3. Capacity building related to renewable energy integration and storage use for developing countries is important task for IRENA.

5. Conclusions

The aim of this workshop was to identify the key energy storage technologies and applications to support the accelerated deployment of renewables, and to identify what applications, best practices and lessons should be highlighted in IRENA's global technology roadmap for electricity storage. Based on these insights, the aim of the roadmap is to identify priority areas for action, and specify activities for international cooperation among different stakeholders, and provide a framework to monitor progress.

The conclusions of this workshop are that:

1. Electricity storage is only one of the solutions for renewable energy grid integration, and that deployment of storage technologies should be considered alongside other options. The list of other options includes investments in more flexible generation mix, interconnectors, electrification of end-use sectors, and electricity for thermal energy storage.
2. The **costs of electricity storage options** is a key driver for its deployment, but there is a lack of transparency and the economics are highly dependent on the physical circumstances, the market conditions, the investor's or societal perspective, and the location within the value chain. Pumped hydro is by far the cheapest option, but in Germany its business model has disappeared due to the lower peak prices. In most locations, capital cost reductions in the range of 30 to 50% would be required to make battery technologies viable for residential and small-scale applications for self-consumption in most locations. At the same time, battery technologies are an economic options for countries without net metering and high retail prices, or island or off-grid systems that depend on imported diesel fuels. Finally, battery technologies for grid support are seen as the most expensive option to provide flexibility to the grid, however new mechanisms and tools to value storage services can make electricity storage options profitable.
3. **Technical solutions** exist for all application areas, and most technologies are commercially proven, and their delivery costs are or should decline with time. However, large-scale deployment will also require improvements in safety, reliability, and durability and advances in software support.
4. Besides the high-price electricity markets and opportunities for self-consumption, there are a number of countries have developed **innovative policies and regulation** that support the deployment of renewables and at the same time support their integration into the energy system. Valuing of electricity storage application through regulation and the development of ancillary/capacity markets requires more attention. Furthermore, a key question to consider is how (and if) obligations to balance power in the electricity systems need to be distribute differently, or whether it is sufficient is to allow the responsible party to access ancillary services from the generator or any other market actor
5. Electricity storage for **grid stability services** to promote the continued deployment of variable renewables will unlikely to become economically feasible in the short-term. Instead, electricity storage should also be used to provide dispatchability and longer-term storage (> 1 hour) at the

same time. The development of ancillary markets and grid codes are two of the important instruments that will drive this development.

6. Electricity storage for **dispatchability** will most likely be located at the generation side, or combined with generation by consumers (e.g. rooftop solar PV and/or electric vehicles). The key drivers for electricity storage for dispatchability are twofold. First, deployment will depend on the costs for alternative solutions, such as additional interconnection and cheaper, more flexible and robust smart grids components (smart inverters, smart meters). Second, methods to attribute value and price storage services, and subsequently procuring and contracting mechanism for market deployment. The electrification of the transport sector could be a game changer, but would require new development in software and control systems.
    a. Dispatchability can become an important application for providing grid reliability in developing countries where renewables deployment is rapidly growing.
7. **Longer-term storage** for electricity will be most relevant for load shifting and self-consumption. The existing generation mix, demand profiles and interconnections will determine the demand for load shifting. Nodal pricing and capacity markets could be designed to promote storage, although it would also create a platform for other technology solutions. Of these options, electricity storage also is the most expensive option. Storage for self-consumption could become an important application for households in developed economies (especially if retail prices are high) as well as households requiring uninterrupted power in emerging economies. At the same time, self-consumption could become interesting for small- and medium-size enterprises with relative high electricity prices.
8. Electricity storage for **off-grid solutions,** especially for islands and mini-grids, is already near commercial viability in augmenting power management and frequency regulation techniques. However, the additional capital expenditures required for renewables deployment in combination with storage is creating an important barrier, because there is a lack of funding and accepted loan guarantees available for islands and rural applications. Policy makers can support storage deployment by adopting standards, by creating capacity and flexibility markets and facilitating the deployment of new business models to attract new business investments.
9. **Governments and power utility regulators** have a big role to play in incentivizing targeted and accelerated use storage systems. Four key barriers must be addressed: accounting separately for the cost of storage technologies in pricing frameworks; training of planning and operational staffs in regulator and utility staffs; more business case demonstrations at the operational level; unawareness of opportunities by most policy makers, power utilities and consumers.
10. The **roadmap** should focus on both the prioritisation of action items for electricity storage deployment for renewables as well as the identification of international cooperation activities. Ideally, key activities with progress indicators, cost/ budget outlays and timelines should be prepared for the individual stakeholders (government renewable energy agencies, regulators, utilities, rural electrification agencies, developers and investors) and for different regions.
11. Key areas for **international cooperation** across the different applications are exchange of knowledge and best practices among policy makers and regulators, support for standardisation, and support specific technical cooperation activities on RD&D, design of capacity/ancillary markets, valuation methodologies, and modelling frameworks.

6. References and additional resources

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6.1 Additional resources provided by participants

The European Commission has a number of relevant electricity storage demonstration projects funded by the European Commission's FP7 programme:

- POWAIR, Zinc-Air flow batteries for electrical power distribution networks http://cordis.europa.eu/projects/rcn/96222_en.html
- Stallion, Safety testing Approaches for Large Lithium Ion Battery Systems http://cordis.europa.eu/projects/rcn/106483_en.html
- Stabalid, STAtionary BAtteries LI-ion safe Deployment http://cordis.europa.eu/projects/rcn/106262_en.html
- 4 projects dealing with interfaces in rechargeable batteries and supercapacitors: Baccara: http://cordis.europa.eu/projects/rcn/109512_en.html

SIRBATT: http://cordis.europa.eu/projects/rcn/109513_en.html
HI-C: http://cordis.europa.eu/projects/rcn/109252_en.html
INFLUENCE: http://cordis.europa.eu/projects/rcn/109833_en.html

- 2 demonstration projects:
  INGRID http://cordis.europa.eu/projects/rcn/107967_en.html
  ESTORAGE http://cordis.europa.eu/projects/rcn/107957_en.html
- Mapping of ongoing energy storage projects supported by EC:
  http://gridplus.eu/news/energy-storage

Good examples of specific regulation for storage technologies are the US Federal Energy Regulatory Commission Order 755 (Frequency Regulation Compensation in the Docket Nos. RM11-7-000 Organized Wholesale Power Markets) and Order 784 (Third-Party Provision of Ancillary Services; Accounting and Financial Reporting for New Electric Storage Technologies).