IRENA
International Renewable Energy Agency

Renewables and ELECTRICITY STORAGE

A technology roadmap for REmap 2030

June 2015

About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity. www.irena.org

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Authors: Ruud Kempener (IRENA) and Gustavo de Vivero (IRENA)

For further information or to provide feedback, please contact: rkempener@irena.org or secretariat@irena.org.

Disclaimer

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CONTENTS

List of Figures

List of Tables

List of Boxes

ABBREVIATIONS

CAES	compressed air energy storage
CEA	Central Electricity Authority of India
DOE	United States Department of Energy
EPRI	Electric Power Research Institute
GW	gigawatt
GWh	gigawatt-hour
IEA	International Energy Agency
IESA	Indian Energy Storage Alliance
IRENA	International Renewable Energy Agency
KIT	Karlsruhe Institute for Technology
kW	kilowatt
kWh	kilowatt-hour
kWp	kilowatt-peak
MNRE	Ministry of New and Renewable Energy
MW	megawatt
MWh	megawatt-hour
NREL	National Renewable Energy Laboratory (U.S.)
PGCIL	Power Grid Corporation of India
PV	photovoltaics
USD	U.S. Dollar

INTRODUCTION TO REMAP 2030

In June 2014, the International Renewable Energy Agency (IRENA) launched a global renewable energy roadmap called REmap 2030. The aim is to assess pathways to double[1] the share of renewable energy in the global energy mix by 2030 (IRENA, 2014). REmap 2030 is the result of a collaborative process between IRENA, national experts in and other stakeholders around the world.

The REmap 2030 approach runs along two parallel tracks of analysis:

- A country-based analysis to identify actions for technology deployment, investment and policy development. The number of countries included in the REmap analysis grew from 26 in 2014 to 40 in 2015, covering more than 80% of global energy demand.
- A series of technology roadmaps to garner cross-border insights on actions needed to double the share of renewables in the global energy mix.

The country-based analysis of REmap 2030 suggest that national renewable energy plans would increase the renewable share in annual global power generation from 22% in 2014 to 27% by 2030. However, the results also suggest that existing plans underestimate current market growth, especially for variable renewable energy (VRE) sources like solar photovoltaics (PV) and wind power. Consequently, the roadmap reveals the option to deploy an additional 800 gigawatts (GW) of solar photovoltaics (PV) and 550 GW of wind power between 2010 and 2030.

If countries bring this to fruition, the share of renewables in the power sector would increase to more than 40% by 2030. For VRE sources – mainly solar PV and wind power – the share would increase from 3% of power generation in 2014 to around 20% in 2030 (see figure 1). Furthermore, almost half of PV deployment could be achieved in a distributed manner in the residential and commercial sectors, at both urban and rural sites.

This technology roadmap is developed to examine the consequences and opportunities of the power sector transformation in more detail. A range of measures support the integration of higher shares of VRE in the power, sector, including interconnectors, demand response, smart grid technologies and new pricing mechanisms. Energy storage is only one of many options to increase system flexibility. IRENA's forthcoming technology roadmap on renewable energy grid integration examines all options in more detail, including the role of electricity storage compared to other options.

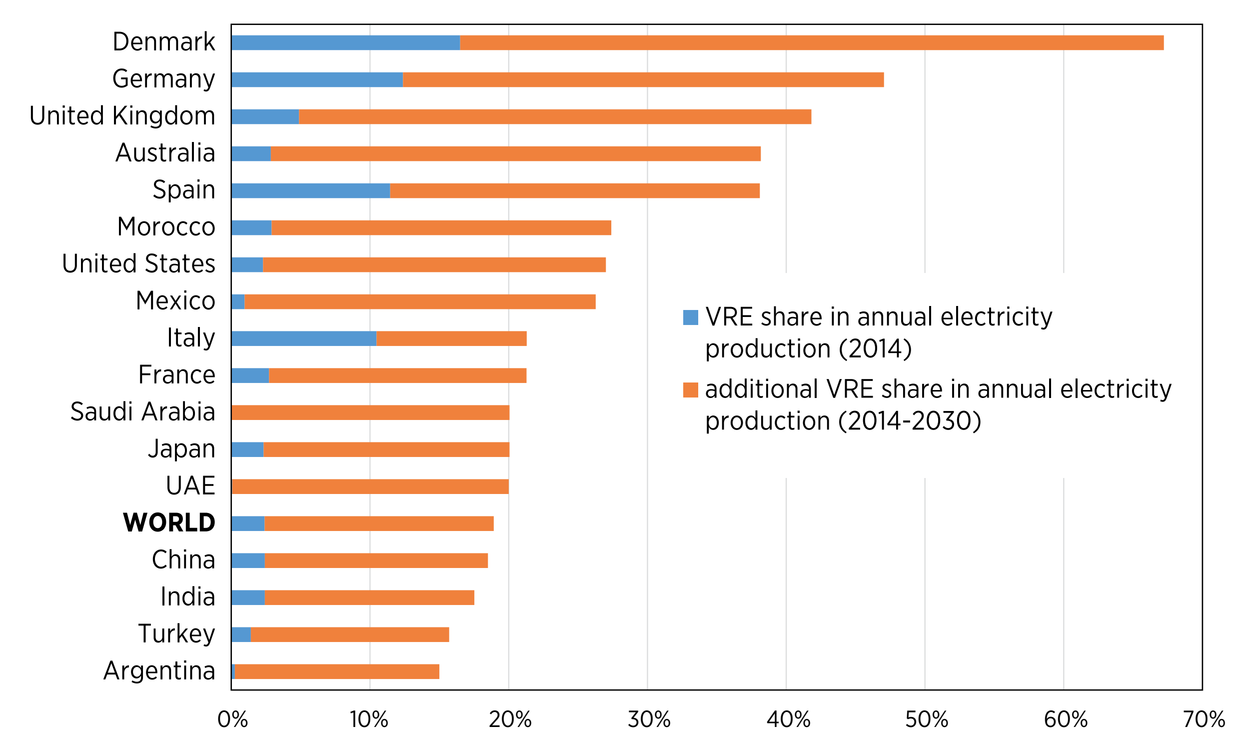
However, countries considering a transition to power systems based on renewables between now and 2030 must look closely at electricity storage options. Storage should not be considered an end in itself. Rather, it is a means to support a reliable, efficient, cost-effective and clean power sector by facilitating the deployment and integration of renewables. Such considerations apply to countries of three types:

1. Countries with VRE shares exceeding 30%, combined with even higher ambitions;
2. Countries with VRE shares exceeding 20%, with constrained grid infrastructures.
3. Island countries, or those including islands, and countries with remote off-grid power systems.

Until 2030, the number of countries in the first category will be limited. For instance, it includes Australia, Denmark, Germany, UK, Spain and some states in the US. The number of countries in the second category will also be limited. Examples include India, Italy and Japan. Countries in the third category will make up the largest group. They include many of the 52 small developing island states with ambitious plans to move their power sectors towards renewables. For example, countries like Dominica, Fiji, Guyana, Maldives, Nauru, Samoa, Solomon Islands, Timor-Leste, Tonga, Tuvalu and Vanuatu are targeting renewable energy shares of at least 50% before 2030. This category also includes countries in sub-Saharan Africa and other regions where

1 The aspirational target for REmap 2030 is derived from the Sustainable Energy for All initiative, which is co-chaired by the United Nations Secretary-General and the World Bank President.

Figure 1: Annual share of annual variable renewable power generation in 2014 and in 2030 if all REmap options are implemented



Source: IRENA, 2014.

off-grid renewable energy systems can provide electricity access in rural areas. Furthermore, the cost of renewable power generation has decreased such that PV and wind power are cheaper than the diesel generators traditionally used to supply remote communities and islands. Global assessments suggest that 250 GW of the existing 400 GW of installed diesel generators could be replaced by renewable power generation technologies (Blechinger *et al.*, 2014). This warrants the storage to accommodate night-time electricity supply or during periods lacking wind or sun.

For these three groups, the growth of VRE and its greater participation in future power systems will require a rethink by decision makers. Electricity storage technologies provide new opportunities and can play a significant role in restructuring the power system. The importance of storage technologies is demonstrated in REmap 2030, which estimates that 150 GW of battery storage and 325 GW of pumped-storage hydroelectricity will be needed to double the share of renewable power generation by 2030.

In this context, IRENA has developed the present complementary global technology roadmap on electricity storage for renewable power. The roadmap focuses on electricity storage systems, although it recognises that thermal energy storage[2] will in many cases be a cheaper solution for storage power from VRE (IRENA and IEA-ETSAP, 2013a).

The aim of this roadmap is to identify in more detail priority areas for action, specify activities for international cooperation among different stakeholders and provide a framework to monitor progress. The choices in this roadmap reflect input and feedback gathered from over 150 stakeholders attending four international IRENA electricity storage policy and regulation workshops in Germany, India, and Japan.

2 Thermal energy storage stocks thermal energy by heating or cooling a storage medium so that the stored energy can be used at a later time for heating and cooling applications. Examples of thermal energy storage technologies are hot water tanks, through phase change materials like ice or paraffin, or through chemical reaction like ammonia dissociation or methane steam reforming.

Box A: Assessing the global electricity storage market for renewables

International and national assessments of the global electricity storage market have been hindered by uncertainty about which technologies and market segments to include. A central question for this roadmap is whether storage is used to support the integration of renewables or for other purposes.

IRENA's global renewable energy roadmap (REmap 2030) assessed the plans for pumped-storage hydroelectricity in the 26 countries, which suggests that the total capacity will increase from 150 GW in 2014 to 325 GW in 2030. The battery storage capacity for renewables integration is based on the country-by-country analysis of electric vehicle sales of around 80 million vehicles by 2020, and the assumption that the discarded batteries of these vehicles would become available after 2028.[3] The total available battery storage capacity available would be around 250 GW, conservatively assuming that 50% of these batteries would be used for second-life applications, and that only 10% would be available to support the integration of renewables. Considering a total installed VRE capacity of 2885 GW by 2030, REmap 2030 suggests that 5% (or 150 GW) of the VRE capacity would be supported by second-life batteries.

Other studies have used modelling tools to assess national and global market potential. In 2009, the International Energy Agency (IEA) estimated a global energy storage capacity of 180-305 GW (including large hydropower). This assumes around 30% of annual power generation from VRE by 2050 (IEA, 2009). An updated IEA study estimated around 460 GW of energy storage with 27% VRE in annual power generation by 2050 (IEA, 2014). In comparison, a recent market study by CitiGroup suggests an energy storage market (excluding pumped-storage hydroelectricity and car batteries) of 240 GW by 2020 (CitiGroup, 2015). Navigant Research estimates that around 20 gigawatt-hours (GWh) out of 50 GWh of advanced battery storage systems in the utility sector will be supporting the integration of renewables. Other applications will provide ancillary services, peak shaving and load shifting (Jaffe & Adamson, 2014).

An alternative approach would be to assess manufacturing capacity plans. By 2020, motor vehicle producer Tesla's gigafactory is scheduled to produce 35 GWh while energy service provider Alevo's manufacturing plant is expected to produce 16.2 GWh. Chinese battery and vehicle producer BYD has announced plans to ramp up production capacity from 10 GWh in 2015 to 34 GWh in 2020.

National studies are also available. Research institute Fraunhofer ISE has made estimates of storage requirements to achieve 100% renewable energy in Germany. This amounts to 24 GWh of stationary battery applications, 60 GWh of pumped hydropower, 33 GW of electrolysers and 670 GWh of heat storage (Henning & Palzer, 2013). Estimates for India are 15-20 GW by 2020 of which 2.2 GW is for solar and wind integration and 2.5 GW for rural electrification (Indian Energy Storage Alliance (IESA), 2014).

3 Assuming 100 kW/50 kWh batteries with 25% capacity loss and 80% depth of discharge available.

At the end of the roadmap a set of indicators are provided to track progress and compare the different applications and features of electricity storage systems. The indicators were divided into two groups: (1) indicators for tracking the technology progress and deployment of electricity storage systems (2) indicators for tracking electricity storage system advantages for integrating renewable energy.[3]

SUMMARY OF KEY FINDINGS

Electricity storage systems convert electricity into other forms of energy (*e.g.* potential, thermal, chemical or magnetic energy) and then reverse this process to release electricity. In the power sector, the most common form of existing electricity storage (99% of installed capacity) is pumped-storage hydroelectricity. This use electricity to pump water to an elevated reservoir in periods of excess power in the grid. In periods of high electricity demand, the water is subsequently released to run conventional hydropower turbines to revert to electricity production.

Pumped-storage hydroelectricity can start up within a couple of minutes and can thus be used to provide balancing and reserve to systems with variable renewables. Their main drawback is their relatively low roundtrip efficiency of around 70-80%, as well as geographical restrictions. These are dictated by the need for relatively large water reservoirs and large elevation variations between lower and upper reservoirs to provide sufficient capacity.

In the transport sector and in remote regions with unreliable or no centralised electricity grid, lead-acid batteries are the dominant technology to store electricity or provide backup capacity. Lead-acid batteries have been relatively cheap but their limited efficiency and lifetime made them less suitable for renewable energy integration. The relatively recent developments in consumer electronic and electric vehicle battery storage has boosted the development of advanced battery storage systems to support renewable energy integration in the power sector (IRENA, 2015a). In addition, flywheel technologies, compressed air energy storage (CAES), supercapacitors and superconducting magnetic electricity storage systems are used to support the integration of renewables into the power sector.

In the last couple of years, several roadmaps have been published examining the opportunities for energy storage at the global, regional, national, state and sectoral level.[4] They suggest that additional research and development in electricity storage systems is needed to increase cost-competitiveness relative to non-storage options available in the power sector. The exception to this is thermal storage and pumped-storage hydroelectricity. Furthermore, these roadmaps suggest that policy action is needed to support the deployment of energy storage options. Figure 2 provides an overview of the latest cost assessments for different electricity storage technologies.

Experience so far demonstrates that technological progress is not sufficient to boost storage deployment. Electricity storage systems are already available today, but their deployment levels are very limited compared to the rapid growth in variable renewable power generation. This means that technological development should actively complement an adequate regulatory environment, industrial acceptance and progress on different issues still needing regulatory support and research and development funding. Some examples are pilot projects or new procurement mechanisms and business models that help quantify the value of storage applications. They enable electricity storage to compete on a level playing field with traditional alternatives.

The electricity storage roadmap produced by IRENA indicates that electricity storage systems should be a broadly deployable asset for enhancing the integration

4 Roadmaps have been produced at a global level by IEA, for Europe by the European Association for Storage of Energy (EASE), European Energy research Alliance (EERA) and Grid+, for Japan, France, Australia, UK, USA and India by New Energy and Industrial Development Organization (NEDO), Agence de l'Environnement et de la Maitrise de l'Energie (ADEME), Clean Energy Council (CEC), Centre for Low Carbon Futures (CLCF), National Alliance for Advanced Transportation Batteries (NAATBatt) and the United States Agency for International Development (USAID) respectively. Roadmaps for electricity storage in the transport sector have been devised by New York Battery and Energy Storage Technology Consortium (NY-BEST) for New York, State and by Fraunhofer ISI, United states Driving Research and Innovation for Vehicle efficiency and Energy sustainability (U.S. DRIVE) and the European Association for Advanced Rechargeable Batteries (RECHARGE).

Box B: Cost and value of electricity storage

Except for pumped-storage hydroelectricity and conventional CAES, the cost of electricity storage systems has been one of the factors inhibiting their large-scale deployment. For advanced battery storage systems, the costs are expected to decline rapidly due to growing demand and manufacturing capacity expansion. This is driven by demand for batteries for electric vehicles and intense international competition between multinational electronics companies like Panasonic, Samsung SDS and LG Chemicals.

Two important elements need to be considered when assessing the economics of electricity storage: cost and value. Electricity storage costs can be expressed in power (watts), capacity (watt-hours) and useable kilowatt-hour (kWh) per cycle. The latter is a cost indicator for storing and releasing 1 kWh of electricity on top of generation costs. Table 1 compares three battery storage systems commercially available for deployment in the German residential sector in 2012.

Table 1: Battery storage performance and costs for residential systems in the German market in 2012

Battery technology	lead-acid	li-ion	li-ion
Battery power (kW)	5	5	5
Battery capacity (kWh)	14.4	5.5	8
Depth of discharge	50%	80%	100%
Useable capacity (kWh)	7.2	4.4	8
Number of cycles	2800	3000	6000
Price (EUR)	8900	7500	18900
EUR/kW	1780	1500	3780
EUR/kWh	618	1364	2363
EUR/useable kWh	1236	1705	2363
EUR/useable kWh/cycle	0.44	0.57	0.39

EUR = euros; kWh = kilowatt-hours

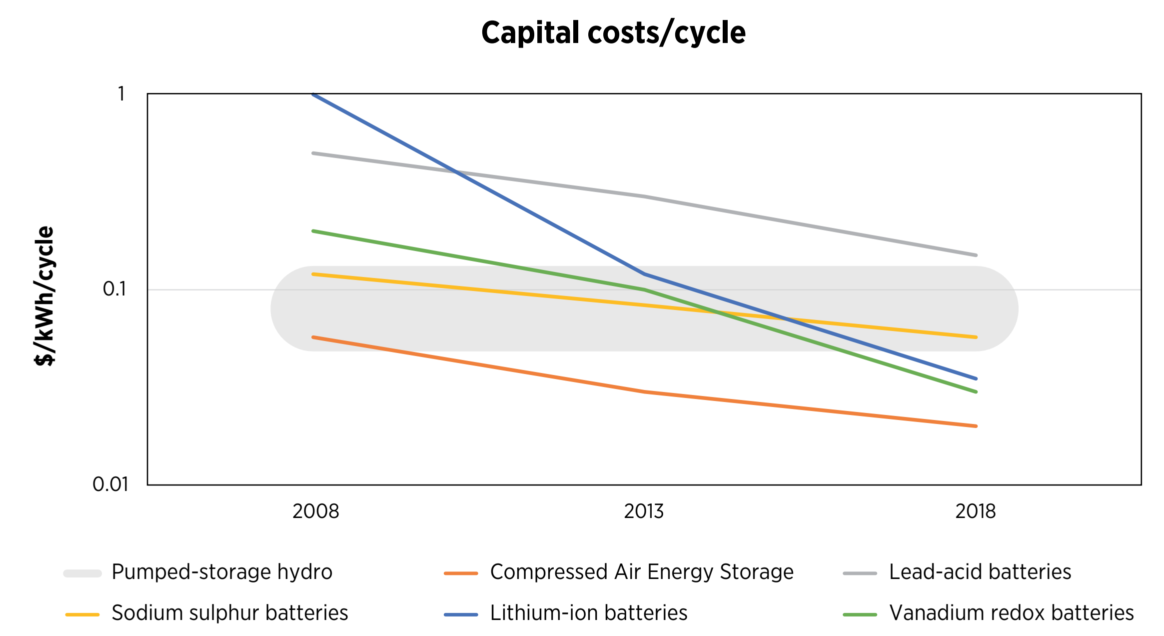
As shown in Table 1, costs are a function not only of the system price but also of attributes like depth of discharge, roundtrip efficiency and number of cycles. The results show that storing electricity in 2012 for self-consumption from a rooftop solar PV system would add EUR 0.4-0.6/kWh to generation costs. However, the costs of residential battery storage systems have fallen substantially while performance continues to improve. In late 2014, German residential storage systems (including inverters and installation) with around 6000 cycles could be bought for around EUR 2000-2200 per kilowatt (kW) or EUR 1000-1300/kWh (Petersen, 2014). This results in costs per cycle of EUR 0.16-0.30/kWh. Advanced lead-acid residential storage systems were around EUR 1400/kWh. The Tesla Powerwall, launched in April 2015, has a retail price of EUR 385/kWh (battery only) or EUR 0.16 kWh/cycle[5] for the system.

The costs of utility-scale storage systems also continue to decline. In the US, they are around 2500 US Dollars (USD)/kW or USD 1700/kWh at present (of which a third is balance-of-system costs). Hawaii is already achieving USD 1500/kW or USD 1000/kWh (UBS Research, 2014).[6] Based on discussions between utilities and vendors, the storage costs will have reduced to USD 525/kW or USD 350/kWh by 2020 (The Brattle Group, 2014). Assuming around 6000 cycles for these types of systems, the costs of storing 1 kWh are around USD 0.06/kWh. In comparison, the current costs for battery packs for electric vehicles are between USD 300-410/kWh, and are expected to reduce to around USD 200/kWh in 2020 (Nykvist & Nilsson, 2015).

5 Assuming 5000 cycles and EUR 2250 for inverter and installation. Based on exchange rate for 30 April 2015 (the release date of the TESLA Powerwall) at EUR 0.9 per US Dollar (USD.).

6 USB Research assumes 1.5 hours of storage.

Figure 2: Cost assessments for electricity storage systems



Source: The Brattle Group, 2014; Walawalkar, 2014.

Projects for other electricity storage technologies are provided in figure 2. Adding these costs to generation costs means that variable renewable electricity storage into the grid still approximately doubles the electricity consumption costs.

In the longer term, the Tesla threshold of USD 100/kWh (based on material costs) is viewed as a lower limit for the price of lithium-ion (li-ion) batteries. However, alternative battery storage technologies like nickel-cadmium, metal-air or flow batteries are already challenging this threshold.

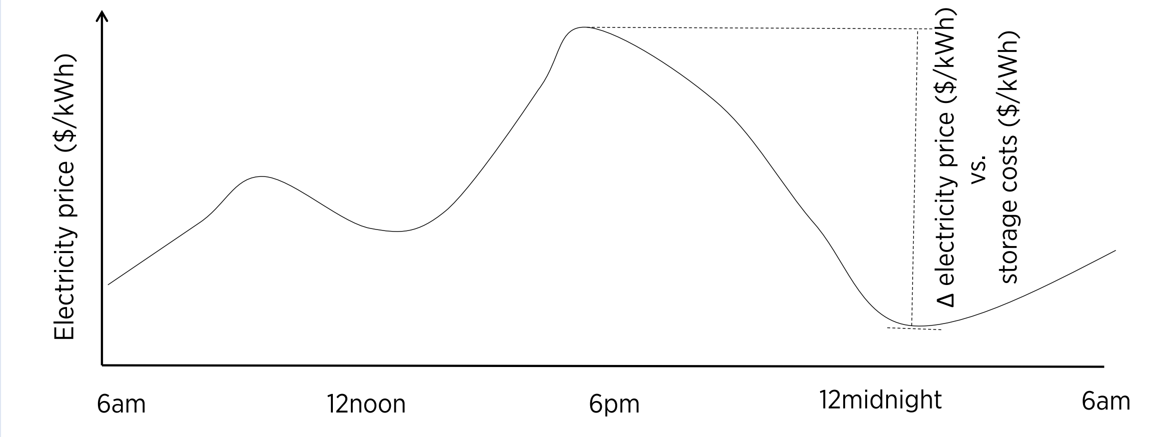
Assessing the value of storage is the second element. It has traditionally been worked out in a particular way, especially for pumped-storage hydroelectricity. Storage costs are calculated as the difference between electricity prices during storage and during production (see figure 3).[7] The same principle also can be applied to residential storage. Solar PV production costs combined with storage costs can be cheaper than the difference between the price received for feeding power back into the grid and residential prices for buying electricity from the grid. In these circumstances, there is an economic case for storage, and its costs should be measured in USD/kWh/cycle.

The traditional evaluation of electricity storage means that storage will significantly add to the costs of integrating renewable power generation into the grid, despite cost reductions projected for 2020. Furthermore, the significance of electricity storage costs will probably continue to grow as renewable power generation costs are expected to continue to decline.

However, storage can also be used to assist the grid in other ways and provide multiple value streams even from the same asset. For example, primary reserve is measured in power (watts), while secondary and tertiary reserves are valued in capacity (watt-hours). This means that different cost and value indicators are needed to measure storage value in these markets. For example, the German utility WEMAG operates a five mega-

7 Figure 3 assumes that electricity prices correspond with electricity demand. Thus higher demand in the morning and afternoon peaks corresponds with higher electricity prices.

Figure 3: Assessing value of storage per kilowatt-hour



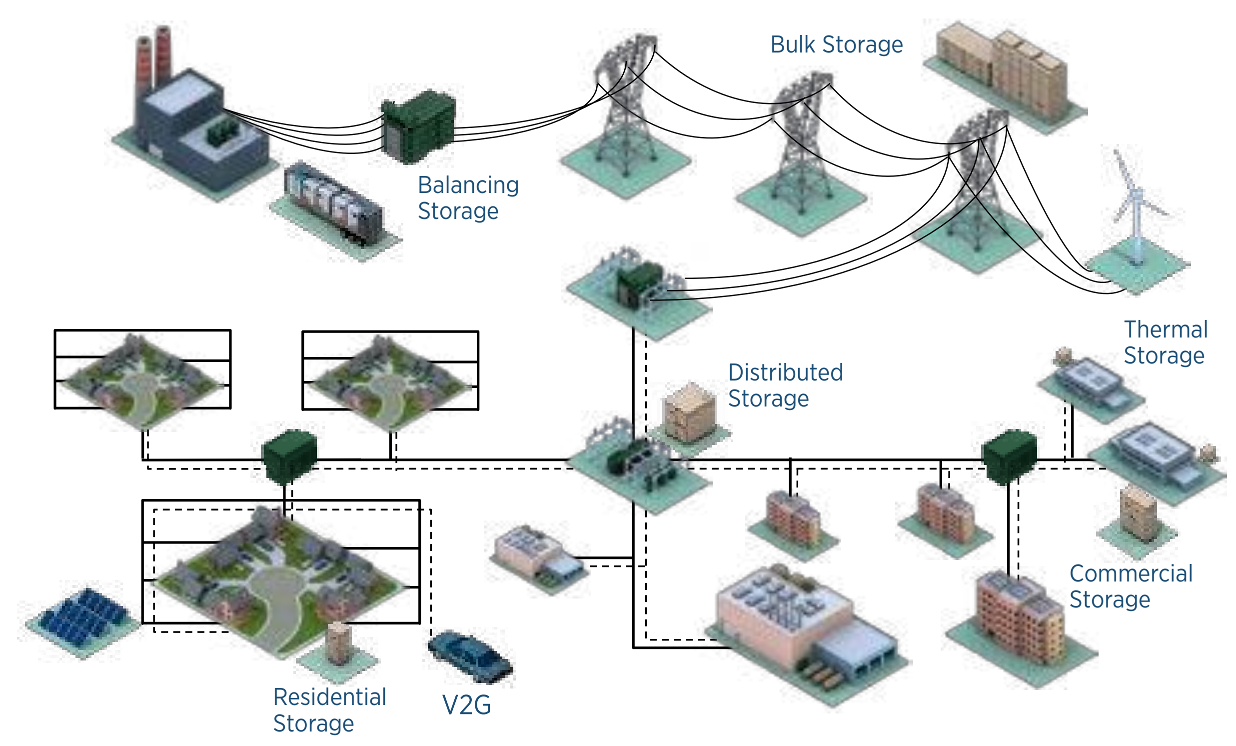
watt (MW)/five megawatt-hour (MWh) battery storage park in Schwerin that bids into the primary reserve markets and makes an average EUR 2 700/MW per week. Similarly, the value of a pumped-storage hydroelectricity should not only be measured by its ability to provide instantaneous capacity in case of an unexpected thermal power plant outage. It also needs to be measured according to its ability to sustain generation over a longer period. For example, Taloro PSH provided 210 MW of power generation capacity within 13 minutes following an unexpected thermal power plant outage in Sardinia in Italy. It sustained production over six hours (1114 MWh) while the thermal power plants were being fixed (Grigatti, 2015).

With the exception of reserve markets, the problem is that many of these system-wide values of storage investments cannot usually be captured by outside investors. These values can be as much as 30-40% of the total system-wide value of storage (The Brattle Group, 2014), although the specific value depends on the cost of alternative solutions available. They include increased reliability, transmission and distribution network support, reduced power outages and increased efficiency. Furthermore, electricity storage systems challenge conventional regulation due to their multiple functionality. This is because a single unit can operate at the same time in several markets throughout the day. For example, the battery storage park in Schwerin would only require a software update to start bidding into the secondary markets. In many cases, regulations and policies particular to specific regions prevent electricity storage systems from providing multiple benefits.

of high shares of VRE generation. Its functions include supporting the local integration of power generation from VRE in distribution networks, supporting the grid infrastructure to balance VRE power generation, and supporting self-generation and self-consumption of VRE by customers (figure 4). More importantly, policy makers interested in energy storage system deployment in any of these three application areas need to consider the impact of energy storage on the power system as a whole. This is particularly the case for storage systems supporting the deployment of variable renewable power generation in islands and off-grid systems. These insights have led to the formation of the five priority areas discussed in the following sections.

The benefits of electricity storage systems cross the boundaries between the power system value chain (generation, transmission, distribution and end-use) in both grid and off-grid systems. This means electricity storage systems cannot be addressed with a single policy covering the different possible locations and services. Instead, dedicated policies are needed for each of these application areas. At the same time, policies need to ensure consistency and consider the broad scope of regulatory options for electricity storage systems (including grid codes, pricing mechanisms and the creation of new markets). They need to consider integrating power into end-user sectors through storage applications (*e.g.* power-to-gas or electric vehicles).

Figure 4: Potential locations and applications of electricity storage in the power system



Approach

The roadmap is based on a combination of literature reviews, studies and stakeholder workshops. The studies are published as separate IRENA reports and include:

- Battery Storage for Renewables: Market Status and Technology Outlook (IRENA, 2015a)
- Electricity Storage Technology Brief (IRENA & IEA-ETSAP, 2013b)

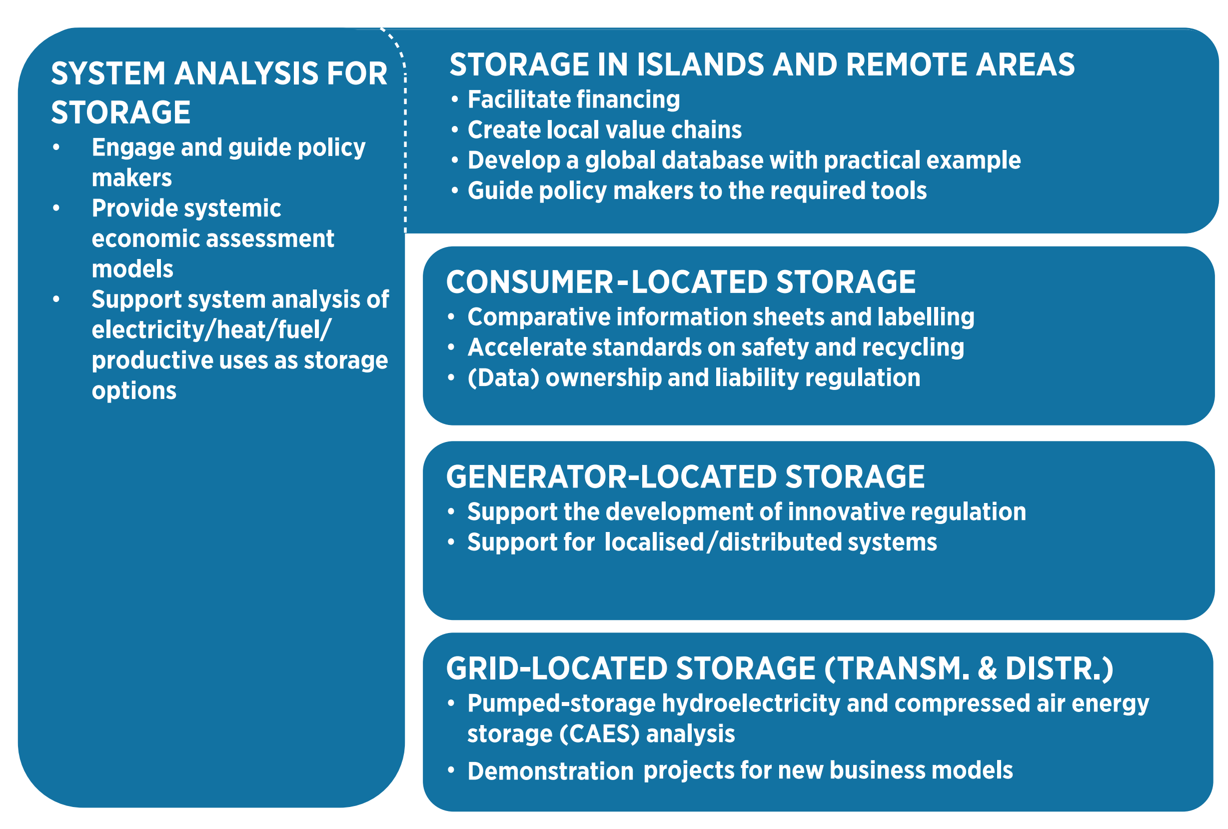
The workshops took place between March 2014 and March 2015 and were conducted in Germany, India and Japan. In total, 150 stakeholders participated in one or more of these stakeholder workshops. In the first workshop, participants were asked to identify key application areas in which electricity storage can support renewable energy deployment. The insights of this workshop led to the identification of different priority areas. In the next two, participants identified the key technology requirements and policy barriers, and identified opportunities for international cooperation within them. In the final workshop, the blueprint for this roadmap was shared. Representative stakeholders were invited to comment on the separate priority areas and identify action items. Each workshop concluded with proceedings shared online and with the participants. These form the basis for this technology roadmap.

Priority areas for action

Based on the approach outlined in the previous section, this technology roadmap has identified 14 action items subdivided over five priority areas (figure 5).

1. **System analysis** helps to assess the role of storage in different power sector segments, in comparison with other options to support renewable energy deployment. Analysis of this type is required for all countries considering energy storage policies. It complements activities in any of the other priority areas.
2. **Storage in islands and remote areas** is relevant for a large number of countries (identified as Category 3 countries). This is the most imme-

Figure 5: Priority areas and action items for the IRENA technology roadmap on electricity storage



diate priority area where electricity storage can support renewable power deployment.

3. **Consumer-located storage** is important for countries where household electricity prices are high compared to rooftop solar PV power production costs, or where consumer electricity feed-in is discouraged or limited. This priority area is particularly relevant to countries that already have or are expecting a high share of rooftop solar PV systems in the power sector (mostly Category 1 countries).
4. **Generator-located storage** is important for countries in Categories 1 and 3. These include island countries, as well as those with islands or remote off-grid power systems, those with inadequate grid infrastructure to link renewable energy resources to demand centres, and those facing other interconnection constraints.
5. **Storage in transmission and distribution grids** is important for countries making the transition to power systems based on renewables but with limited power system flexibility (Category 2 countries). Pumped-storage hydroelectricity is the key technology in this area, with advanced compressed air energy storage currently in the demonstration phase. Smaller, more distributed storage technologies are also of interest for providing local grid support where there is a high penetration of local variable renewables.

The power sector has been dominated for over a century by a single framework matching centralised electricity production with the fluctuating needs of local consumers in real time. Given that background, electricity storage can truly create a revolution. The rapid growth of renewable power generation is an important driver accelerating this development. Three other drivers are stimulating change. Firstly, large electronics companies looking for new markets for their battery storage systems have initiated a technology push, Secondly, industry and consumer interest in electric vehicle battery development is growing. Thirdly, demand is rising for reliable and affordable power for the 1.6 billion people who lack electricity access. Policy makers should consider the impacts of these trends now and prepare a timely response to ensure that policy frameworks are ready and business models can be deployed once these drivers converge.

In the following sections, this technology roadmap describes each of these five priority areas and 14 action items in more detail. For some of these action items, policy makers are in the driving seat. For others, industry, academia or stakeholders like insurance companies or consumer associations need to take the lead. Responsibilities among stakeholders may be differentiated at a local level. However, international cooperation across these 14 action items will be critical to ensure the world is ready for the next generation of renewable power systems. In this context, the indicators are an important tool for tracking progress and adjusting action items and priority areas accordingly.

PRIORITY AREA 1: SYSTEM ANALYSIS FOR STORAGE

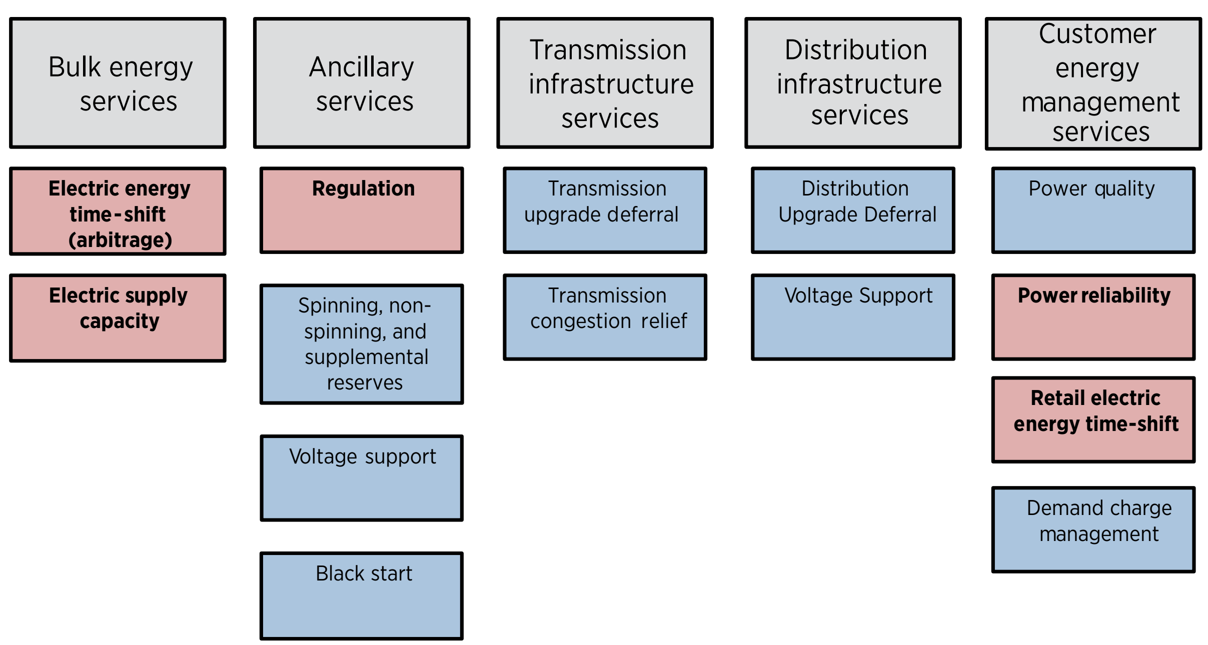
An electricity storage systems can support renewables at different locations in the power sector and through different services. The location at which a storage system is placed and the service provided by electricity storage are independent variables. This means a residential battery storage system coupled to rooftop solar PV can at any point in time also function as a generator providing ancillary services to support the grid. Similarly, electricity storage coupled to a wind park can act as an electricity consumer through a simple switch. Thus policy makers creating a framework to support a specific storage function will always need to consider the fact that storage could at any point be used for other functions too.

Electricity storage can add considerable value to the management of the power system if the regulatory framework allows. However, its multi-functionality means there is still no clear direction for a legal definition of energy storage. This is obstructing the development of appropriate policies and legal frameworks (Crossley, 2014).

Electricity storage can do much more than support the integration of or transition towards renewables. Figure 6 provides an overview of 14 different services it can provide to the grid. The services highlighted in red are those of direct relevance to renewable energy integration. However, electricity storage systems supporting renewable energy integration can also provide any of the other grid services needed for efficient and cost-effective power system management.

Countries considering electricity storage options to support the transition towards renewables need to take a systems perspective. This includes a trade-off

Figure 6: Electricity storage services and their relevance for renewable power integration



Boxes in red: Energy storage services directly supporting the integration of variable renewable energy

Source: based on Department of Energy (DOE) / Electric Power Research Institute (EPRI) 2013 Electricity Storage Handbook in Collaboration with National Rural Electric Cooperative Assocation (NRECA), 2013.

between the different options available to support renewable energy integration. Interconnectors, transmission and distribution infrastructure expansion, and more flexible generation options are a few examples. Others include capacity and/or flexible market as well as ancillary service market creation, nodal pricing to direct the siting of renewable energy projects, demand-side management, and smart grid technologies. Other options are available, such as a shift to more decentralised approaches attracting new stakeholders paid for the delivery of certain services or shifting grid infrastructure management to local stakeholders. In addition, policy makers need to balance the need for electricity storage with other storage options. These include thermal energy storage, the conversion of electricity into hydrogen or gas, or end-use sector electrification. The key challenge is not only to choose among these options but also to find ways to combine them in an optimal yet flexible manner.

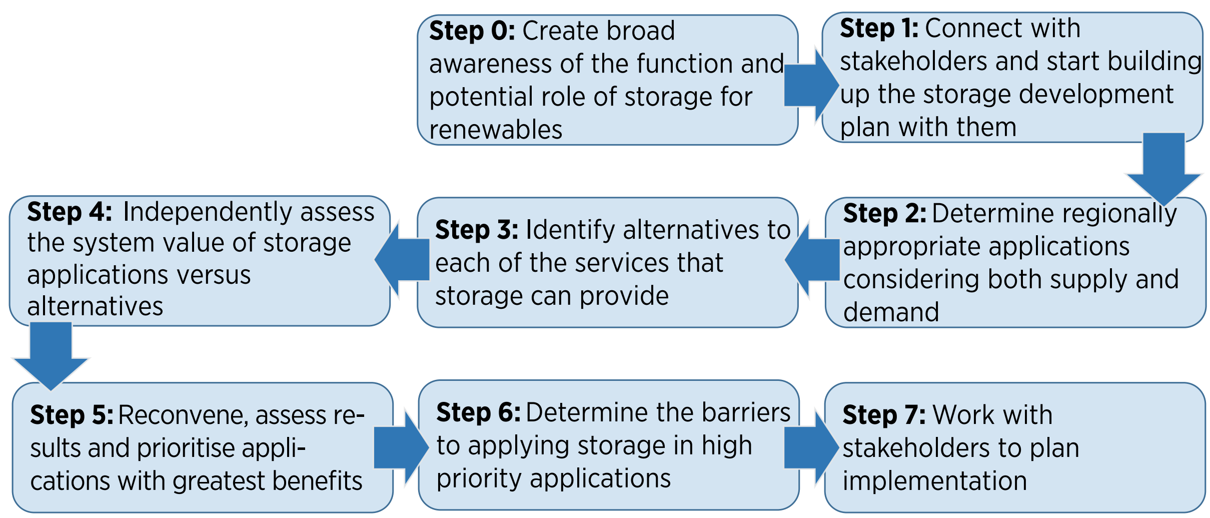
There are advantages to avoiding picking winners among the flexibility options by focusing on the creation of a fair, open and technology-neutral environment. This can be done in three ways. Firstly, one can eliminate or reduce barriers to the interconnection of beneficial resources. Secondly, it is possible to create technology-neutral mechanisms or markets allowing resources to provide benefits and be compensated appropriately for the benefits they provide. Thirdly, one can focus procurement on the required capabilities rather than a specific technology. The exact means of achieving a technology- neutral approach can vary greatly depending on the region. However, the overall philosophy of technology neutrality will allow the most innovative, cost-effective and beneficial technologies to rise to the surface.

Action 1.1: Engage and guide stakeholders

Electricity storage development requires the active engagement and commitment of stakeholders to establish an adequate environment to value and benefit from electricity storage applications. Regulators and policy makers, system operators, utilities, consumer advocates, environmental organisations, industry, financial institutions and power system experts are some of the main stakeholders to draw in. Policy makers should guide power sector evolution, including overall grid infrastructure development, the role of storage and its interaction with renewables.

An eight-step process is proposed to engage stakeholders (figure 7). All steps should be based on inputs specific to each region, and each step should be com-

Figure 7: Procedure for engaging and guiding stakeholders in developing energy storage policies for renewables



Based on Strategen Consulting, 2015.

plemented with best practices and tools etc. to inform the decision process and show what can be achieved. Stakeholder engagement is iterative and geared toward enabling education and consensus for the final regulatory framework, goals, priorities and implementation approaches.

Step 0 and **Step 1** make up the preparatory phase of national renewable electricity storage policy development. Step 0 means organising webinars and workshops to engage a broad constituency, create awareness and engagement and understand the regional factors that might lead towards the best solutions. During this process, external experts from different fields (governments, industry, academia, etc.) should be invited to share best practices or research and development projects. Once this broad engagement has been completed, the first step consists of identifying specific stakeholders to run the process. Experiences from California (see box C) provide a few lessons for effectively connecting with stakeholders, outlined below.

- Identify 'champions' committed to the development of renewables and electricity storage and ensure they are personally engaged throughout the whole process.
- Understand the goals and challenges these individuals face in their respective country/jurisdiction and the relative perspectives of related stakeholders both inside and outside their organisation.
- Include both proponents and opponents and discuss energy storage system strengths and challenges compared to traditional solutions. This includes any existing regulatory/legal, educational/cultural and financial obstacles and specific drivers in each country like fuel prices, greenhouse gas emission targets, transmission constraints etc.
- Jointly brainstorm potential barriers to energy storage benefits, and bring in relevant experience from other countries as necessary to address any concerns.

Steps 2, 3 and **4** consist of a number of analytical activities (see Action 1.2: Provide systemic value assessment of storage). These mean bringing in independent analysts recognised by all stakeholders involved. During this stage, the fundamental motivation for using storage is identified and the applicability of storage at different locations of the power system determined. Stakeholders have to come to an agreement on the analysis inputs. Besides technology and knowledge transfer, this stage also enables stakeholders to acknowledge the benefits and challenges of implementing electricity storage systems. It is important to consider alternatives (either through technology or regulation and/or market design) as an intrinsic part of any analysis.

Steps 5, 6 and 7 should result in a practical implementation plan recognised by all stakeholders. During this process, it is important that applications providing the greatest benefits to the system are prioritised and that any barriers are systematically removed. These may involve cooperation across multiple jurisdictions. This is why the identification of a key core of stakeholders in the first stage is so important. A conclusion may emerge at this stage that electricity storage is not suitable, not cost-effective or not necessary for renewable energy deployment.

At the residential level, electricity storage systems require the engagement of new stakeholders such as insurance companies, the construction industry, installers and the general public. Some activities should therefore be guided to help inform, educate and engage these new stakeholders. Site visits and more specialised international workshops are examples.

Box C: Energy storage policy and market development in California

California represents a practical example of the successful involvement of policy makers in developing a regulatory framework to support the progress of renewable energy and storage.

It has a renewable portfolio standard in place to procure 33% of electricity from renewable energy resources by 2020. The state is considering a further increase in the renewables procurement target. In 2014, the large investor-owned utilities provided 21% of their retail electricity load from renewable energy resources. On the customer side, nearly 2.4 GW of rooftop solar PV and 23 MW of wind power have been installed.

In 2010, California's legislature signed Assembly Bill No. 2514 into law. This required that the California Public Utilities Commission (CPUC) consider energy storage procurement targets for load-serving entities if energy storage was found to be commercially viable and cost-effective. The goal was to utilise energy storage to optimise the grid, integrate renewables and reduce greenhouse gas emissions. In 2013, the state launched a new stakeholder process to engage utilities, industry, ratepayer advocates and other interested parties. Their task was to evaluate applications for energy storage in California's grid, as well as its cost-effectiveness compared to other alternatives. Following this stakeholder process and the resulting analytical findings, the California Public Utilities Commission established storage procurement targets for the largest three investor-owned utilities. This prompted a mandate to procure 1325 MW of storage capacity by 2020. Besides the three utilities, other load-serving entities were also obliged to purchase a targeted energy storage capacity equivalent to 1% of peak load by 2020. The procurement mandate established eligibility and other requirements. For example, pumped-storage hydroelectricity exceeding 50 MW is not eligible. Storage facilities have to be operational by 2024.

The energy storage procurement targets for the three largest utilities in 2014 were 90 MW for Southern California Edison, 90 MW for Pacific Gas and Electric and 25 MW for San Diego Gas & Electric. These targets were subdivided by grid connection (transmission and distribution) and customer. In November 2014, Southern California Edison announced that it had procured 261 MW of energy storage for 2014 to satisfy local capacity requirements resulting from power plant retirements. This is much more than the required target of 90 MW (see table 2). Similarly, San Diego Gas & Electric is allowing for a maximum procurement of 800 MW. Pacific Gas and Electric solicited 50 MW of storage connected to the transmission grid, 24 MW to distribution circuits and 10 MW of storage connected to customer sites.

Table 2: Southern California Edison procurement of energy storage in 2014

Seller	Resource type	MW
Ice Energy Holdings	Behind-the-meter thermal energy storage	25.6
Advanced Microgrid Solutions	Behind-the-meter battery energy storage	50
Stem	Behind-the-meter battery energy storage	85
AES	In-front-of-meter battery energy storage	100

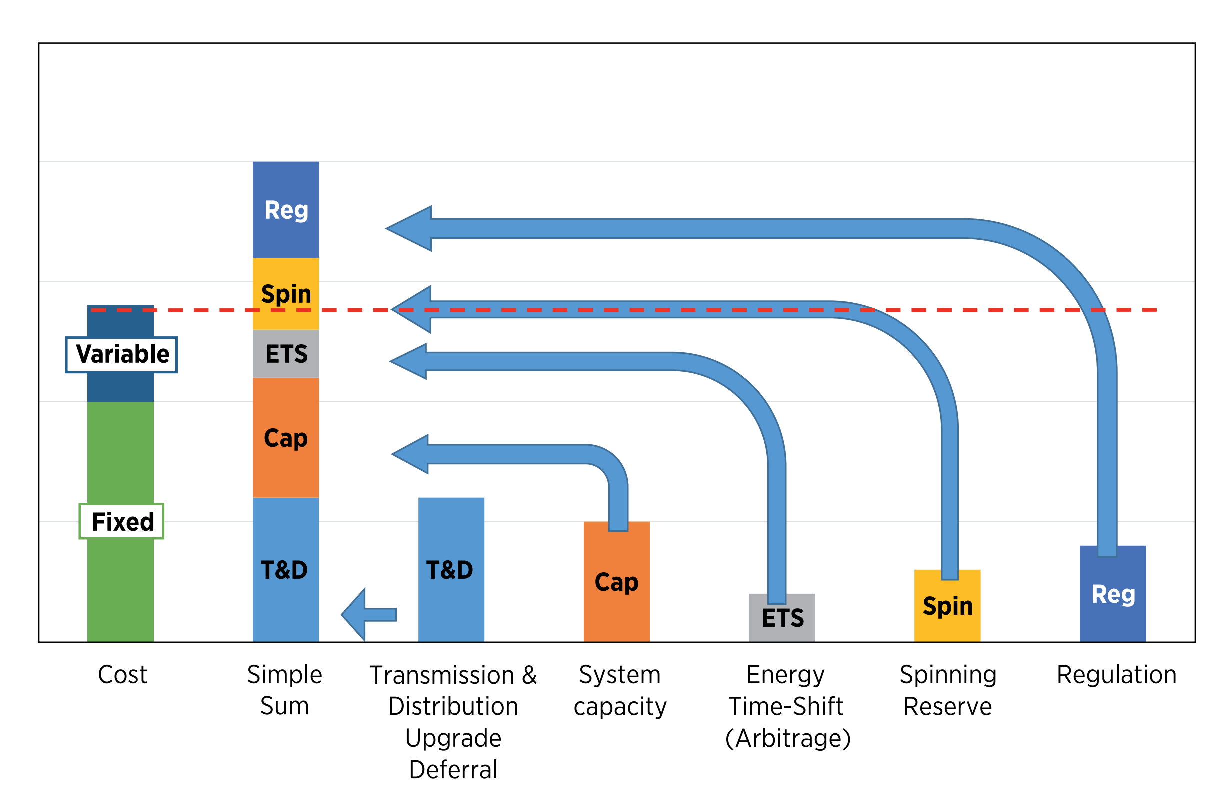
Following these mandates, the California Public Utilities Commission has produced an energy storage roadmap. This was completed in collaboration with the state transmission system operator, the California independent system operator (CAISO) and the California Energy Commission (CEC). The roadmap identifies concerns that need to be resolved to facilitate energy storage deployment (CAISO, CPUC, & CEC, 2014).

The important lesson from California is that the policy makers did not devise their energy storage policy with a mandate in mind. Instead, they started off with a much more exploratory policy to assess the potential impacts of storage, and engaged stakeholders from the beginning. Over time, Californian policy makers and other stakeholders increased their involvement and understanding of VRE technologies, storage and other applications. All this turned into a strong legal and regulatory framework enabling utilities to rate base energy storage assets and services. This provided the necessary financial risk-mitigating framework to encourage utility procurement.

Action 1.2: Provide systemic value assessment for storage

Any policy aiming to use energy storage for renewables integration will require an assessment of the benefit of adding storage and an understanding of what value it might deliver to the whole system. However, it is possible to implement storage at different levels of the value chain while these technologies interact in a complex way with different parts of the system. This makes it

Figure 8: Comparing costs to a stack of energy storage benefits



Adapted from EPRI, 2013.

very difficult to assess the economic and technical benefits and obstacles to electricity storage systems. In addition, storage system valuation is very specific to each region's conditions.

It is very important to develop and use transparent and widely accepted economic assessment tools. These are needed to measure the value and impact of energy storage on the whole system, identify hidden benefits and assess their economic profitability. Unless there is a general consensus on the validity and key rationale behind the use of these tools, major stakeholder engagement and action will be difficult to obtain. Ultimately, these tools need to support an efficient decision-making process and guide the process to achieve them (*e.g.* by designing rules and markets for energy storage). Storage can contribute to several objectives at the same time. A methodology is thus required to rank the different value propositions for storage and any incentives associated with supporting these functions (see figure 8). The financial and public sectors should be involved in providing inputs as well as utilities.

It is critical to include the effective valuation of flexibility in tools for the systemic storage value assessment (Martinez & Hughes, 2015). Tools should assess the value of storage or alternative solutions for facilitating higher shares of VRE penetration within the system. However, they should also measure how storage supports the system's technical and economic capacity to deal most efficiently with stresses it experiences. They need to measure how different indicators are affected (*e.g.* ancillary service costs, response times etc). This can be achieved by assigning a monetary value to ancillary services, accurate forecasting, capacity and reaction speed. Externalities should also be calculated and included into the analysis to obtain a broader valuation of storage systems that is closer to reality. The intrinsic uncertainty (reflected in weather patterns, unpredictable demand profiles, the future fuel prices) and dynamics of the power systems should also be considered by the assessment tool. Finally, modelling results are only as good as the modelling inputs. The extent to which key stakeholders are willing to support policies and programmes based on modelled system results will depend highly on the extent to which they agree with the inputs used. This is why the stakeholder process discussed in Action 1.1 is so critical.

International cooperation is a key factor for accelerating the development of tools of this kind. It facilitates the exchange of international experience and best practices. It is recommended that valuation methodologies are shared as this will help adapt best practices to other systems. EPRI in California has provided a leading example of best practice in developing an energy storage valuation tool. It has created an innovative methodology and software for quantifying the value of energy storage in power systems called the Energy Storage Valuation Tool[8] (EPRI, 2013).

Box D: Assessing the value of electricity storage in Italy

Following rapid solar PV deployment, Italy introduced a net-metering scheme called Scambio sul Posto (SSP) in 2009. This acts as a virtual energy storage system for electricity produced but not consumed in the same period. The scheme provides economic compensation based on differentiated prices depending on when the electricity is consumed or fed into the grid. This is preferred to a scheme providing physical compensation in terms of kWh consumed and fed into the grid.

Gestore dei Servizi Energetici (GSE), the national agency promoting renewables and energy efficiency in Italy, plays the central role in the SSP scheme. GSE obtains data on the electricity fed in and consumed from the grid by renewable power generators. It collects data on distribution costs from the Italian Regulatory Authority for Electricity and Gas (AEEGSI) and electricity prices from the Italian Electricity Market Manager (Gestore Mercati Energetici – GME). With this information, GSE calculates the value of the electricity fed into the grid and the costs of the electricity consumed from the grid. If the value of the electricity input is greater than the costs of electricity consumed from the grid, the renewable energy power generator is paid the difference (minus administration costs). Alternatively, it can use this economic credit to buy electricity at a later point in time. GSE also reimburses the grid operator for the dispatch costs associated with balancing the grid. Thus the grid operator is paid for its services to allow the electricity system to be used as a virtual energy storage system.

From 1 January 2015, all renewable power generation plants up to 500 kW are eligible for the SSP scheme. This includes high-efficiency combined heat and power plants up to 200 kW and hybrid plants with non-renewable power generation of less than 5%. In 2013, almost 400 000 plants were covered by the scheme with a total installed capacity of 3.7 GW. The regulator has recently approved a decision stating that renewable power plants with storage systems are also allowed to participate (GSE, 2015).

From a government perspective, the SSP scheme has been an alternative model to the regular incentive scheme initially adopted. It has fostered distributed renewable energy power generation and has provided a clear view of energy prices. For the user, the SSP scheme provides a clear framework for working out the economic credit from network feed-in. It will also allow consumers to determine whether self-consumption through electricity storage systems is economically more attractive than feeding into the grid. On the down side, SSP creates a high administrative burden for both government and users. This is due to the considerable number of players involved and the high quantity of data to be matched and verified to calculate economic compensation.

8 The Energy Storage Valuation Tool has been used in the development of California's energy storage procurement targets and subsequent system-level production cost modelling. This models the economic dispatch and greenhouse gas impacts of all resources on the grid and includes energy storage.

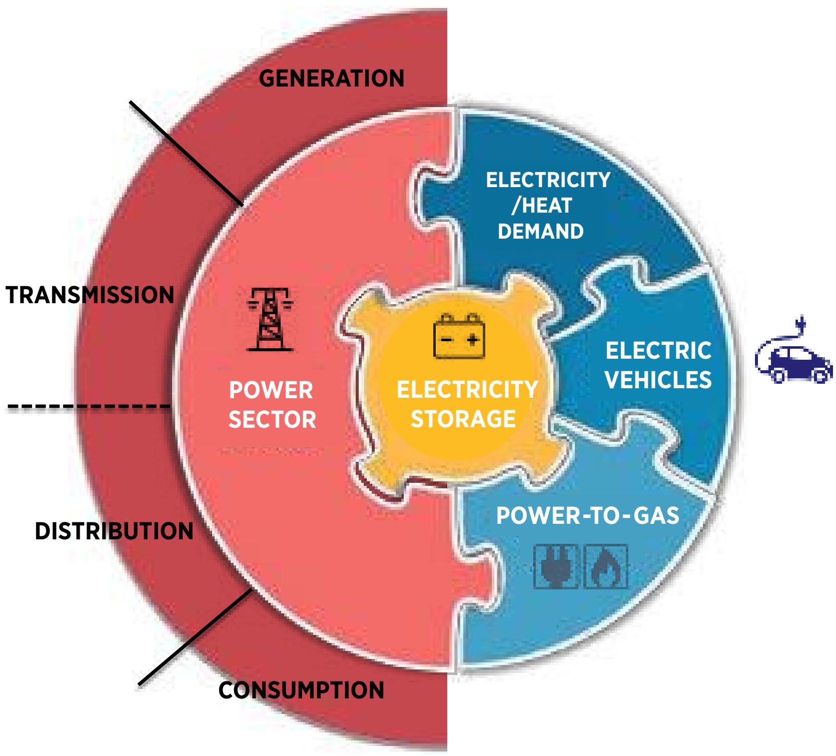
Action 1.3: Support system analysis of electricity/heat/fuel/productive uses as storage options

At a national and state level, policy makers have started to consider the role and extent to which electricity storage is needed for a transition towards renewables. In a country like Germany, this debate is still ongoing, while California has already set targets to ensure storage will be part of the solution. The answers to these questions depend on a number of factors. These include the characteristics of present and future energy demand, present and future grid infrastructure, renewables ambitions and autonomous developments in electricity storage in industries like home appliances and electronics. Furthermore, clear trade-offs exist between the need for electricity storage systems in the power sector and other solutions for VRE integration. These include transport electrification, electricity/heat demand developments in residential and commercial buildings, and the potential to convert electricity into gas or hydrogen (figure 9). These trade-offs can only be managed through dynamic and integrated modelling of the whole energy system.

Due to the cross-sector impact of storage systems, a model of the entire system should support the analysis of storage and its interaction with related systems. These include, for instance, electricity/heat, electricity-to-gas, transport electrification etc. The impact of storage on these systems results in additional market segments and benefits that need to be considered.

For instance, transport electrification will result in growing electricity demand. Batteries for electric vehicles could be (re)designed for use in stationary applications at the end of their mobile life. End-of-life batteries from electric bicycles are already repackaged and resold as residential battery storage systems.

Figure 9: Different system options available for storing electricity produced from variable renewables



Box E: Relevance of electric vehicles to storage for renewable energy grid integration

Transport electrification is one option for increasing power consumption and easing variable renewables integration in the power sector. Transport electrification can occur through modal shift (from short-haul flights to high-speed rail) or electric bicycles and electric cars, buses, trams or trains.

The first modern electric vehicles to enter the market were hybrid electric vehicles (HEVs) like the first-generation Toyota Prius. HEVs have both a combustion engine and electric motor, but their battery pack is not charged through an external power source. Early HEVs used nickel-metal hybrid batteries, but later models increasingly use li-ion. Plug-in hybrid electric vehicles (PHEVs), like the Chevrolet Volt or the Toyota Prius plug-in version also have a combustion engine and a battery-powered electric motor but can also be charged through external power sources. Finally, battery electric vehicles (BEVs) like the Nissan Leaf or Tesla models only have a battery-powered electric motor. Many PHEVs and BEVs use li-ion batteries instead of the nickel-metal hybrid batteries used in the initial HEVs. The battery size ranges from 1.3 kWh for the HEV Toyota Prius to 16 kWh for the PHEV Chevrolet Volt and 53-70 kWh for BEV Tesla models. In 2013, 1.7 million HEVs, 126 000 BEVs and around 50 000 HEVs were sold. The IRENA renewable energy roadmap (REmap 2030) suggests that around 10% of the car passenger fleet in 2030 could consist of BEVs and PHEVs fuelled with renewable power.

BEVs and PHEVs can be used to support the integration of renewables in three ways. Firstly, public or private vehicle charging stations may enable bi-directional flow of electricity, which allows electric vehicles to participate in grid ancillary services. These include frequency regulation, load shifting or demand response or energy management support in homes (load shifting or rooftop solar PV generation and storage). Secondly, electric vehicle batteries can receive a second life for stationary applications. The State Grid Corporation of China is already engaged in a 14 MW project to assess grid support through the use of second-life li-ion batteries. A recent study on the use of second-life electric vehicle batteries for rural energy access estimates a potential retired storage capacity of 120-550 GWh by 2028 (Ambrose, *et al.*, 2014). Thirdly, electric vehicles could be designed so that batteries are replaced rather than charged at battery changing stations. This concept has been piloted in Israel and Denmark and is now being re-introduced to buses in China. In China alone, the flexibility roadmap of the Energy Research Institute (ERI) suggests that 100 GW of battery storage capacity would be available through electric vehicles (Liu, 2015)

Thus the evolution of li-ion batteries, supercapacitors, flywheels and metal air batteries in the context of the growing market for electric vehicles will underpin developments in the power sector. At the same time, electric vehicle smart charging can provide peak shaving and demand shifting.

Energy system models should be combined with power plant dispatch models, power flow models and possibly also pricing models to help assess the value of storage from different stakeholder perspectives. The interaction with non-energy markets, especially the transport sector, is viewed an important driver for energy storage for dispatchability. This should be considered in planning models.

Practical examples are available of models of electricity storage systems within broader systems. For instance, Germany's Fraunhofer Institute for Solar Energy Systems (Fraunhofer ISE) has developed systemic models to assess the role of storage in both power and other end-use sectors in a transition towards a renewables-based society. As in the case of systemic economic assessment tool development, cross-system models should be adapted to the specific conditions of each region.

Table 3: Key stakeholders in storage system analysis

Stakeholders	Action 1: Engage policy makers	Action 2: Provide systemic economic assessment models	Action 3: Support system analysis of electricity/heat/fuel productive uses as storage options
Policy makers		Commission studies	Design policies that take into consideration the interaction with other systems
Regulators	Share expertise and knowledge	Provide required inputs	
Industry associations	Provide expertise and knowledge		
Statistics and planning departments			Contribute data on trends and future developments
Academia/ research institutions	Provide expertise and knowledge	Create models to support the economic assessment of electricity storage systems	Develop new tools
International organisations	Create communication platforms with policy makers		

PRIORITY AREA 2: STORAGE IN ISLANDS AND REMOTE AREAS

Island systems and remote areas are identified as a separate opportunity (Category 3 countries in the introduction). They present an immediate market for deploying electricity storage systems to increase the VRE share and expand rural electrification through renewable energy deployment, as well as to improve supply reliability. As with larger systems, electricity storage cannot be perceived as a stand-alone technology. It should be viewed as a component supporting the whole power system, including services to optimise operation, energy security, adequacy and reliability.

There are three reasons why electricity storage systems in islands and remote areas are attractive. Firstly, many islands and remote areas rely on diesel generators for electricity production. The cost of generating electricity from diesel generators highly depends on the fuel costs, which means that exposure to fuel price fluctuations and scarcity undermines the energy security of these systems. By contrast, the system costs of renewable power generation are in most cases lower than diesel generators, and this improves energy security. However, isolated systems with high shares of VRE will require electricity storage systems to ensure 24 hour electricity. One estimate shows a worldwide energy storage capacity potential of 5.3 GWh[9] on small islands (Blechinger, *et al.*, 2014). The same applies to remote areas in continental countries. For example, India has estimated that the market potential for electricity storage systems in renewable energy applications would be nearly 6 GW by 2020. Of this, more than one third would be in the off-grid renewables market (Walawalkar, 2014). Secondly, most islands and remote areas have weak interconnections and lack flexible power sources (Balza, *et al.*, 2014). This means that there are not so many alternative solutions to support VRE integration. Thirdly, the limited geographical reach of systems in islands and remote areas means electricity storage can provide several services with a single device. This ranges from short-term applications like augmenting power management and improving frequency and voltage to long-term applications like power capacity planning. This adds considerable value to the overall system efficiency and effectiveness.

Electricity storage systems for island applications are not only relevant for island states or countries with areas remote from the national grid but also for countries with large grid networks. For example, the state of New York is supporting feasibility studies for microgrids coupled to renewable power generation and electricity storage systems as part of its 'Reforming the Energy Vision' framework. The South Korean government has started a programme providing power purchase agreements to developers creating island systems through a combination of renewable energy technologies and electricity storage systems.

Islands and remote areas have been analysed in a separate section in this study, but they do not require a completely different analysis or approach to large systems. Most of the action in other opportunity areas is also applicable to islands and remote areas. However, some additional action items are particularly relevant to islands and remote areas because they form an immediate and therefore leading market for renewables.

Action 2.1: Facilitate financing

An economic assessment of electricity storage systems should always consider two perspectives. The first is a financial perspective assessing profitability from an investor's point of view. The second is an economic perspective taking a societal point of view, which considers externalities and assesses the benefits to the power sector as a whole. Recent studies show that storage can be competitive for grid applications when its real value to the system is recognised (Dehamna, 2014). Yet many utilities/operators (with the exception of pumped-storage hydroelectricity) do not contemplate storage expansion. This is because they are unaware

9 In comparison, the global market for batteries in consumer products is around 50 GWh, while the battery market for the automobile industry (including heavy vehicles) in 2014 is expect to reach around 7 GWh.

of the technologies available and their lifecycle costs. Upfront financing needed for capital expenditure of VRE sources already creates problems for countries and communities due to limited funding and loan guarantee conditions for islands and rural applications. Thus the additional capital expenditure required for renewable energy deployment combined with storage is a major barrier. The perceived risk and access to funding is one of the major factors considered by investors and utilities choosing technologies to invest in. It is partly based on incomplete information and lack of experience. In addition, it is difficult to build a business case for storage in systems regulated by markets and aiming to achieve high shares of variable renewables. This is due to policy and market barriers. Consequently, electricity storage systems require innovative financial support to achieve greater deployment.

The first action to stimulate financing mechanisms is to engage policy makers. Government commitment to developing policies and financing schemes sets a baseline for supporting renewable energy and electricity storage system implementation. The involvement of public authorities increases financial credibility and reduces risks. Once policy makers are engaged, the main financial obstacles to electricity storage systems must be identified. Diesel subsidies are one of the obstacles frequently faced by most islands and remote areas. They reduce the possibility to fund electricity storage systems, and make other technology options, such as VRE and storage, even less competitive. Another obstacle is the lack of warranty mechanisms. This makes financial institutions reluctant to provide funding to these projects. Alternatively, they set a very high risk-related interest rate, making the economic viability of the project more difficult to achieve. A stable regulatory framework in the form of retroactive regulation measures is absent but needs to reward the system services provided by storage. This is also perceived by investors and finance institutions as an additional risk, which is penalised through high interest rates or support withdrawal. Finally, a major barrier to investment in storage (or other means of system optimisation) is the lack of peak-load pricing or time-of-use pricing.

Secondly, the design of innovative financing mechanisms should not be limited to upfront costs but should also consider the levelised costs of electricity and a value creation perspective. Some electricity storage systems are economically attractive from a lifecycle perspective; this is nevertheless determined to some degree by the type of technology and characteristics of the system. This includes, for instance, the generation mix, resources and regulatory framework. Some studies have shown that electricity storage systems can reduce the levelised costs of electricity of other generation technologies in the system. They can permit a higher penetration of hydropower or allow diesel generators to operate in a more stable way, thus avoiding wear and tear.[10] From an added value perspective, financing mechanisms should include the local value creation of electricity storage systems, their modularity (and the possibility to reposition storage systems at other locations), and opportunities for recycling. Moreover, electricity storage systems should be considered within a portfolio of diverse storage services available within systems on islands and in remote areas. This includes electricity storage through desalination, ice creation, and heating and cooling demand.

Electricity storage systems can provide immediate value but there is a lack of experience of their use. A high-level platform is therefore needed convening policy makers and other relevant stakeholders, including utilities, to discuss finance options with financial institutions like developing agencies and international development banks. To ensure lessons from these niche island system markets are transferred elsewhere, international support is important, including from landlocked countries or countries that lack islands.

Action 2.2: Create local value chains

Electricity storage systems support the efficient management of local renewable energy generation and consumption and must be considered as part of the whole ecosystem interacting with other components. It can play relevant roles at different stages in the value chain. In islands and remote areas, access to information and technology (components) is considered a barrier. It is therefore important to build a local value chain around storage systems to ensure they can be locally managed, maintained, repaired and possibly recycled or disposed of. This is important because storage configuration and development will be strongly determined by local

10 In most cases of distributed generation based on diesel generation, solar PV coupled with advanced electricity storage systems is cheaper than diesel generators. Most of the regions of India (USAID, 2014) provide an example of this.

conditions: local requirements for recycling, local entrepreneurs, local system configuration and local targets. The South Korean government's 'Storage for Islands' programme is a good example of a policy explicitly requiring businesses to develop an investment plant by engaging with the local community.

Training and empowering local human capacity is crucial to create and maintain a sustainable system. For this reason, policies should be conceived and designed to support local entrepreneurs in managing generation, storage, demand and recycling at the end of subsystem life. This will not only facilitate the development of electricity storage systems but will also help realise the value of electricity storage as a system rather than independent technology. Awareness campaigns and technical assistance programmes for electricity storage should be organised alongside existing mini-grid programmes for the renewable energy sector. Examples of existing activities include IRENA capacity-building activities or the Renewables Academy supported by the German government. Local initiatives like training local young people in renewable energy system operations and maintenance in the state of Chhattisgarh, India, are ensuring the full utilisation of systems based on renewable energy. This builds a certain level of end-user confidence in its usability and is increasing its acceptability within communities.

The creation of a local value chain around storage systems will work as a way to generate and maximise the value of local resources. An integrated policy for mobility and energy supply is an important consideration, especially for islands and remote areas. Mobility is the fastest growing market in the storage sector, and the development of an electric vehicle infrastructure that could be replicated across islands could act as a strong driver for deploying electricity storage in island systems.

Unexpected stakeholders are getting involved in storage technologies and therefore should also be engaged in creating a comprehensive value chain. For instance, diesel generator sellers (*e.g.* Caterpillar) are expanding their business into storage solutions. When assessing the local value chain, it is important to make clear that different island systems have different structures and needs (*e.g.* electrification, solar heating systems, desalination).

Box F: Local value creation for energy storage in Bangladesh

Bangladesh is an interesting case study in which action has been taken to create a local value chain around electricity storage systems. One example is the promotion of solar home system battery recycling. Bangladesh has a peak demand of 8 500 MW, but installed capacity generation of 7 500 MW. This results in load shedding in the summer months. The government has plans to increase the share of renewables to 5% in 2015 and 10% in 2020 and has a successful programme containing around 3.5 million installed solar home systems. Together, these solar home systems account for around 200 MW of electricity storage in the form of deep cycle lead-acid batteries.

Battery providers are responsible for end-of-life recycling, which is an important policy affecting the success of this programme. It means there is a major incentive to use storage batteries of good quality and with local supply chains. A mini-grid programme is in place for areas expecting no grid expansion for the next five years, and a favourable tax regime has been introduced for 5-100 MW solar parks. Bangladesh has only one hydropower plant, so will have to explore alternative electricity storage options to support the transition to a grid with higher shares of variable renewables.

Action 2.3: Develop a global database containing practical examples

Although the attention and market demand for electricity storage is growing rapidly, deployment on the ground is still very limited compared to the rapid growth in variable renewable power generation. Information on practical experiences and procedures supporting the assessment and deployment of electricity storage for renewables integration is therefore limited. The creation of a global and standard database has been identified as a key action to promote understanding of the value

Figure 10: DOE Global Energy Storage Database

Source: www.energystorageexchange.org.

proposition of electricity storage systems. It facilitates the engagement of technology developers, policy makers, the finance sector and general public. The DOE Global Energy Storage Database (Sandia National Laboratories, 2015) is the ideal starting point for developing a new similar database (figure 10).

The creation of a global database is relevant everywhere but is particularly important for island and off-grid systems. These not only represent one of the key opportunity areas for deploying electricity storage systems but could also be the first movers in its expansion.

The DOE Global Energy Storage Database already contains valuable project information on technology type, rate power, duration, services provided, ownership model, and stakeholder involved. However, it needs to be extended to answer the question: "I want storage in my system. So what do I do now?" (IRENA, 2012). To answer this question, the database should accommodate the more informed decisions needed for project implementation. It should share information on costs, detailed design, standards, acquisition, contracts, financing streams, and best practices in energy storage system integration, implementation and operation.

There are dramatic differences in market structures and regulatory frameworks. This makes it difficult to compare project results across different countries and transfer the best practice of a particular system to its counterparts elsewhere. A global database should therefore follow a standard format for collecting and presenting the information. This enables assessment and comparison that generates more valuable information applicable to the further development and deployment of electricity storage systems. For this reason, it is recommended that the database should also consider or mention the regulatory framework and technical and economic characteristics of projects. This supplies a better understanding of best practice before adapting a project's experience in the specific context of other systems. The database should also specify advantages and obstacles.

It should be publicly available to ensure capacity building and encourage the acknowledgement of renewable energy integration practices and storage systems use across all stakeholders. It should allow the evaluation and benchmarking of different projects and progress of electricity storage systems around the globe. This will help policy makers establish a regulatory framework consistent with the development and purposes of electricity storage systems. It will establish the foundations for capacity building among technology developers, as well as generating and receiving global knowledge acquired from global experience. It will build more certainty required by financial institutions to fund projects in favour of electricity storage systems development. The database could serve as a beacon encouraging financial institutions to fund storage projects. Moreover, sharing experiences and case studies facilitates international cooperation. It will serve as a benchmark to support decisions based on successful policies, business models and experiences.

Action 2.4: Guide policy makers to the required analytical tools

Policy makers considering electricity storage systems to support renewables integration will need to compare the value of storage with other alternatives. A value assessment of electricity storage for renewable energy deployment is no small matter, because it has both a short and long-term impact on the whole power system (see Action 1.2: Provide systemic value assessment for storage). Furthermore, it depends on existing and expected levels of VRE penetration and thus requires a step-by-step approach for considering future trajectories. This means analytical tools are needed to help evaluate the financial effectiveness of storage systems based on the specific diesel, PV panel and power system storage costs.

Tools are already available supporting the financial assessment of different technologies in a given power system, such as HOMER and RETScreen. RETScreen is a decision support software package to help evaluate the viability and performance of renewable energy projects. The GEMS4 software technology platform is another, and can be used to visualise alternative energy storage designs. Customised solutions are another type, such as the off-grid simulation tool provided by the Reiner Lemoine Institute (Blechinger, *et al.*, 2014). However, tool developers need to provide archetypes that consider a broader range of applications and situations in which storage can be effectively implemented. The inclusion of such archetypes into the software will improve the assessment of the real impacts and viability of storage technologies in the power system. These tools should not be limited to a levelised cost of electricity analysis but should also consider an added value perspective and evaluate the interaction of storage with the whole system.

Policy makers should also be supported in the selection of the appropriate tool, the interpretation of the result, and be educated on the limitations of the different tools to underpin a solid decision-making process. In particular, a guide of this kind should demonstrate when and where the tools are relevant and how to implement them to ensure they have the greatest value. This depends on the specific conditions and target of the system. The guide should also indicate where generic tools may not be applicable, such as the specific challenges of logistics to get batteries to the right location.

Table 4: Key stakeholders in electricity storage systems for renewable energy deployment on islands or in remote areas

Stakeholders	Action 1: Facilitate financing	Action 2: Create local value chains	Action 3: Develop a global database	Action 4: Tools for guiding policy makers
Policy makers	Develop clear renewable energy roadmaps and targets		Support data collection and aggregation at national level	Support the development and implementation of tools
Regulators		Regulatory frameworks to encourage local ecosystems		Use tools to support the decision-making process
Storage/ renewable energy generation developers	Provide information on financial barriers	Facilitate local operation of electricity storage systems/ renewable energy technologies		
Diesel generator manufacturers/ sellers		Engage in the adoption of storage solutions		Provide diesel technology costs and specifications
Education/ research institutions		Train and operation and maintenance engineers and installers	Analyse and compare electricity storage systems for renewables	Create tools for guiding decision-making in electricity storage systems
Financing institutions	Develop finance schemes for electricity storage systems			
International organisations	Spread knowledge to financial institutions		Communicate knowledge to policy makers	
Development agencies	Inclusion of electricity storage systems needs in development plans			

PRIORITY AREA 3: STORAGE FOR SELF-CONSUMPTION OF RENEWABLE POWER

The rapid fall in rooftop solar PV system costs alongside supportive policies like feed-in tariffs and net-metering schemes has fuelled a tremendous growth in households producing electricity on their own rooftops. Commercial businesses like farms, office buildings and small businesses are also using their rooftops to produce electricity. The ability to produce their own electricity and even inject it into the network gives these 'prosumers' a more active role. The growth in rooftop solar PV is expected to continue and shows a potential for 480 GW in 2030 compared to 3 GW in 2010 (IRENA, 2014).

Costs for generating electricity via a rooftop solar PV system including battery storage will – if trends continue – be undercutting the cost of buying electricity from the grid (figure 11). This development is driven by the declining cost of solar PV (IRENA, 2015b) and battery storage systems, rising residential electricity prices and declining incentives for feeding consumer-generated electricity back into the grid. For example, in Indonesia the Chinese battery and vehicle manufacturer BYD is already providing 800 000 homes with 200 watt solar PV panels coupled to 200 watt battery storage systems. The alternative would be to build a local grid. A development of this type gives prosumers even more versatility and decision power.

Some countries, such as Germany, Italy, the US and Australia, are already experiencing strong interest for VRE self-consumption with storage systems, even though deployment is not cost-effective. The latest figures for Germany suggest that 12% of solar PV systems are coupled to an energy storage system. The national subsidy programme has provided loans for 10 000 systems in 2013 and 2014. The demand for residential battery storage systems is partly due to the continuing feed-in tariff decline. Although small solar PV systems (below 10 kWp) have been exempt from a self-consumption tax, the tariff for such systems declined from EUR 0.1275/kWh to EUR 0.124/kWh in the period from August 2014 to June 2015.

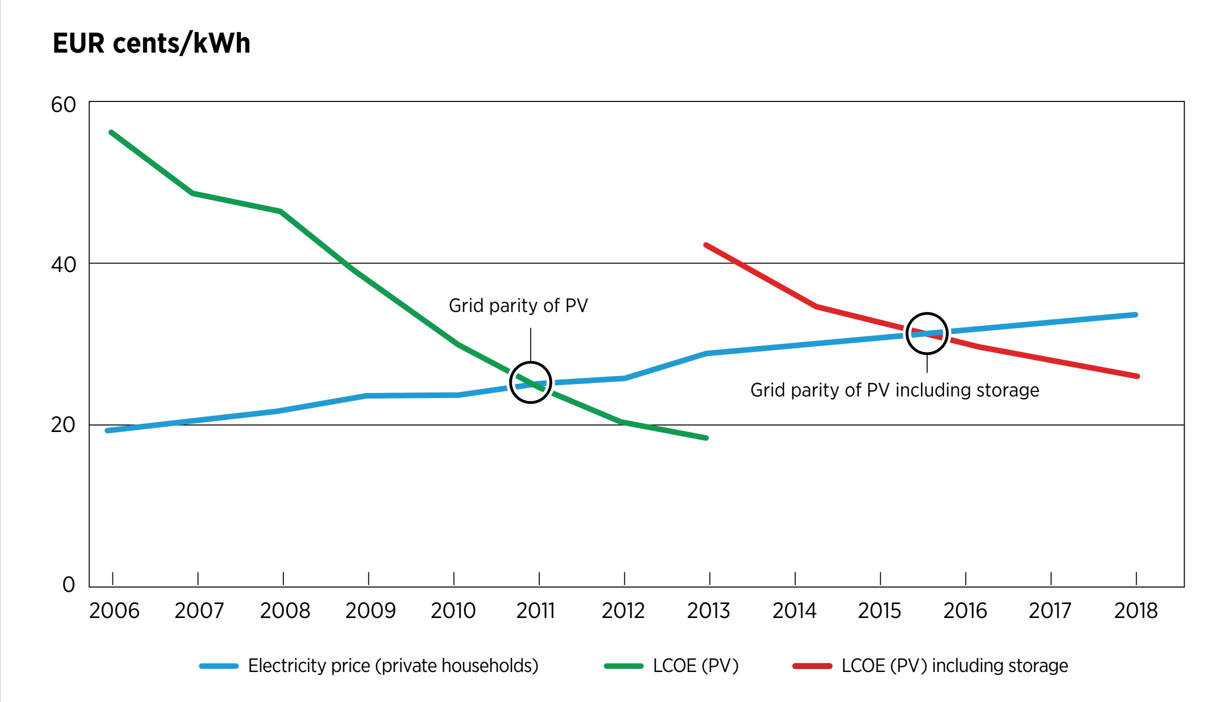
Manufacturers are also driving the increased interest in residential battery storage systems. Major battery manufacturers for consumer electronics like Samsung SDI, LG Chemicals, Panasonic and Sony are increasingly moving into the electricity storage systems market. Meanwhile, large solar PV companies are now selling solar PV systems with integrated storage options. For example, SunEdison recently bought up an electricity storage company. Finally, electric vehicle manufacturers like Tesla and BYD have moved into the market for residential battery storage systems.

This could have tremendous consequences on the way utilities have been managing the grid and could create a new paradigm for power system management. In the traditional model, utilities recover grid infrastructure costs through electricity prices charged to consumers. Utilities now need to revisit their models and identify opportunities to add value to the grid and their business models (RMI, 2014; RMI & HOMER Energy, 2015). This is worrying for both utilities and investors (EEI, 2013; UBS Research, 2013).

Despite these developments, the grid will not become obsolete. More realistically, the energy demand per connection point will continue to decline thus requiring different modes of operating and managing the grid (Khalilpour & Vassallo, 2015). This means that policy makers and regulators should avoid large-scale residential electricity storage system deployment only used for self-consumption without the ability to support grid services. Instead, policy makers should try to incentivise or allow prosumers to provide supporting grid services. For example, Germany introduced a subsidy programme for battery storage systems coupled to solar PV systems. One of the conditions for a subsidy is that the battery storage systems has an open interface accessible by the system operator.[11] Despite this, battery

11 The battery storage subsidy scheme by the German Federal Ministry of Economic affairs and Energy (BMWi) is called 'KfW-Programm Erneuerbare Energien "Speicher" – 275 Kredit' and is administered by KfW.

Figure 11: Grid parity of PV storage in Germany



Source: EuPD Research & BDEW, 2013.

storage systems are not used to support the grid, which has implications for the business and ownership model of these systems.

Solar PV coupled to storage is expected to become cost-effective in regions with high residential prices in the next five to ten years. This means that regulators need to initiate the reform of the regulatory environment. This needs to allow utilities and consumers to use residential storage systems to help manage grids with high shares of variable renewables (including regulation for data ownership). On the technological side, control systems with artificial intelligence are a key area requiring more development.

Action 3.1: Comparative information sheets and labelling

Energy storage for self-consumption is in its early stages[12] and thus little information is publicly available to consumers. Information on consumer applications is a case in point. This is partly due to the lack of consensus on key performance indicators like operation and life cycle costs. Performance indicators that are available are often not relevant for the specific situation in which the electricity storage technologies are applied. Furthermore, many of the current technical datasheets and performance evaluations cannot easily be compared.

Standardised tests and performance requirements are needed allowing operators to compare technologies and discriminate types of manufacturers within specific applications. This may help consumers and any institutions they may need to rely on for finance to decide the right option.[13] Performance indicators of this type would also allow system operators to properly include models of the consequences of residential storage options in their planning tools.

Information sheets on the consumption side of the market must be able to translate technical data into

12 Due to a subsidy policy, Germany has achieved the highest penetration level, with one in 12 solar PV systems coupled to battery storage by the end of 2014.

13 The GRIDSTOR consortium is an existing initiative to create industry standards for system safety, operation and performance for grid-connected electricity storage systems.

understandable and applicable information. They need to inform customers about the products on the market, specifications, applications, practical drawbacks and benefits and how to compare them. They should show which kind of grid services these systems could offer and how they can interact with the grid. Better information sheets can also shape the development of a labelling scheme to make the decision-making process more accessible, transparent and informed. This will transform technical data into a value proposition that can be incorporated by households into their decision-making process.

The information sheets should not only include information on the storage component, such as a battery. It should also consider other components in the system like inverters, charge controllers or other hardware. These sheets can be complemented with other relevant information to support the decision-making process and reduce uncertainty experienced by third parties inside the ecosystem. Examples include insurance companies or banks providing loans to consumers.

Action 3.2: Accelerate standards on safety and recycling

Residential PV system installations are growing quickly and are now starting to be integrated with batteries. This means safety, performance and functionality are becoming a global concern affecting the scale-up of renewable technology deployment coupled with electricity storage for self-consumption. Standards on safety and performance are already in place. The Alliance for Rural Electrification provides an overview of standards applying to batteries for off-grid systems (Alliance for Rural Electrification, 2013). Meanwhile, DOE is supporting protocols to measure and report energy storage technology performance (DOE, 2013). However, more attention should be paid to functionality and recycling. The relevance of safety standards has also grown in prominence due to a number of fires in PV systems coupled with batteries. This is eroding consumer confidence (Karlsruhe Institute for Technology (KIT), 2014). In this respect, standards should consider issues like safety installation, fire response and safety operation.

Even though performance and safety standards are already under development, there are sets of standards that require more attention. Functionality standards are one example (DNV GI & NAATBatt, 2014). Such standards are crucial to ensure harmonisation and compatibility across system components to facilitate the integration of electricity storage systems at different levels of the value chain. The fact that consumers can turn into generators or provide grid services should also be considered through standards on safety operations in the system. To achieve this, one proposal is to create grid codes for PV plus storage systems in households to guarantee grid stability. Creating grid codes on the consumption side will help improve the storage system development scheme.

Standards on environmental issues also require more attention. One of the reasons why the construction of many transmission lines in Germany and India is delayed is due to concerns about their environmental impacts. If electricity storage systems are expected to alleviate the need for transmission lines, then it is important that their environmental impacts are also limited. Most components and materials extracted from end-of-life batteries have an intrinsic financial value and can be used in other applications or to make new products. This area of research needs more work. It is a critical issue given the uptake of storage and PV, especially for batteries with a short-to-medium life. For instance, recycling in Europe is based on a specific European Commission battery regulation (2006/66/EC) obliging manufacturers to recycle. Reduction of toxicity and pollution is another environmental indicator.

Interconnection is another relevant aspect to include in energy storage system standards, both from the technical and regulatory perspective. The same is true for contract procedures, warranties, output performance, and information and communication technologies supporting reliability, security and privacy.

Standards development facilitates international cooperation supporting electricity storage deployment. For this reason, it is crucial to identify the areas in which international standards bodies and agencies should be actively engaged as harmonised international standards emerge. These facilitate the comparison of technologies and experiences from different contexts and identify what specific standards or standard areas are considered to be deficient. International standards bodies should be encouraged to identify standards that will achieve specific objectives. For example, the standards for energy storage could improve safety, alleviate the permit process for storage installation and facilitate equipment standardisation and communication protocol standardisation.

To build valuable and effective standards, technical staff from ministries, financial houses and regulatory and technical bodies must ensure that the projects they support are aligned with them. To achieve this objective, a quality assurance process is essential including proper enforcement measures through periodic monitoring. A procedure should be introduced helping institutions to steer standards through to completion. In addition, countries should provide enough accredited testing laboratories and certification processes to support standards creation and evaluation. Even though clear standards are important for the technology development, electricity storage technologies are constantly and rapidly evolving. Thus standards cannot yet be too rigid for some applications and should be periodically reviewed in order to adapt them to technology progress.

Action 3.3: Create legal frameworks for (data) ownership and liability

Electricity storage has the potential to support system reliability and security of supply, as well as facilitating higher penetration of VRE. Moreover, the use of residential battery storage systems should also play a greater role in supporting grid functions in future. Third parties may seek remote access information and want to control storage systems owned by households. Nevertheless, the models and/or procedures for third party usage are not yet clear. The lack of a clear ownership rights definition is one of the main questions holding back their progress.

However, no legal framework yet exists on the consumption side for extracting the energy storage system benefits above (Crossley, 2014). The conception of electricity storage systems and related markets does not fit into the existing power structure, creating a fundamental difficulty in the development of a legal definition. These systems can be viewed as a generator technology if electricity is supplied or a transmission/distribution technology if it is used to operate the grid. They can be viewed as an electricity consumer if they store electricity. This discrepancy between the legal structure and definition of power systems and their actual operation is significantly increasing regulatory and policy uncertainty in electricity markets internationally. This is affecting residential battery storage system deployment.

The creation of an appropriate legal framework is complicated even further by the different possible ownership models. For instance, households may purchase or lease their storage technology but electricity storage systems could also be owned by the grid operator or PV company. For each of these different ownership models, clear legal rules are needed to effectively guide the potential role of the residential and industrial consumers in supporting the grid. Liability needs to be solved, and this means there is a need to determine who is responsible for the damages and maintenance of the storage systems.

A number of incentives and practices can be used as learning experience. The German subsidy scheme for residential battery storage systems is an example of good practice in a clear ownership model. It requires remote control and access to the storage system and helps to clearly identify boundaries, duties, responsibilities and benefits. The new energy storage decision in Italy (see box D) requires renewable energy plants (other than PV) with electricity storage systems to report electricity absorbed locally as well as from the network (GSE, 2015). The California Public Utilities Commission has also been developing regulation on access to data on energy use (CPUC, 2014).

Table 5: Key stakeholders in electricity storage options for renewable power self-consumption

Stakeholders	Action 1: Information sheets & labelling	Action 2: Standards	Action 3: Ownership regulation
Policy makers		Support and promote the development of standards (facilitate international cooperation)	
Regulators	Enforce the employment of information sheets and labelling	Set a friendly regulatory environment to develop standards	Define ownership regulation
Utilities			Provide requirements
Distribution system operators		Use standards and provide feedback	Impact and are affected by the ownership structure
Storage/renewable energy generation developers	Create templates and provide feedback	Use standards and provide feedback	Storage manufactures can be part of the ownership structure
Industry/technical associations	Create templates	Work on labelling schemes	
Consumer associations	Collect and provide feedback		
National certification authorities		Adopt, implement, test and verify standards	
Standard bodies		Develop standards	
Financial institutions			Provide funding according to ownership structure
Insurance companies			Share data and experience

PRIORITY AREA 4: STORAGE COUPLED TO RENEWABLE POWER GENERATION

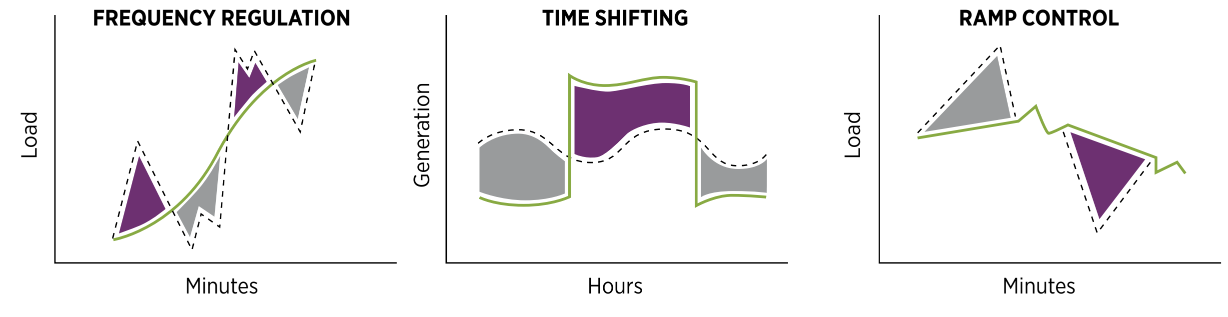
For most countries, the share of renewable power generation is relatively low compared to conventional power generation, and there are no technical barriers against feeding electricity into the grid. Where the share of variable renewables is increasing rapidly, the role of baseload power generation plants may need to be revisited, and more flexible generation options should be considered (IRENA, 2015c).

However, renewable power generation may result in regional distribution networks that face voltage problems due to rapid changes in production. Alternatively, they have insufficient capacity to deal with reverse flows into the transmission network. Such issues are particularly relevant for smaller electricity systems like those in islands and remote areas. In these cases, electricity storage systems coupled to renewable power generation could provide generators with additional functionalities that can be translated into new generator revenue streams as well as benefits to the system.

Electricity storage located on the generator side is not only useful for distribution grid operators but can also provide advantages for renewable power generators. For example, they can allow the storage of electricity when prices are low or when electricity cannot be injected into the network due to grid constraints such as congested lines. This improves revenue streams, helps avoid curtailments of VRE generation and reduces the occurrence of negative pricing in countries like Germany and Denmark with high penetration of variation renewable energy that allow negative prices. Furthermore, electricity storage systems can help smooth the production profile of VRE generators, by avoiding abrupt fluctuations in generation due to changes in weather conditions and allowing predetermined generation profiles. Such systems help significantly to flatten the load curve by allowing electricity time-shifting *i.e.* storage during inexpensive periods and release when prices are higher. For countries with stringent grid codes, electricity storage can ensure that renewable power generators meet the required conditions.

Figure 12 shows the benefits of using electricity storage systems on the generation side specifically to support the integration of VRE. These applications facilitate a smoother and more stable production profile, allow more predictable production and higher forecasting accuracy, reduce curtailments and increase plant utilisation.

Figure 12: Services that electricity storage systems can provide to integrate power generation from variable renewables



Source: Monnier, 2015.

Policy makers should recognise, however, that policies supporting renewable power generation deployment may have adverse effects on electricity storage systems coupled to renewable power generation and vice versa. For example, net-metering or a flat-rate feed-in tariff may discourage storage for self-consumption or balancing. Similarly, stringent regulation on self-consumption or balancing may discourage investments in renewable power generation.

Action 4.1: Support the development of innovative regulation

Technological development is not enough to capture the benefits of electricity storage systems for renewables. It should be actively complemented by a sound regulatory framework and policies that value flexibility and remunerate grid services. Such regulation would allow electricity storage systems to capture several revenue streams to achieve economic viability and would assign the responsibilities and costs for providing the necessary flexibility. If the upfront costs of solar PV and electricity storage systems continue to decline as predicted (see figure 11), policy makers will need to be proactive in developing policies that fully promote the benefits of these technologies to support renewable energy deployment while securing efficient system functioning.

Flexibility does not command a price in many energy systems, and this is one of the reasons there are no business models related to electricity storage. To unleash the potential of existing electricity storage technologies, policies are necessary to create a value for flexibility capacities. The importance of flexibility has already been demonstrated in several power systems around the world. For instance, the Power Grid Corporation of India (PGCIL) expects that 20 GW of flexible generation is required in 2016-17, including storage and supercritical thermal generators (PGCIL, 2012). Well-functioning secondary and tertiary control markets and well-designed capacity markets can help create a value for flexibility. Assigning higher dispatch priority for generators with some output predictability due to storage also gives value to flexibility. This mechanism is applied in French islands. Creating value for flexibility will not only promote load shifting practices with storage use but will also significantly attract new business investments and therefore support energy storage system deployment.

Electricity storage systems are in the middle of a research and development phase and evolving and changing quickly. It is therefore recommended that technology-neutral policies are developed that do not lock a specific storage technology into the system. For instance, one could request renewable energy generators to assure grid stability capabilities by establishing technical standards/codes for different renewable energy penetration levels. The generator could then use market means to find grid stability service providers such as electricity storage systems. Innovative regulation that values the provision of grid stability services in generation to support renewables development will also provide strong incentives for electricity storage systems.

The incentives provided by the regulatory framework to support electricity storage systems development can be either direct (*e.g.* time-of-supply variable feed-in tariffs) or indirect (*e.g.* measures supporting the benefits of storage applications). For example, the South Korean government has amended its regulation in 2015 to allow energy storage system owners in the generation market to participate in frequency regulation. Meanwhile, the French islands implement a feed-in tariff mechanism applied to wind power generators coupled with storage devices with 30 minute production forecasts. These have limited variation in real production (Al Shakarchi, 2015). In the case of indirect incentives, the Indian regulator uses unscheduled interchange and power factor incentives which could be used to support electricity storage deployment (IESA, 2014). When the approach is to give financial incentives through subsidies, they must be according to cycle or stored energy/capacity of the electricity storage system rather than capital costs. A subsidy based on performance standards rather than capital costs would encourage the use of advanced and more efficient products rather than their less efficient counterparts.

Some examples of innovative regulation to support electricity storage system development in the generation side include French islands, Puerto Rico, China, Germany and Japan. Besides the feed-in tariff for wind generators with storage applications, French islands made a proposal for PV systems in 2012 which require forecasting and a trapezoidal production pattern with specific ramp-up and ramp-down rates. The Puerto Rico Electric Power Authority Request for Proposals expects power producers to smooth their production and provide frequency control. China is currently providing preferential access to the grid for wind parks with generation profiles that are smoother and closer to forecast production. All these policies induce the introduction of electricity storage systems without technology prescription.

Action 4.2: Support for localised/distributed systems

Communities around the world are turning to renewable power generation to provide locally generated and locally owned power systems. For example, in Germany almost 150 regions have signed up to an initiative to generate 100% of their electricity from renewables. In the US there are more than 900 community-owned transmission, distribution and generation companies that are exploring renewable energy options.

Electricity storage systems are needed as a load balancing technology that maximises the utilisation of local resources and in turn leads to the efficient management of local supply and demand. This will assist the transition of locally owned systems towards renewables. For instance, Panasonic is currently running a trial to implement residential battery storage systems in community microgrids installed in houses/buildings with multiple households (Miyamoto, 2014). This allows energy sharing and value creation among a group of households. Systems of this type would reduce the energy bill for single homes and could also be used to increase demand-side flexibility, optimise procurement and balancing processes, support grid stability, manage loads and avoid grid infrastructure investments.

In some cases, communities are looking at a number of electricity storage technology options to provide different functionalities. Examples include flywheels for fast response combined with battery storage systems and hydrogen production or thermal energy systems for power management.

Box G: Electricity storage for local use

If electricity storage is used to support the production and consumption of local renewable energy sources, the use of these electricity storage systems should also be considered within its local context. A number of options to integrate electricity storage locally include:

- productive use of electricity storage systems, such as charging stations for mobile phones, water pumping stations, water desalination processes or cooling facilities
- integrating electricity storage systems in zero energy buildings
- coupling electricity storage to air conditioning systems and ice banks, especially in countries with hot climates
- creating local business models to run and maintain electricity storage systems
- developing off-grid cities

The localisation of an energy storage supply chain will require local manufacturing, local technicians and operators, and local opportunities for local recycling. Load balancing will need to focus on maximising the utilisation of local resources and reduce the need for scarcely used thermal generation. This is a guiding principle for developing energy storage for local ecosystems

Localised/distributed systems that are operated autonomously (*i.e.* disconnected from the main grid) will be an important market for electricity storage systems. For such systems, it is essential to adopt an end-user and community ownership model enabling local communities to own, run and maintain localised energy systems. While end-users could commit to this with an affordable fee-for- service option, the community needs to be involved right from the beginning through its participation in planning, installation and subsequent daily operations and maintenance.

Capacity building is also crucial to support the development of localised systems by training the labour force to maintain and operate the system, for instance. However, it is even more important to train trainers to continue the capacity building loop and establish the basis for in-house knowledge creation and sharing. Training trainers will allow site-specific knowledge to develop that will help manage the elemental benefits and challenges of the localised system in the most efficient way.

However, there is limited experience of how such localised electricity power systems should be organised and managed. In order to gain experience, the support of demonstration projects in localised/distributed systems is recommended. These help to determine the adequate ownership structure, understand the benefits and obstacles of operating them, the impact of storage and how they will interact with the grid infrastructure at large.

Table 6: Key stakeholders in electricity storage systems for renewable power generation

Stakeholders	Action 1: Innovative regulation	Action 2: Localised/distributed systems
Policy makers	Design innovative policies and incentives to support the development of electricity storage systems	Determine relationship between community-owned and nationally/privately owned infrastructures
Regulators	Develop and guide the regulatory framework	Define the role of national regulation in localised/distributed systems
Renewable energy generators	Analyse opportunities and barriers of regulatory framework and provide feedback	
Grid operators	Indicate requirements	
Academia/research institutions	Analyse and share best practices	Capacity building
Local community		Share needs and expectations

PRIORITY AREA 5: STORAGE IN TRANSMISSION AND DISTRIBUTION GRIDS

Transmission and distribution is the last priority area identified by this roadmap in which electricity storage systems can be deployed to increase the share of VRE. They do so mainly by providing a wide range of grid support services for efficient network operation. Opportunities for electricity storage systems in transmission and distribution grids is particularly relevant for countries facing grid constraints in managing variable renewables integration (Category 2 in the introduction). Electricity storage systems can be applied on many levels and make an impact on the grid. This makes it very difficult to measure the benefits and implications of using them and assess how different storage technologies interact and where storage is cost-competitive.

Experiences so far suggest that the costs of advanced electricity storage systems are too high to provide balancing services to the grid. The exception is pumped-storage hydroelectricity and the two existing CAES projects. For example, a 2 MW li-ion battery for primary reserve in Italy is estimated to have a payback period exceeding 23 years. The sodium sulphur battery for reducing transmission grid bottlenecks has a payback period of 27 years (Mazzocchi, 2014). One study examined whether electricity storage systems could reduce constraints in transmission capacity in Tamil Nadu in India (where for nine months of the year the transmission capacity is underutilised). It suggests that capital costs have to be reduced by 80% to make it economically viable (USAID, 2014). However, advanced electricity storage systems can provide value in some specific cases. For example, the German utility RWE is cost-effectively using a 1 MWh battery storage system instead of strengthening the distribution lines to serve load in a local community. This is because the area will be connected to the transmission network in a couple of years' time. In this particular case, the additional distribution lines would become obsolete while the battery storage system can be transported and used in other applications (Metzger, 2015).

Electricity storage system costs, however, are only one part of the equation. The economics of energy storage also depends on the structure and pricing mechanisms of power markets. The creation of new and in some cases disruptive transmission and distribution services will prompt a rethink. It will create new business models that will structure the development of both and grid infrastructure management. Examples of these new services include optimised generator programmes, smooth generation and consumption variability, higher power security (supply and congestion management), and improved electricity quality (voltage and frequency). In the context of these services, technology development is needed not only in storage systems but the grid itself. This would include the use of smart grids and also possibly the development of super inverters to manage disaggregated load and generation patterns.

A number of countries are looking at market mechanisms to support a more flexible energy system, including efforts to support capacity markets. In this context, a key question is who has the obligation to balance power in the electricity system. Another is how different ways of structuring this obligation affect power market development (or whether it is sufficient to allow the responsible party to access ancillary services from the generator or any other market player). Any policy maker supporting the development of electricity storage systems in transmission and distribution networks will need to take into account the interplay between technological and market developments.

Action 5.1: Pumped-storage hydroelectricity and CAES analysis

Pumped-storage hydroelectricity is the main technology used to provide electricity storage services in the grid. Along with CAES, it is at present the only storage technology capable of cost-effectively storing large amounts of electricity (terawatt-hours) over multiple days. Japan (26 GW), China (23 GW), and the US (20 GW) have the highest installed capacity for pumped storage. Europe has around 230 pumped-storage hydroelectricity with a total capacity of 41 GW. Around

7 GW is located in Italy and France, and around 5 GW in Austria, Germany and Spain (Global Data, 2015). Many of these pumped-storage hydroelectricity were built in the 1970s and 1980s. This was the result of energy security concerns in that decade alongside a need to mediate baseload power production from nuclear power plants (National Renewable Energy Laboratory (NREL), 2013; Gutierrez & Arantegui, 2013). In Italy, pumped-storage hydroelectricity with a capacity of 5 GW were built in the early 1980s in anticipation of nuclear power expansion. However, many of these have been underused since then due to the nuclear veto in the 1987 national referendum (Grigatti, 2015). Only two CAES projects exist amounting to 440 MW, one in Germany and one in the US.

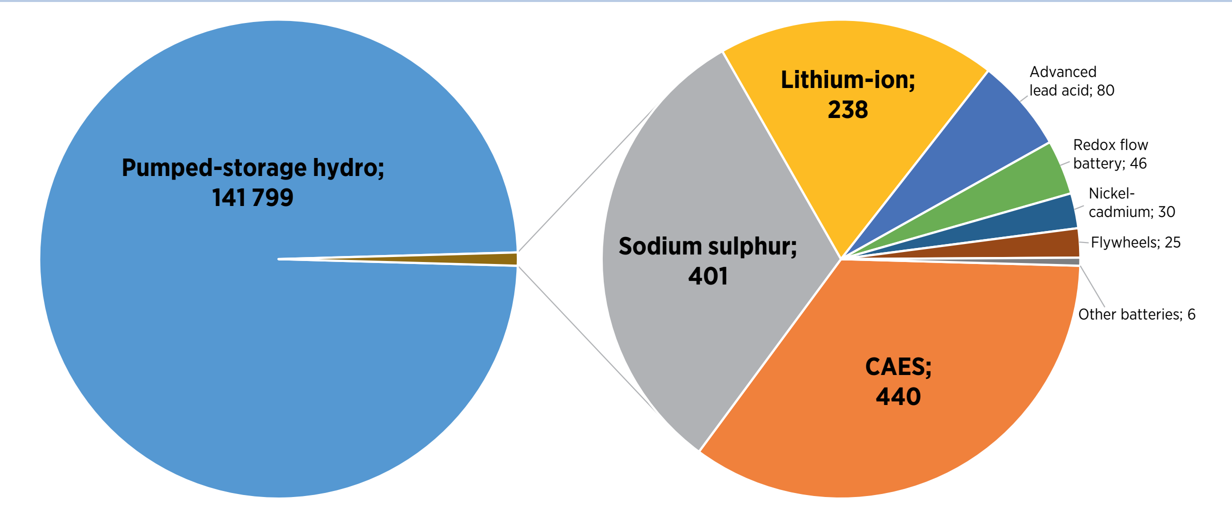
Pumped-storage hydroelectricity should be separately evaluated when considering storage options to support power system operations due to their commercial competitiveness and large capacity and storage duration. This means they should be the first storage options evaluated for helping balance grids with high shares of VRE. Pumped-storage hydroelectricity should be considered both within one's own national boundaries and in neighbouring countries.

Neighbouring pumped-storage hydroelectricity and make a large-scale impact. This means the analysis of these technologies must be extended to the impact they may have in supporting grid operation and participating in different markets. This includes, for instance, frequency regulation, balancing and capacity markets (NREL, 2014). A comprehensive understanding of these technologies and their potential will inform the initial decision to choose storage options and help measure the benefits of acquiring electricity storage systems.

Box H: Pumped-storage hydroelectricity in Brazil

Brazil has a special auction mechanism that uses pumped-storage hydroelectricity and renewable power generation to enhance security of supply. This is organised exclusively for renewable generators (wind, solar, biomass, small hydropower) building their plants and/or selling their energy for system reserve purposes. The electricity traded in such auctions is used in pumped-storage hydroelectricity to fill up reservoirs and support system stability by providing energy reserves in times of drought. This scheme takes advantage of the large storage capacity of the Brazilian hydroelectric system.

*Figure 13: Share of pumped-storage hydroelectricity in global electricity storage system (in MW)**



* *The data has been verified and augmented with data from the DOE global database for capacity installed to date (lithium-ion, vanadium redox flow, zinc bromine redox flow and nickel-cadmium) for operational projects.*

Source: Navigant Research (Dehamna, Eller & Embury, 2014) for installed battery capacity by type, and GlobalData (2015) for the pumped-storage hydroelectricity capacity.

Nevertheless, the installation, efficiency and costs of these technologies are highly dependent on the geological characteristics of the site.

Action 5.2: Support demonstration projects for new business models

Both technical demonstration projects and research and development are needed to measure the impact of storage systems and cut the costs existing and emerging storage technologies. However, technology development is only one part of the equation. Demonstration projects are needed that help define monetisation models supporting the development of storage technologies (DNV GI & NAATBatt, 2014). There is very limited experience or best practice in cost and finance models. More research is needed to understand how electricity storage systems at different levels add value to energy efficiency, demand response, renewable energy deployment and grid service support. Additionally, the creation of new and in some cases disruptive services through electricity storage systems in transmission and distribution will prompt a rethink or create new business models. This will not only guide the development of storage systems but also reshape the progress of transmission and distribution activities.

Box I: India's national storage mission

In 2015, India announced ambitious plans for rapidly expanding wind power and solar PV deployment. India has tremendous renewable energy resources including an estimated 750 GW of solar PV and approximately 1000 GW of wind (Ministry of New and Renewable Energy (MNRE), 2014). It has already deployed a significant amount of renewables including 130 GW of hydropower, 22 GW of wind, 20 GW of bioenergy and around 2 GW of solar PV. Off-grid renewable energy capacity is estimated at around 825 MW (WB, 2014). For 2022, India has the ambition to increase its solar PV target of 20 GW to 100 GW. This means adding at least 12 GW in solar PV per year. For wind energy, India has been considering an increase from 3 GW to 10 GW per year.

However, the rapid growth of power consumption means India is already facing grid infrastructure constraints. Power shortages in 2012-13 resulted in a gross domestic product loss of 0.4%. Load shedding is common due to the peak power deficit, and businesses have a competitive disadvantage due to the need for batteries and diesel generators as backup power. Land acquisition or right-of-way issues have been partly responsible for obstructing the development of transmission and distribution infrastructure. This led to delays in more than 120 transmission projects in 2011 (FICCI, 2013). Consequently, relieving grid congestion and improving the power grid infrastructure is a main priority for the central government.

In 2012, the Indian government had already asked PGCIL to assess the transmission infrastructure and control equipment needed to achieve renewable power generation capacity additions in the country's 12th plan. This amounts to 47 GW in wind and 10 GW in solar by 2017 rising to 164 GW and 35 GW respectively in 2030. The report, entitled 'Green Energy Corridor,' found that an additional intra-state transmission network would be required to facilitate transfer from states with plenty of renewable power to offer[14] to other states. Furthermore, smart grid technologies like forecasting methods, STATCOMs, synchrophasors, dynamic compensators and switchable/controlled bus reactors would be required to maintain frequency and voltage. It stated that renewable energy management centres would need to be established to exchange data and models to support the renewables integration (PGCIL, 2012). In the estimates for renewables integration in India's power infrastructure, more than 90% would be used for transmission system strengthening and expansion and 5% for energy storage technologies. Less than 5% would be used for smart grid technologies and the establishment of the renewable energy management centres (PGCIL, 2012). Since then, the Central Electricity Authority (CEA) has introduced connectivity standards. These are applied to wind and solar PV generation plants with requirements for harmonics, Direct Current Injections, Flicker, fault-ride through and reactive power support.

14 Tamil Nadu, Andhra Pradesh, Karnataka, Gujarat, Maharashtra, Rajasthan and Himachal Pradesh.

The standards also apply to active power injection for wind generation plants connected at higher voltage levels (more than 66 kV) (CEA, 2013) (NITI Aayog, 2015).

Despite the limited role of energy storage, MNRE is keen to understand the transformative role electricity storage can play in grid infrastructure. Consequently, the Indian government is examining the potential for pumped-storage hydroelectricity (CEA, 2013). MNRE has published a call for expressions of interest in energy storage projects. Based on the feedback received, it is now developing a National Storage Mission to coincide with the national missions on solar, wind and biomass. A guiding principle for supporting them is to explore new business models for energy storage projects and ensure energy storage technologies provide grid services beyond the support for renewables integration. At the same time, the Power Grid Corporation of India is funding three 500 kW/250 kWh demonstration projects in the context of its Frequency Response Pilot Project. This includes an advanced lead-acid project, a li-ion project and possibly a flow battery project. For decentralised power systems, MNRE is supporting decentralised distributed generation in villages where grid connectivity is not cost-effective or where there are only limited hours of supply. Decentralised distributed generation projects receive subsidies of 90% towards capital expenditure for connections to households below the poverty line if financed with 100% capital subsidies at 3000 Rupees per connection (Ministry of Power (MOP), 2015).

The importance of new business models rests on the need to quantify the overall value of storage in the various services it provides to the system. A single storage system may have the potential to capture several revenue streams to achieve economic viability. In the case of transmission and distribution, electricity storage has applications for grid stability, transmission congestion management, demand-side management etc.

Before developing demonstration projects to assess the impact and added value of storage in transmission and distribution, key questions should be answered. Who has the obligation to balance the system? How do the different ways of structuring this obligation affect power market development? Is it sufficient to allow the responsible party to access ancillary services from the generator or any other market player? The answer to these questions will have an impact on the way storage systems are valued and therefore affect the development of business models that support electricity storage systems. To answer them it is crucial to consider the interplay between technological and market developments.

Establishing a sound regulatory framework and market mechanisms or pricing schemes will help storage operators create revenue generation models encouraging investments and fostering the development of electricity storage systems. A number of countries are looking at market mechanisms to support a more flexible energy system including efforts to support capacity markets.[15] The establishment of this type of regulatory framework and market mechanism could also be introduced in the demonstration projects so to analyse its impact, benefits and disadvantages.

Demonstration projects will help value storage in two different ways. Investors will be able to assess profitability, and system operators will be able to assess the value for system operations. The results of demonstration projects should be implemented analysing the added value of electricity storage systems to the whole system. This will generate measures, financial business models, policies and appropriate and cost-effective incentives supporting energy storage system development. These measures should be introduced gradually to allow markets to adjust.

A number of activities foster business demonstration project planning and implementation. Examples include roadmap development (*e.g.* the China system flexibility roadmap which provides a major role for electric vehicles) and requests for proposals (*e.g.* French island and Puerto Rico requests for smoother VRE generation with electricity storage support). Expressions of interest are another (*e.g.* Indian expressions of interest for energy

15 Colombia introduced a reliability charge in place of the traditional capacity charge scheme in December 2006, while the UK and France introduced new capacity markets in 2014 and April 2015 respectively.

storage demonstration projects for supporting renewables generation).

Business cases based on policies or demonstration projects planned a long way down the line can harm deployment prospects. Once demonstration projects have been built and key findings extracted, sharing best practice and demonstration experiences may help set up bankable projects. The key objective is to reduce developer and financial risk, scale up and ensure faster deployment. This will guide businesses and investors as they adjust investment models to include storage value.

Table 7: Key stakeholders in electricity storage systems to support grid infrastructure

Stakeholders	Action 1: Pumped-storage hydroelectricity and CAES analysis	Action 2: Demonstration projects for new business models
Policy makers	Analyse the role and incentives of these technologies in the new framework of power systems (higher shares of variable renewables)	Promote experimentation
National departments		Provide funding and support for demonstration projects
Storage operators	Assess the potential of these technologies in the system	Engage in demonstration projects and share lessons
Grid operators	Analyse the impact of these technologies on the grids	Engage in demonstration projects and share lessons

TRACKING PROGRESS FOR POLICY MAKERS

As a facilitator of international cooperation, IRENA is looking for opportunity areas and key action items that foster the development and deployment of electricity storage systems. Indicators are a useful tool to track progress and compare the different applications and features of electricity storage systems. Indicators have been divided into two groups. The first group tracks the technology progress and deployment of energy storage in the system from the supply point of view. The second tracks the need for and benefits of electricity storage systems, showing for instance how much the system is benefiting from storage applications from the demand point of view. These indicators can be implemented to analyse and track the progress of storage systems.

Table 8: Indicators of technological progress in storage systems for renewable power deployment

Indicators of technology progress	Suggested measure
Costs	• cost per cell • cost per system • cost per KW • cost per KWh • cost per KWh/cycle
Deployment levels	• energy from storage systems (MWh) – behind/in front of meter • storage installed capacity (MW) – behind/in front of meter • solar home systems
Technology performance	• energy storage capacity • energy & power density (MWh/kg, MW/kg) • number of cycles & cycle life • roundtrip efficiency (%) • calendar life
Investment streams	• financial records in energy storage system investments
Standardisation	• standards (performance, safety, environment) • certification schemes • labelling schemes
Policies	• research, development and demonstration funds • grid codes • regulation • subsidies

Nevertheless, the deployment of electricity storage systems is not an end in itself. Their purpose is to support a reliable, efficient, cost-effective and clean power sector by facilitating renewable energy deployment. Therefore, table 9 lists a number of indicators to track the value of electricity storage systems for renewable energy deployment in four out of the five priority areas. These indicators will be more difficult to collect. However, they will act as a more powerful and clear guidance on how electricity storage systems can be used most effectively to facilitate a transition towards renewables.

Table 9: Indicators to evaluate the benefits of storage systems for renewable power deployment

Indicators assessing value of electricity storage systems for renewables	Suggested measure
Storage in islands and remote areas	• share of variable renewable power generation (with or without storage systems) • accuracy of variable renewable power generation forecast with storage systems • number of diesel generators in islands/remote areas replaced/augmented by renewable power generation technologies
Consumer storage	• consumer savings through self-consumption coupled with electricity storage (i.e. payback period) • improved quality of electricity access
Generator storage	• number of variable renewable energy installations with storage systems (MW) • reduced curtailment rates • savings in generation capacity investments (peak units) related to electricity storage systems
Grid storage	• reduction of ancillary service costs due to the utilisation of electricity storage systems • reduction in transmission and distribution investments (peak units) related to better use of the networks with storage systems • number of network congestion incidents solved with storage systems • number of grid voltage stability problems solved with storage systems

CONCLUSIONS

In most cases, electricity storage systems are not a prerequisite for a continuous increase in renewable power generation. However, they will certainly be able to facilitate the short-term transition from diesel generators to renewable power generation in isolated electricity systems on islands and in remote areas. Policy makers and utilities planning, managing and operating systems in these types of environments need to be better informed about the role electricity storage can play in a transition towards renewables. However, they cannot do this alone. As front-runners, they will face the greatest and most immediate barriers, so support from other countries will be needed. This will help them come up with new procedures, tools and solutions to overcome these immediate barriers.

In larger systems, pumped-storage hydroelectricity is the most important electricity storage technology supporting VRE integration into the grid. However, policy makers should recognise that electricity storage systems can impact system operations in both the short and long term and will have a positive effects even beyond the integration and transition towards renewables. This is true at any level in the power sector – consumer, distribution, transmission, generation or in the form of electric vehicles or productive use. A better understanding of these consequences is needed – either through studies, demonstration projects or stakeholder consultations. This will guide both renewable energy and electricity storage policies.

In the next five to ten years, the costs of rooftop solar PV combined with advanced electricity storage systems will decline to levels where it may become cost-effective in regions with high residential electricity prices. This could mean a large number of consumers start producing and consuming their own electricity more cheaply than buying electricity from the grid. Although this situation will not diminish the importance of transmission and distribution grid infrastructure, it will affect utilities' existing models for recovering expenditure for maintaining and managing the grid. As a consequence, policy makers and regulators now need to start creating regulatory frameworks that ensure any electricity storage systems for self-consumption will also be able to support the grid. A regulatory framework of this type will require methods and procedures allowing for aggregation. This will support technology developments for control systems, software and procedures to deal with (data) ownership.

This technology roadmap has identified 14 action items across five priority areas to facilitate the development of policies on electricity storage for renewables. Each priority area has its own dynamics, however they also interact. For example, increased battery storage system deployment at a residential level will impact electricity storage systems for VRE grid integration in distribution and transmission networks. For policy makers, this necessitates dedicated action in each priority area while ensuring consistency at the national level. International cooperation facilitating learning and support for these activities will be critical to effective deployment.

Policy makers, however, are only one of many stakeholders that need to take action. This technology roadmap has identified the key stakeholders for each action item and has suggested specific ways forward. International cooperation among and between stakeholders will be key to ensure lessons are shared. This technology roadmap recognises that technology characteristics and costs will evolve as time passes. Some action items will become obsolete while others have to be reinforced or restructured.

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International Renewable Energy Agency

IRENA Headquarters
P.O. Box 236, Abu Dhabi
United Arab Emirates

IRENA Innovation and Technology Centre
Robert-Schuman-Platz 3
53175 Bonn
Germany

www.irena.org

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