Workshop Proceedings

Electricity Storage: Technologies, regulation and policies supporting small- and large scale deployment of renewables

New Delhi, 3 December 2014

IRENA Innovation and Technology Centre, Robert Schuman Platz 3, 53175 Bonn

Opening of IRENA's International Electricity Storage Policy and Regulation workshop by Secretary Upendra Tripathy, Ministry of New and Renewable Energy, India.

1. Introduction

The International Renewable Energy Agency (IRENA) organised its third "International Energy Storage Policy and Regulation Workshop" on 3 December 2014 in New Delhi, India. The workshop took place alongside the 2nd International Conference & Exhibition on Energy Storage and Microgrids in India from 3 to 5 December 2014.

The aim of the workshop was to identify key technology solutions, regulatory challenges and policies needed to support the accelerated deployment of bot decentralised and utility-scale renewables, examine the lessons that can be drawn from India, and to identify opportunities for international cooperation and exchange of best practices and lessons. Workshop participants consisted of policy makers, industry representatives, academia, and other relevant stakeholders. The workshop was attended by 40 people.

1.1 Structure of the workshop

The workshop was opened by Secretary Upendra Tripathy, Ministry of New and Renewable Energy MNRE) of the Government of India. Subsequently, Mr. Gurbuz Gonul, Acting Director of IRENA's Country Support Programme provided the key insights of IRENA's renewable energy roadmap (REmap 2030), the lessons from the previous two workshops and an overview of IRENA's activities on energy storage so far. IRENA's activities include:

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

The introduction presentations were followed by two keynote presentation followed by a panel discussion. The first keynote presentation was provided by Dr. Walawalkar, Chairman of the Indian Energy Storage Alliance, and was followed by a discussion on the specific opportunities for energy storage in off-grid systems. The second panel discussion addressed the topic of electricity storage for the integration of utility-scale renewables projects, and was opened by a presentation by Smt. Varsha, Joint Secretary of the Ministry of New and Renewable energy. The insights from the panel discussion are provided in Section 4.

The workshop concluded with four roundtables; two roundtables addressed the technology and policy needs for storage for small-scale renewables deployment, and the two others addressed technology and policy needs for storage for utility-scale renewables deployment. Section 5 provides an overview of the questions and the outcomes of the discussion. At the end of each roundtable, participants were encouraged to identify three key areas where international cooperation activities are warranted.

The structure of these proceedings is as follows. First, the background for IRENA's activities in electricity storage will be provided (section 2), and subsequently the specific context for energy storage in India (section 3). Section 4 provides the insights from the expert panel, and section 5 will discuss the insights of the four roundtables. Section 6 will provide overall conclusions from the workshop, and their relevance for IRENA's electricity storage roadmap.

2. IRENA and energy storage

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

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

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

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

At the global level, the share of vREs is still very small – less than 3% of electricity production came from wind and solar PV in 2013. In most cases, grid operators can handle vRE shares up to 20% of annual production without significantly increasing the power system costs in the long run (IEA 2014a). For example, pumped hydro has been used for many years in most countries to support load shifting from electricity production at night time to support peak hours during daytime. However, for some countries the variable nature of wind and solar PV is already creating a new paradigm for managing and operating grids. In the month of December 2013, for example, Denmark produced 55% of all electricity generation from wind power.

Another characteristics of wind and solar PV is that they are modular – their size can be tailored and expanded as demand for electricity grows. According to REmap, the share of distributed solar PV deployment would increase from 7% of total installed capacity in 2010 to around 38% in 2030. Producing electricity close to demand centres means reduced need for costly transmission lines and it can provide electricity for small islands, remote locations, and for local communities on the spot. On the other hand, in some cases the wind and solar resources are far away from demand centres, and additional transmission lines are needed to connect wind turbines in windy locations across demand centres a country.

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

2.1 Context, scope and timeline

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

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

In the last two years, IRENA has already developed a number of analyses for specific electricity storage markets. IRENA's electricity storage technology brief provides an overview of the different electricity storage technologies (IRENA-IEA-ETSAP, 2012a). For islands, IRENA has developed a guide for decision-makers that outlines possible strategies for electricity storage (IRENA, 2012b). For off-grid applications, IRENA organises the bi-annual International Off-Grid Renewable Energy Conference and Exhibition (IOREC) featuring storage solutions. The latest advances in battery storage technologies are examined in IRENA's publication "Battery Storage for Renewables: Market Status and Technology Outlook" released in January 2015.

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

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

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

The blueprint of the technoloy roadmap report will be presented on the 10 March during IRENA's 4th International Electricity Storage Policy and Regulation workshop in Düsseldorf, Germany. This roadmap will be critical in identifying how countries can benefit from this emerging paradigm.

2.2 Electricity storage for distributed and utility-scale renewables deployment

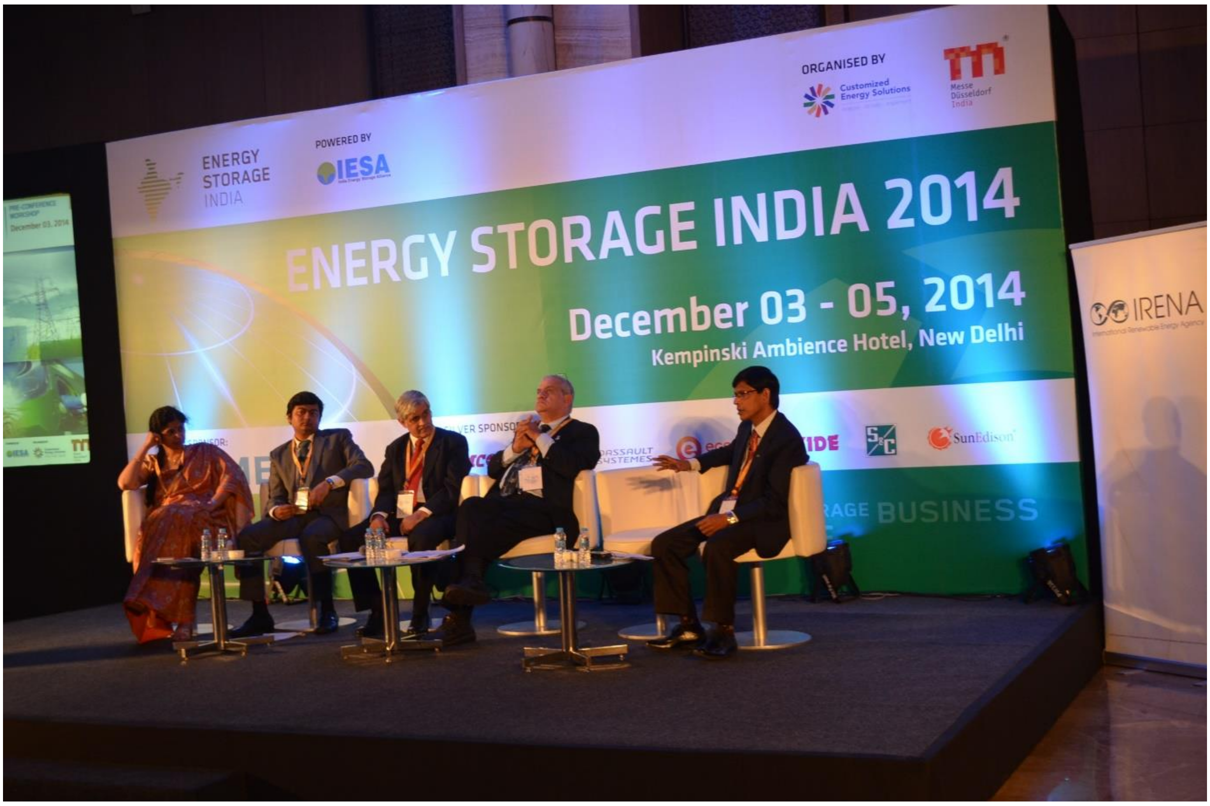
This workshop was the third in a series of International Energy Storage Policy and Regulation Workshops to inform IRENA's technology roadmap on electricity storage. The kick-off meeting for this roadmap took place on 27 March in Dusseldorf, Germany, and brought together representatives from 13 IRENA countries, industry representatives, academia, and other relevant stakeholders to identify key areas where electricity storage can support the deployment of renewables. The second workshp took place on 7 November in Tokyo, Japan, and focused on residential battery storage applications for self-consumption of solar PV power production (the presentations and proceedings can be found here).

Two of the key areas for renewables deployment identified in the first workshop were:

- The deployment of electricity storage systems for off-grid renewable energy systems, such as in islands, rural areas, and in individual electrification systems (i.e. solar home systems);
- The deployment of electricity storage systems to aid in the integrating of utility-scale and grid-connnected renewable power generation capacity.

India was chosen as the location for the third workshop, because it features opportunities for both applications of electricity storage. On the one hand, a large percentage of rural households will be connected to electricity and electricity storage may play an important role in this developments. Furthermore, India has ambitious targets to grow its share of distributed renewable power generation in India. On the other hand, India's 30 GW of wind energy capacity is already connected to the grid, but there are a number of problems to transmit production across states. Again, electricity storage could plan an important role to address this issue.

With this as background, the title for IRENA's third International Energy Storage Policy & Regulation workshop was "Electricity Storage: Technologies, regulation and policies supporting small- and large scale deployment of renewables". The workshop took place in New Delhi alongside the 2nd International Summit and Expo on energy storage and microgrids.



The second discussion panel on electricity storage for utility-scale renewables integration with (from left to right): Smt. Varsha, Joint Secretary, Ministry of New and Renewable Energy, India; Dr. Aga, R&D project leader, Alstom Power; Mr. Batra, Chief Engineer, Central Electricity Authority; Mr. Dr. Galal Osman, Vice President, World Wind Energy Association; Md. Abdur Rouf Miah, Director at Powercell, Ministry of Power, Energy & Mineral Resources, Bangladesh

3. Electricity storage in India

The workshop was opened by Shri Upendra Tripathy, Secretary of the Ministry of New and Renewable Energy of the Government of India. In his opening speech, Secretary Tripathy mentioned that the Government of India is considering to increase it solar PV target from 20 GW in 2022 to 100 GW in 2019. This target would increase the share of renewables from the 3% RE obligation in place to 10.5% by 2019. MNRE is working with States to understand how such an ambitious target would impact the generation profiles in different States, and the possible challenges for evacuating power across the transmission network. The Green Energy Corridor project focuses on strengthening the interconnection across States, whilst within each State there will be nodal agencies that will be supported by a national platform supported by the Ministry. Furthermore, MNRE recognises that deployment opportunities may differ substantially among States depending on their population density, the need for power sources in the agricultural sector, and rural electrification needs. As part of this ambitious plans, MNRE will also focus on the opportunities for solar PV in cities with deployment on rooftops and close to existing power stations. In total, 50-60GW could be deployed in a distributed manner. Furthermore, MNRE is considering policy to oblige power producers expanding their fossil fuel fleet to pair expansion with at least 10% renewable power generation.

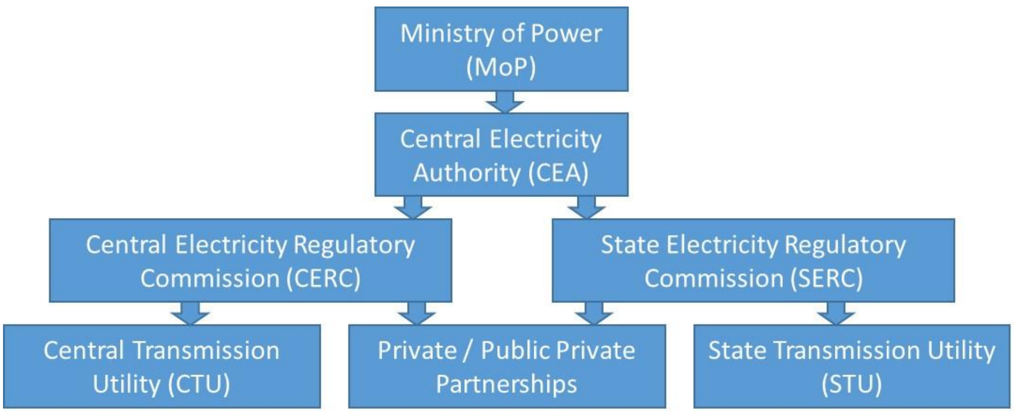
Alongside these ambitious deployment targets, the Government of India has plans to develop a "Solar Army" consisting of new jobs for installers and operators of solar PV plants. Also, an association of renewable energy agencies will be created for standardisation and certification of renewable energy technologies, with dedicated shops to by solar products. Furthermore, a number of demonstration projects are planned, and India will strengthen its international cooperation activities on research, development and demonstration projects. Finally, the Government of India is organising from 15-17 February its first Renewable Energy Global Investors Meet & Expo (RE-INVEST, www.re-invest.in) to attract investments into the renewable power sector

These recent developments show that India exemplifies many of the opportunities and challenges for electricity storage for renewables integration. First, India has tremendous renewable energy resources with an estimated 750 GW of solar PV and around 1000 GW of wind (MNRE, 2014). Second, India has already significant deployment of renewables with 130 GW of hydro, 22 GW of wind, 20 GW of bioenergy and around 2 GW of solar photovoltaics. Off-grid renewable energy capacity is estimated to be around 825 MW (WB, 2014). For 2020, India has the ambition to increase its solar PV target of 20 GW to 100 GW, which means an additional solar PV capacity of 20 GW per year. For wind energy, India has been considering an increase from 3 GW to 10GW per year. Third, India has many different geographical conditions ranging from desserts to long coast lines to the highest mountain areas, which means that energy storage technologies can be tested and explored in different scenarios. Fourth, India's grid infrastructure has difficulties to keep with demand growth. Load shedding is coming, and peak prices have been introduced to reduce consumption. Furthermore, India has a large programme to provide electricity to the 43% of rural households without access. Distributed renewable power generation, in the form of solar home systems or mini-grids, can provide a quick solution for electricity access, but back-up systems in the form of diesel generators, biobased power generation, small hydro or electricity storage, would be required to ensure that electricity is available around the clock.

3.1 India's power grid infrastructure

Reliable, affordable and secure electricity production is a key element to ensure continued growth of industrial and commercial activities in India and to satisfy the rising demand of residents. However, the current grid infrastructure is already strained. Power shortages in 2012-2013 resulted in a GDP 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 back-up power (FICCI, 2013).

Figure 1. Overview of India's transmission market structure



The current challenges for the Indian grid infrastructure stem for the high growth rates in electricity consumption from both industry and residential consumers. India's power generation capacity grew with more than 100% between 2002 and 2013 to keep up with the soaring electricity demand. In July 2014, the power generation capacity stood around 250 GW. Over the same period, the total length of transmission and distribution lines grew with only 50%. In 2033, total annual peak demand is estimated to increase to around 611 GW (MoP, 2014a). The lagging transmission and distribution infrastructure is partly due to land acquisition or Right-Of-Way (ROW) issues leading more than 120 transmission projects facing delays in 2011 (FICCI, 2013). Consequently, relieving grid congestion and improving the power grid infrastructure is a main priority for the central government.

Furthermore, the Indian Power system is divided into five regional grids (Northern, Southern, Eastern, North-Eastern, and Western). End of 2013, all of these grids have been interconnected through high-voltage transmission lines, but the inter-regional transmission capacity is relative low compared to installed capacity. In 2012, India had around 200 GW of power generation, but only 25 GW of inter-regional transmission capacity (Lall, 2013). In July 2014, transmission capacity reach 250 GW (MoP, 2014a) and it is expected that the inter-regional transmission capacity will reach around 65 GW in 2017 (PGCIL, 2012). In comparision, total renewable energy capacity (excluding hydropower is estimated to be 83 GW in 2017 (MoP, 2014a). For 2022, an estimated 135 GW of non-hydro renewable power generation is expected. At the same time, it is estimated that the Northern and Southern regions will have deficit up to 20 GW by 2022 (MoP, 2014a).

At the same time, India is diversifying its power generation mix through growth in biomass-based power generation, concentrated solar power, wind power and solar photovoltaics. A renewable energy purchase obligation (RPO) has been introduced that requires power distribution companies to buy 5-10 percent of their electricity from renewable sources, or by renewable energy certificates (REC). One REC stands for 1 MWh of renewable power generation, and there is a separate market for solar renewable energy certificates (SREC). RECs can be traded across the various States. Up to 2014, about 15 million RECs have been issues, and more than six million RECs have been traded since the implementation of the REC mechanism. The National Load Despatch Centre is the nodal agency for this mechanism (POSOCO, 2014).

In 2010, the Government of India announced the National Solar Mission with an ambitious plan for 20 GW of solar by 2022. Following the solar mission and the continued expansion of wind power, the Indian Government asked the Power Grid Corporation of India (POWERGRID) in 2012 to assess the transmission infrastructure and control equipment needs to achieve the RE power generation capacity addition planned in the 12th plan (47 GW of wind and 10 GW of solar by 2017). For 2030, the report envisioned 164 GW of wind and 35 GW of solar. The so-called "Green Energy Corridor" report found that additional Intra State Transmission network would be required to facilitate transfer of RE power from RE rich States[1] to other States. Furthermore, smart grid technologies like forecasting methods, STATCOMs, synchrophasors, dynamic compensators and switchable/controlled

[1] RE rich States examined were Tamil Nadu, Andhra Pradesh, Karnataka, Gujarat, Maharashtra, Rajasthan, and Himachal Pradesh.

bus reactors would be required to maintain frequency and voltage, and Renewable Energy Management Centres (REMCs) would need to be established to exchange data and models to support the integration of renewables. Furthermore, the Indian Electricity Grid Code is the right venue for addressing topics like voltage ride through provisions, voltage and reactive epower (VAR) support, frequency and inertial response support, and reserves respond (NITI Aayog, 21015). The Central Transmission Utility (CTU), the Central Electricity Authority (CEA), and the Power System operation Corporation (POSOCO) were identified as key stakeholders to examine the role of energy storage for RE grid integration. Table 1 provides an overview of the estimated costs associated with the different options for integrating renewable power generation (Power Grid Corporation, 2012).

Table 1. Estimated costs for the integration of renewables in India's power infrastructure (Power Grid Corporation, 2012).

Solutions for RE grid integration in India	Estimated costs (Rs. Cr)	Relative share
Intra State Transmission System Strengthening	20466	48%
Inter State Transmission System	18848	44%
Dynamic Reactive Compensation	568	1%
Real Time Dynamic State Measurement Scheme as well as Communication Systems	451	1%
Energy Storage	*2000*	*5%*
Establishment of RE Management Center	224	1%
Total	42557	100%

Similar studies have been conducted at a state level. For example, the State of Gujarati assessed the policy and regulatory challenges needed to integrate up to 10GW of solar PV and 35GW of wind power within its grid infrastructure, and concluded that interstate trading of renewable energy will be needed to deal with the power surplus situation. On the policy and regulatory side, the report recommended to explore energy storage options in more detail (TERI, 2013).

Since then, the Central Electricity Authority (CEA) has introduced connectivity standards for wind and solar PV generation plants with requirements for Harmonics, Direct Current (DC) Injections, Flicker, fault-ride through, reactive power support as well as active power injection for those wind generation stations connected at higher voltage levels (>66 kV) (CEA, 2013).

At the same time, the CEA been examining additional strategies for integrating large scale renewable power projects In November, the CEA published a report that suggested that States should set their RE purchase obligations according to their capacity to balance the combined variability of load and RE generation. Furthermore, States should examine technical and regulatory measures to enhance the flexibility of conventional generation to increase the balancing capacity, and finally seek cooperation with the Renewable Energy Management Centers in RE rich states to make optimal use of transmission infrastructure (CEA, 2013).

Since the 'Green Energy Corridor' report, India has increased its ambition for renewable power generation and has accelerated its implementation (MNRE, 2014). In terms of renewable power generation, the Government of India (GoI) is exploring more ambitious targets for both wind and solar. For solar, the GoI has proposed to set up 25 Solar Power Park of over 100 MW per park or over 500 MW for so-called Ultra Mega Solar Power Project. In each solar park, land will be made available for solar project developers and grid interconnection will be provided (MNRE, 2014). For wind power, the GoI is exploring the option to increase annual capacity addition from 3 to 10 GW per year (MNRE, 2014d).

Regarding the strengthening of the transmission infrastructure, the Ministry of Power is implementing an Integrated Power Development Scheme (IPDS) with funds to strengthen sub-transmission and distribution networks in urban areas, metering of distribution transformers/feeders/consumers in urban areas, provisions for solar panel, and smart grid deployment (MoP, 2014b). For rural areas, the Deendayal Upadhyaya Gram Jyoti Yojana (DDUGJY) programme has been launched to strengthen sub-transmission and distribution networks, including metering, in rural areas (MoP, 2014c) Furthermore, the Cabinet has approved the North Eastern Region Power System Improvement Project (NERSPSIP) to strengthen the Intra State Transmission and Distribution System in November 2014 (Business Standard, 2014), and 19 GW of additional transmission capacity is under construction. Another 21 GW is expected to be built before 2018.

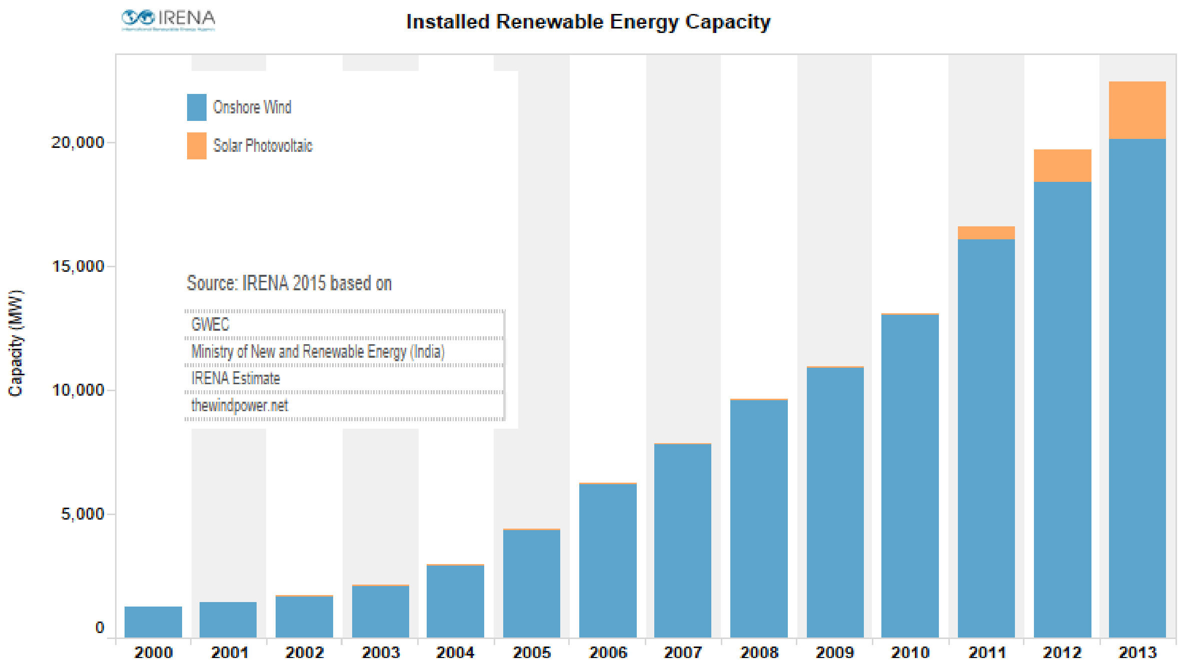
On a longer-term perspective, it is estimated that the peak load will increase to 283 GW by 2022 and more than 600 GW by 2034 (CEA, 2014).

3.2 Electricity storage for the integration of utility-scale renewables

India’s transmission and distribution network faces a number of challenges at the same time (IESA, 2014). First, rapid expansion is needed to keep up with the growing demand, but there are administrative hurdles and delays for expanding the transmission network. There was still a peak power deficit of around 9% (12 GW) (FICCI, 2013), and many cities have load shedding and higher electricity peak prices to reduce peak demand. Second, electricity supply and demand is not evenly distributed across the country, so new inter-regional transmission capacity is needed. Third, around 60% of the existing power generation capacity consists of coal thermal plans with limited capability to respond quickly to fluctuations in power demand and supply. Fourthly, India’s distribution networks have reported average losses of around 26%, with the worst distribution networks having losses averaging 54%.

Renewable power generation from wind and solar PV are rapidly increasing, and are addressing the need for more diversified power mix and additional generation capacity across the country. However, at the same time they require additional measures to handle their variable generation patterns. India is the 5th largest installer of wind power, and has a total installed capacity of 22 GW by the end of 2014 (IRENA, 2015). The majority of capacity is installed in five states: Tamil Nadu (>7 GW), Gujarat and Maharashtra (>3 GW), Rajasthan (>2.5 GW), and Karnataka (>2 GW). These five states are expected to add an additional 20 GW by the end of 2017. The problem for integrating wind power generation into the grid is that the peak wind season in some of these states (e.g. Gujarat and Tamil Nadu) runs from May to August, whilst peak power requirements are in October when wind resources are low (CEA, 2013). This means that wind power generation contributes to overall electricity consumption up to 35% per month in the wind peak season, and as low as 5% per month in the peak demand season. Grid balancing has been achieved through reduction of generation in coal-based power plants in Tamil Nadu and gas-fired plants in Rajasthan. However, the the coal-fired power plants are relative old and are constraint in their flexibility. Furthermore, the use of hydropower for regulation is limited to the non-irrigation based stations, which in the case of in Tamil Nadu is only 1.3 GW.

Figure 2. Solar PV and wind power capacity in India from 2000 to 2013



Solar PV production mainly takes place in utility-scale plants with a total installed capacity of around 2 GW (mostly concentrated in the Gujarat, which reached around 1 GW in 2014). The GoI has currently opened a number of solar parks allowing 20GW of solar PV to be added to the grid between 2014 and 2019. Each park is at least 500 MW in size, and up to 2500 MW. They are connected to the state transmission or the central transmission network.

Distributed renewable power generation can provide value system support to the Indian grid. In Mahrashtra, distributed renewables are providing valuable voltage support at weak points, and renewables can support local reliability by allowing “islanding” of distribution networkds when surrounding grid is in fault/blackout (NITI Aayog, 2015).

Electricity storage coupled to renewable power generation can address any integration challenges associated with utility-scale wind and solar PV plants, and some of India’s current regulatory regimes provide favourable circumstances. There is a surcharge on electricity production during peak times on the short term energy exchange of around INR 2.75 per kWh (USAID, 2014), and many businesses and villages are using diesel generation (> INR 18 per kWh) in case of black-outs. Furthermore, the

Indian regulator uses Unscheduled Interchange (UI) and power factor incentives that could be used to support electricity storage deployment (IESA, 2013). The Power Grid Corporation of India (PGCIL) expects that 20 GW of flexible generation, including storage and supercritical thermal generators, is required in 2016-2017 (PGCIL, 2012). PGCIL also has three 500kW/250kWh demonstration projects in place in the context of its Frequency Response Pilot Project, including an advanced lead-acid project, a lithium-ion project, and (possibly) a flow battery project.

The cheapest option is pumped hydro. India has nine pumped hydro storage schemes in place with an aggregated installed capacity of almost 5GW. Out of these nine plants, only five plants with an aggregated installed capacity of 2.6GW are actually working in pumping mode. The other four schemes have problems with vibrations or tail pool dams haven not been constructed yet. Two pumped hydro storage plants with an aggregated capacity of 1GW were under construction in 2013, and another 2.5GW of pumped hydro plans are being investigated. In total, the CEA estimates a potential of almost 100GW of pumped hydro with 40% located in the Western region (CEA, 2013).

USAID has examined the option for energy storage systems to reduce constraints in transmission capacity in the region of Tamil Nadu, where for 9 months per year the transmission capacity is underutilised (USAID, 2014). Assuming capital costs of around INR 4692 per MW/day for the transmission network[2], they calculated that current battery storage systems are not cost-effective and need cost reduction of around 80% in capital costs.

3.3 Electricity storage for the decentralised and off-grid deployment of renewables

In 2012, over 43% of rural households did not have access to electricity (USAID, 2014). However, India has extensive plans to rapidly increase electrification. On the one hand side, India is extending the distribution networks to connect rural villages[3]. Under the DDUGJV scheme, the Ministry of Power has sanction the electrification of 124,786 villages, expansion of the electrification in 602,910 villages. Furthermore, connections to 108,913 unelectrifed villages and intensive electrification of 314,160 villages was completed (MoP, 2015). On the other hand, India is supporting decentralised distributed generation (DDG) to villages where grid connectivity is not cost effective, or where there are only limited hours of supply. DDG project receive subsidies towards capital expenditure of 90%, whilst connections to Below Poverty Line (BPL) households if financed with 100% capital subidies @ INR 3000 per connection (MoP, 2015).

The household load for individual village is assumed to be 200W, and the majority of electricity demand is for lighting or businesses after sunhours. So both individual solar home systems as well as

[2] This estimate is at least a factor three lower than the costs for the transmission network in the USA (USD 65-390/kW/day for the US, compared to USD 27/kW/day in the case of India).

[3] A village is deemed electrified, if 10 percent of all the households of the village has electricity access and if electricity provided to public spaces such as schools, panchayat officers, health centres, community centres and dispensaries (Vasudha Foundation, 2013).

microgrids could be used to provide electricity, but electricity storage systems or back-up power would be required to provide electricity at night.

Most decentralised distributed generation is based on diesel generators, which can provide electricity with a nominal cost of INR 30 per kWh. According to USAID, solar PV coupled with advanced electricity storage systems are in these cases cheaper than the diesel generators (USAID, 2014). IESA estimates an energy storage market of around 1.4 GW for rural microgrids and 1 GW of grid connected rural electrification.

3.4 Electricity storage for other applications

There are a number of other markets for electricity storage in India. Many industrial and commercial users (including clusters of small- and medium-size enterprises) are already deploying lead acid batteries or diesel generators to provide back-up power. Advanced electricity storage systems could be used to replace traditional back-up power sources, and also be used to reduce the costs of peak pricing to industrial and commercial users (USAID, 2014). IESA estimates a market of around 1.3GW for this applications. The other option is to couple advanced electricity storage systems to utility-scale renewable power generation plants on site, which would allow for smoothing of the power generation mix (IESA estimates a market of around 1 GW in 2022). Finally, there is a large market for electricity storage systems coupled to solar PV panels or small wind turbines for powering telecom towers. India's has around 500,000 telecom towers, and only 2% are provided with renewable power. IESA expects a potential market of around 700MW in 2022. USD 300 million purchase to replace diesel generators with lithium-ion batteries.

4 Insights from the expert panel

The aim of the expert panels was to provide a status update on the latest technology and policy developments in India, and form the basis for the group discussion and the roundtables.

The expert panel were divided into two groups. The first group was opened by Dr. Rahul Walawalkar, Chairman of the Indian Energy Storage Alliance and covered electricity storage applications in off-grid systems.

Table 2a. List of discussants on the topic of energy storage for decentralised and off-grid renewables.

Expert	Organisation	Topic
Mr. Rahul Walawalkar (Keynote presentation)	Chairman of India Energy Storage Alliance & Vice President Customized Energy Solutions Ltd.	Status overview and key issues for renewables with storage in off-grid systems
Mr. Vinod Kala (Moderator)	Managing Director, Emergent Ventures	India's electricity storage roadmap
Mr. Shirish Garud	Head Energy Systems, TERI	Technological advances in renewable energy minigrid and offgrid systems.
Ms. Usha Rao	Senior Sector Specialist, KfW	Financing schemes for off-grid storage systems
Mr. Shudhir K. Chaturvedi	Chairperson, Joint Electricity Regulatory Commission for Goa, and all Union Territories	Storage for Indian islands
Mr. Bodha Raj Dhakal	Nepal Electricity Authority	Distributed RE deployment in Nepal

The second group was opened by Smt. Varsha Joshi, Joint Secretary of the Ministry of New and Renewable Energy, and covered electricity storage applications for utility-scale renewable energy generation.

Table 2b. List of discussants on the topic of energy storage for the integration of utility-scale renewables.

Expert	Organisation	Topic
Smt. Varsha Joshi (keynote presentation)	Joint Secretary, Ministry of New and Renewable Energy	How can residential battery applications be used to support the integration of renewables into the grid?
Mr. Pankaj Batra (moderator)	Chief Engineer, Central Electricity Authority	Towards a Renewable Energy Economy
Mr. Vipluv Aga	R&D project leader, Alstom Power	R&D advances in storage
Mr. Adbur Rouf Miah	Director, Ministry of Power, Energy & Mineral Resources, Bangladesh	Grid integration of renewables & solar home systems programme
Mr. Gagal Osman	Vice President, World Wind Energy Association	Global experience on storage for renewables integration

An overview of presentations and background files can be found at:

http://www.irena.org/menu/index.aspx?mnu=Subcat&PriMenuID=30&CatID=79&SubcatID=475.

4.1 Electricity storage for off-grid renewable energy systems

The deployment of electricity storage systems for microgrids is expected to be the largest market segment for India with around 1.43 GW in 2022. Furthermore, options for electricity storage systems can be found in grid-connected rural electrification systems (1 GW) as well as in townships (510 MW).

The costs of electricity storage systems are expected to rapidly decline with capital costs on par with lead-acid batteries. Due to increased improvements in cycle numbers in advanced electricity storage system, the costs per cycle are in most cases already lower than lead acid (see Figure 3a, 3b, and 3c).

Figure 3a. Capital cost trends for electricity storage systems (Walawalkar, 2014)

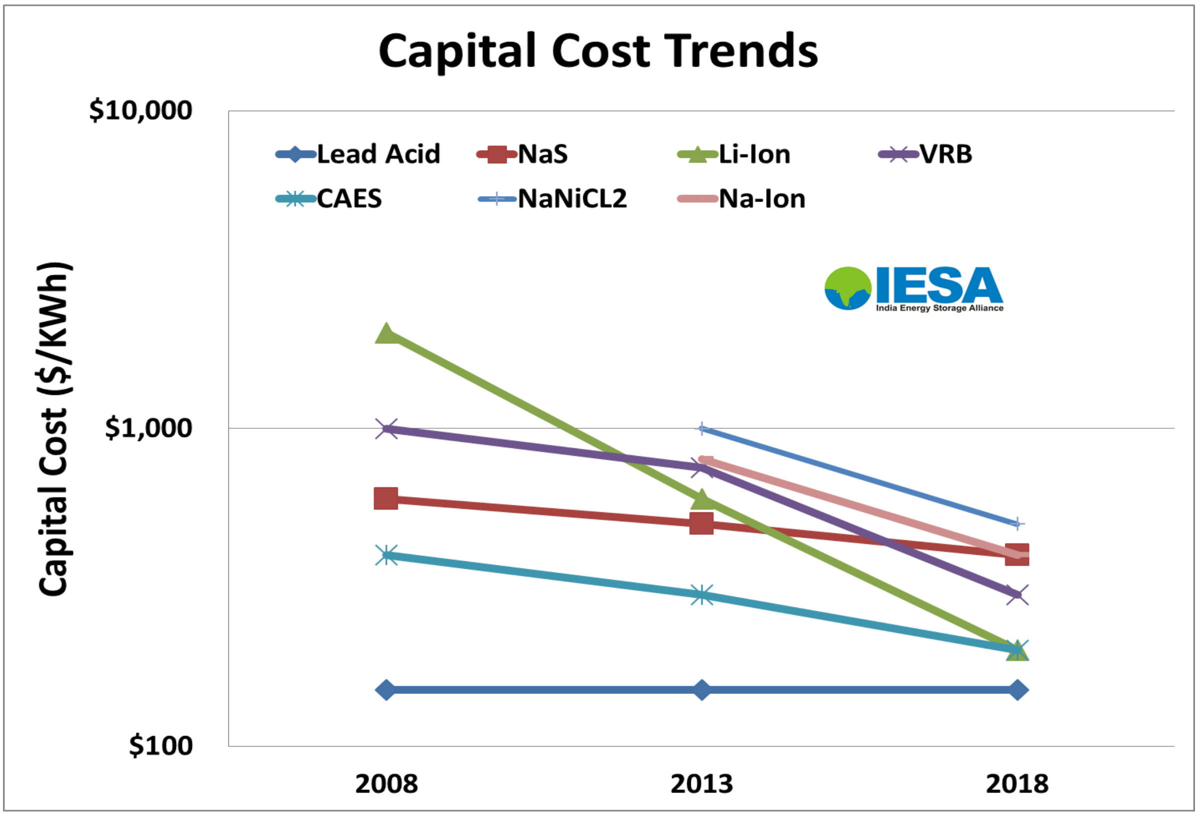


Figure 3b. Cycle life trends for electricity storage systems (Walawalkar, 2014)

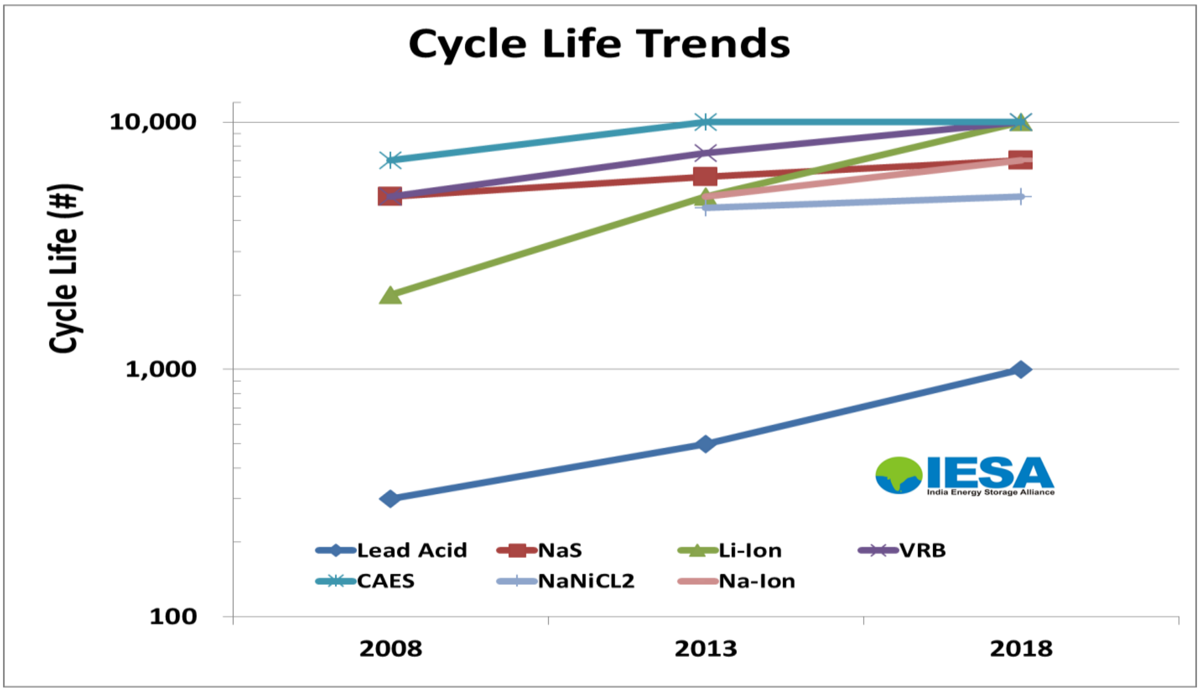
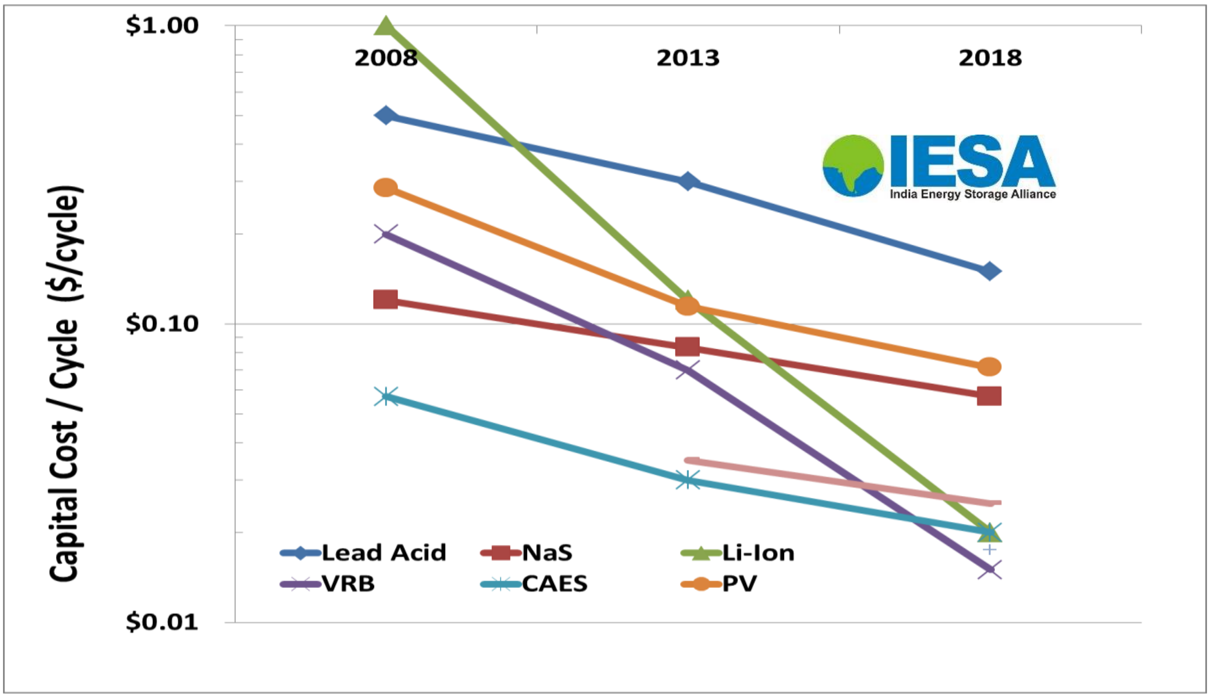


Figure 3c. Capital costs per cycle life trends for electricity storage systems (Walawalkar, 2014)



Although the expectations are that the costs for electricity storage technologies will rapidly decline, renewables-based mini-grids with storage are not commercially viable yet. TERI has been pioneering the development of mini-grid systems from early stand-alone solar/biomass/hydro systems to advanced smart mini-grid systems with state-of-the-art system designs and components. Furthermore, they are working on solar street lighting, solar home systems and plan to open a Center of Excellence to study energy storage technology, initially focussing on thermal storage.

The technology is progressing rapidly, and ready to deploy. However, the main challenge lies in the business model, partly due to the fact that rural villages cannot afford the tariffs yet and load factors are often relatively low. There is also the question on how to finance storage systems for these mini-grids: Should they financed based on capacity or life cycle or by grid support services that could be delivered once these mini-grids are connected to the grid? Should they be sold or leased?

Electricity storage in off-grid renewable energy systems will also be important for India's islands. Many of the coastal areas and islands are tourist attraction, and have land constraints for ground mounted solar installations. They range in size (up to 15 MW), and load is dominated by residential and commercial electricity usage. Distributed rooftop solar PV is one of the key options for replacing the expensive diesel generators, but will require storage systems to operate throughout the day and night. The key question is how these distributed solar PV systems can be coupled to electricity storage systems to ensure reliable and affordable electricity. In comparison, Andaman & Nicobar islands where diesel is used for power generation has cost of generation approximately INR 30/ kWh. Lakshadweep islands has diesel based cost of generation ~ INR 40 / kWh

From a policy perspective, it is therefore important to differentiate between electricity storage systems in off-grid applications, where the right ownership models needs to be stimulated, and grid-connected storage systems where grid support is an important factor. The panellists emphasised that, except for islands, eventually electricity storage in off-grid mini-grids and grid-connected systems will converge. This means that policies at some point need to converge, or at least ensure that electricity storage in off-grid systems is able to support grid functionalities. Ms. Rao mentioned mentioned experience in other parts of the world that show that behind-the-meter storage per se does not necessarily reduce the load on the grid and bring about the flexibility required. Thus behind-the-meter applications, including storage in off-grid systems, that are supported by policy should be required to act in support of the grid once connected.

Considering the complex business models as well as high-tech applications that are required for effective grid-tied storage systems, Indian companies and research institutions can play an important role in developing this industry and a pro-active policy from India's government can create the right framework to foster the development of storage for electrical energy.

The case of Nepal was also discussed during this panel. One third of Nepal's population does not have access to electricity, and distributed solar home systems require 5/6 hours of storage to be useful for the communities. So far, lead acid batteries are used, but Nepal has many problems with malfunctioning batteries and a limited lifespan. There are also a number of mini-grid developments without storage, and an effort to provide solar district lights.

1.2 Electricity storage for utility-scale renewable energy systems

Electricity storage will be crucial for operating India's grid if renewable deployment will continue to grow, and pumped hydro storage systems are the most cost-effective and economic solution that should be considered. A roadmap for developing pumped hydro storage would therefore be an important first step.

Technology deployment, however, should also be accompanied by the right regulatory framework. Grid codes, for example, are a powerful tool that allow power generators to identify the right technical solutions to achieve a particular functionality. For example, China is currently provided preferential access to the grid for wind parks with generation profiles that are smoother and closer to the forecasted production. This policy induces the introduction of electricity storage systems without technology prescription.

Finally, the case was made that policies should consider how electricity storage systems can support local production and consumption of renewables. Solar and wind power generation have the advantage that they can be deployed in a distributed manner, and provide generation close to demand. Electricity storage systems can support such local ecosystems, however the electricity storage systems should then also be considered a part of this ecosystem. Therefore, policies should support local entrepreneurs for the management of generation, storage, and demand and recycling at the end of life.

Besides India, the case of Bangladesh was discussed. Bangladesh has a peak demand of 8500 MW, but a generation capacity of 7500 MW resulting 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 with 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. An important policy for the success of this programme is that battery providers are responsible for end-of-life recycling, which means that there is an important incentive to use storage batteries of good quality and with local supply chains. A mini-grid programme is in place for those areas where no grid expansion is expected in the next five years, and a favourable tax regime has been put in place for 5-100 MW solar parks. Bangladesh has only one hydropower plant, so will have to explore alternative electricity storage options to support a transition towards a grid with higher shares of variable renewables.

5 Roundtable results

The roundtable took 1.5 hours, and workshop participants were free to choose one of the four roundtables. Each roundtable consisted of around 5-8 workshop participants. The discussion was subsequently summarised according to the three questions outlined at the start of the workshop (see Table 3). At the end of the discussion, the groups would prioritise their recommendations for international cooperation activities and present the results back to the workshop.

Table 3. Topics of roundtables

Roundtable	***Facilitator***	***Questions***
2. Technical issues large scale storage	Rahul Walawalkar	- What are the key technologies suitable for large scale storage for renewables integration today? - What technological features for electricity storage would be required by 2030? - Which stakeholders need to act to achieve these technological objectives?
3. Policy issues large scale storage	Pramod Kulkarni	- Which policy measures on energy storage can be regarded as best practices for renewables integration today? - What policy measures on energy storage would be needed to support the expansion of renewables towards 2030? - Which stakeholders need to act to achieve these objectives?
4. Technical issues small scale storage	Heiko Stutzinger	- What are the key technologies suitable for small scale storage for renewable off-grid systems (including minigrids/islands)? - What technological features would be required to enable deployment of renewables off-grid systems by 2030? - Which stakeholders need to act to achieve these technological objectives?
5. Policy issues small scale storage	Gurbuz Gonul / Chitra Narayanswamy	- Which policy measures on energy storage can be regarded as best practices for renewable off-grid systems (including minigrids/islands) today? - What policy measures on energy storage would be needed to support expansion of renewable off-grid systems towards 2030? - Which stakeholders need to act to achieve these objectives?

5.1 Technical issues associated with electricity storage for utility-scale renewables deployment

Question 1: What are the key technologies suitable for large scale storage for renewables integration today?

For India, the key technology for the integration of utility-scale renewable power generation is pumped hydro, but it has geographical limitations, it is vulnerable to monsoons, and the tariff are not sufficient to make it a business model based on peak- and off-peak pricing.

Other key technologies are compressed air energy storage (CAES), li-ion batteries, ice storage and demand response, thermal storage coupled to CSP, flow batteries, and gas storage.

Question 2: What technological features for electricity storage would be required by 2030?

In the future, electricity storage technologies should be able to provide a range of ancillary services supporting the grid. Costs need to be reduced, and from a technical perspective there are opportunities to increase the duration of storage, life time, ramp rates, efficiency and in particular system efficiency.

Labelling and standardisation will become important factor, including environmental impacts (including toxicity issues) during operation and recycling. Localisation will be an important factor.

Question 3: Which stakeholders need to act to achieve these technological objectives?

Key policy makers and institutions that need to be involved are: Central Electricity Regulatory Commission (CERC), State Electricity Regulatory Commission (SERC), Ministry of New and Renewable Energy (MNRE), Ministry of Power (MoP)

- Finance institutions: Banks/funding agencies/power purchase agreements
- Industry: storage technology companies/inverter development/system integrators
- Utilities/renewable energy developers: storage operators/independent power producers (IPPs) /ancillary service provides/renewable developers.

*Question 4: Based on the previous answers, what are the three key areas where IRENA members can support electricity storage deployment for renewables through **international cooperation** activities?*

Access to technology and development to support cost reductions and localisation. This requires development and engagement of local manufacturing, supply chain as well as service sector jobs

Sharing of best practices and demonstration experiences to establish bankable projects. The key objective is to scale up and ensure faster deployment. It would help reduce risk for developers and financers.

Support for the development of policy roadmaps and target setting to encouraging appropriate adaptation. Credible long-term plans will address concerns about economic viability of storage and provide neutral policy signal for developing appropriate policies. It would also help to provide appropriate inputs for technology and system developers.

5.2 Policy issues associated with electricity storage for utility-scale renewables deployment

Participants represented individuals with experience and knowledge of electricity needs and power grids in Bangladesh, Korea, US and India. The response to the questions were the participants' own assessment and perspective for the level of current renewable penetration and in the framework of their country's unique power infrastructure and topology.

The four countries represented ranged from those with high level of current renewable penetrations (US) or likely to have it in very near future (India); or those with little renewable use (Bangladesh) and physically fragmented use of renewables (Korea). However the countries are also differentiated by the existence or non-existence of organized markets for energy, capacity and methods of procurements. The above distinctions affect their policy choices.

Question 1: Which policy measures on energy storage can be regarded as best practices for renewables integration today?

Current sources of power and their price also affect each country's desire to look at energy storage as a solution for integrating large-scale energy storage. In Bangladesh availability of low priced, natural gas based electric generation is perceived as a cheaper option to meet the electrical needs. Although programs exist for a supporting renewables, large scale renewable penetration is deemed to be expensive and hence addition of energy storage to facilitate renewable integration is looked upon even more expensive; and any policy for use of energy storage for renewable integration must begin with assessing the benefit of adding storage and understanding what value it might deliver. For South Korea the issues are different. A country consisting of 60 islands, with each its own microgrid will invariably have a combination of solar/wind/diesel on each island. In such island microgrids with solar and wind generators, storage has played a crucial role. (E.g. Hawaii, Puerto Rico, some Japanese island). So for South Korea the policies must begin studying each island's ability to absorb a higher renewable penetration, and their impact.

Participants from India thought that policies that only look at storage to solve large-scale renewable integration will solve a very narrow problem, and thus policy regarding the use of any storage must also consider other benefits that would be delivered by the use of energy storage. The US experience with the policies for large sale renewable integration is already based on the study and analysis of impact on the power grid stability, and is founded on assessing pros and cons of adding energy storage. Consequently the US policies on the use of energy storage for large scale renewable integration are relevant only when other countries have done similar studies in the context of their own electric infrastructure and energy priorities.

Question 2: What policy measures on energy storage would be needed to support the expansion of renewables towards 2030?

In order of priority, the participants identified the following policy measures:

1. Policy formulation must be based on studies to assess the benefit of energy storage linked with renewables.
2. Develop policies that address the use of energy storage for large-scale renewable integration in the larger context of the overall electrical grid requirements and should be country specific.
3. Need a policy that authorizes "smart" financial incentives that encourage and reward use of energy storage for large-scale integration.

Other suggestions were:

4. Issues such as power quality, load shedding, time of use and time of the day pricing should influence policies on the use of energy storage for renewable integration.
5. For an effective policy the use of energy storage must be aligned to renewable generation scheduling and dispatch.
6. Use of storage for renewable integration must be aligned with all other energy markets and technology options.
7. Need policies to support the use of energy storage RD&D (for use in helping large-scale renewable integration).
8. To help with studies listed under item # 2 above, policy must require collection of data in a standard format to help assess impact of using or not using energy storage for large-scale renewable integration.

Question 3: Which stakeholders need to act to achieve these technological objectives?

Almost everyone thought that the government should be the initiator of the studies to assess the value of energy storage for large-scale renewables but the studies should be done by stakeholders who do not have a vested interest in the study outcome.

*Question 4: Based on the previous answers, what are the three key areas where IRENA members can support electricity storage deployment for renewables through **international cooperation** activities?*

The stakeholders could benefit from experience of conducting similar studies and their findings observed elsewhere; e.g. in the US and Germany. Although their ground conditions are different, the methodology and analysis might valuable for 2030 policy priorities.

5.3 Technical issues associated with electricity storage for small-scale renewables deployment

Question 1: What are the key technologies suitable for small scale storage for renewable off-grid systems (including minigrids/islands)?

Continued technology development is still needed for renewable energy technologies that can be deployed in off-grid and distributed systems. The most important technologies are solar PV, wind power, and biomass.

The electricity storage technologies for the integration of renewables in smaller scale distributed systems are:

- Compressed Air
- Water Storage / Hydro
- Battery & Inverter
- Hydrogen, Electrolysers, Fuel Cell
- Lithium Ion Battery
- Lead Acid Battery
- Electric Vehicles
- Flywheel Technology
- Thermal Storage (Heat/Cold)
- Geothermal Storage

Question 2: What technological features would be required to enable deployment of renewable off-grid systems by 2030?

- Reduce the size of the device
- Clever energy management
- Reduce the costs
- Increase efficiency
- Increase the number of cycles
- Shorten response time
- Lower maintenance
- Safety and security standards
- Plug & play solutions
- Simple to install & maintain

Question 3: Which stakeholders need to act to achieve these technological objectives?

- Research Groups (like Fraunhofer) and academia
- Enable the local community to own and run and maintain the assets “community power = citizen power”
- Local government
- Government central
- Investors
- Banks
- Private investors
- Angel investors
- VC / PE investors
- Clusters
- Technology developers
- Equipment manufacturers
- ESS companies
- Associations
- IRENA
- ADB Bank
- Testing & Certification Institutions

*Questions 4: Based on the previous answers, what are the three key areas where **international cooperation** can support IRENA members in electricity storage for renewable deployment?*

- Bring all the groups together
- Education
- Local demo projects
- Support R & D cooperations
- Database / flyer / info-material
- Update calls / meetings
- Local events & information
- Build networks
- Portal for information sharing / networking
- Provide funding support & contacts
- Matchmaking
- Support local action
- Have task force to make local impact / education / analysis

5.4 Policy issues associated with electricity storage for small-scale renewables deployment

Question 1: Which policy measures on storage can be regarded as best practices for renewable off-grid systems (including minigrids/islands) today?

The team was of the opinion that the knowledge gained from past and ongoing projects and pilots on RE off-grid systems, could be taken as **learnings** from their different degrees of success and sustainability. The learnings are:

1. It is very essential to have end-user and community ownership in the use of RE based off-grid systems. While end-users could commit to it with an affordable *fee for service* option, the community needs to be involved right from the beginning through their participation in the planning, installation and subsequent daily operations and maintenance. Free provision of power is not sustainable and such models have consistently failed
2. Economy of scales with increasing demand does not necessarily ensure in reduction of costs of the products; instead in an unregulated climate the prices can considerably increase retarding its use
3. Measures that can de-incentivize the use of RE based off-grid systems are the differential approach to subsidies for urban and rural communities in an energy scarce scenario. The urban communities in Nepal connected to the grid but not guaranteed of regular power supply, have to invest in upfront costs with a 30% excise duty without any financial incentives. Their rural counterparts on the other hand get a flat 80% subsidy on the entire system.
4. Creating a pool of semi-skilled workers, such as an army of technicians for RE based systems has been successfully shown in the state of Chhattisgarh, where local youth are trained for operations and maintenance of such systems. This helps in full utilization of the RE based systems, and builds a certain level of confidence on its usability with the end users.

Question 2: What policy measures on energy storage would be needed to support expansion of renewable off-grid systems towards 2030?

- There is need for a global adoption of standards for energy storage, where the standards presently set by IEC or as pursued in Germany could be followed to begin with. Countries must provide enough accredited testing laboratories and certification processes. Quality assurance must be ensured with proper enforcement through periodic monitoring.
- Given that the costs of RE based off-grid systems increase considerably with the inclusion of energy storage, ownership and provision of storage facility could be part of distribution infrastructure set up by the local utilities. Local entrepreneurs and power producers then have to bear only the net costs of the RE based systems, which are realized over a period of time from sale of power to the communities.

- Financial incentives through subsidies must be based on per cycle/per stored energy in the energy storage system and not on the capital costs. This encourages the use of advanced/more efficient products that are costlier than their less efficient counterparts.

Question 3: Which stakeholders need to act to achieve these objectives?

- The *state and central regulatory commissions* who must look at provision of energy storage as an essential for the optimal use of RE based off-grid systems and their eventual integration to grid
- The *local power utilities* in rural and island areas who must provide for energy storage as a part of their distribution facilities
- The *end-users* whose capacities need to be built on the need for energy storage and its requirement for optimal use of RE based off-grid systems and to get 24x7 power supply
- The *local entrepreneur/power developer* in use of energy storage for optimally meeting daily and seasonal demands in rural and island regions. Subsequently their systems can also be tail end power producing units for the central grid, ensuring guaranteed supply with the help of the energy storage
- The *local and central financing institutions* who provide the financial support through low interest loans

*Question 4: Based on the previous answers, what are the three key areas where IRENA members can support electricity storage deployment for renewables through **international cooperation** activities?*

1. IRENA providing the needed platform for exchange of learnings and best practices used for energy storage in off-grid systems
2. Encouraging the use of standards for quality assurance and showcasing existing standards for adoption
3. Developing toolkits and learning modules in use of electricity storage for micro & mini off-grid system.

6 Conclusions

The aim of this workshop was to examine the role that electricity storage technologies may play in supporting the deployment of renewables in both off-grid and distributed systems as well as utility-scale systems in India, and to identify what applications, best practices and lessons should be highlighted in IRENA's global technology roadmap for electricity storage. Based on these insights, the aim of the roadmap is to identify priority areas for action, and specify activities for international cooperation among different stakeholders, and provide a framework to monitor progress.

The conclusions of this workshop are that:

1. India: A Land of Opportunities

India is diverse in its geographical conditions, renewable energy resources, electricity demand profiles, and infrastructure characteristics. With its ambitious plans for the development of renewables and the development of its grid infrastructure, India provides a host of opportunities to deploy energy storage options. For the centralised grid, this means that India has to create incentives and support to effectively use the pumped hydro storage systems already in place. On the other hand, India can become a hub for advanced energy storage developments coupled to the mega-scale solar PV parks as well as in off-grid systems and residential applications.

2. Grid versus off-grid

The workshop discussed the technology and policy needs for electricity storage in small-scale versus utility-scale renewable energy systems. From the discussion, it is clear that this distinction is not so clear-cut. Although differentiated policies are needed at the moment, in particular regarding the business and finance models and regarding the need for community engagement which will be much stronger for electricity storage in off-grid systems, it is envisioned that off-grid or distributed systems will eventually be connected to the main grid. This means that energy storage systems in off-grid systems should be designed such that they can be used to support the central grid at a later stage. This includes policies that consider the ownership issue. Once decentralised minigrids are connected to the main grid, who will be owning and operating them? A lack of clarity will deter investors in minigrid systems today.

3. Technology to System

There is still room for individual electricity storage technologies to develop, both in terms of costs and performance. However, at this point in time there is no more need for additional demonstration projects focusing on the technical aspects. Instead, India should already move towards policies that support the development of viable systems for electricity storage. This could demonstration projects that examine innovative finance structures, new tariff models, or innovative regulation. Furthermore, electricity storage systems should be developed such that they can become simple artefacts (plug & play), and the use of standards will be crucial to ensure the interoperability of different components of the system.

4. From Global to Local

With its tremendous opportunities for electricity storage, India has the opportunity to attract innovative businesses and local manufacturing of electricity storage systems to its country. However, an important aspect for successful deployment of energy storage systems will be the development of a local ecosystem. This is relevant for both grid and off-grid applications. Energy storage will be particularly relevant for integrating local renewable energy resources, and will need to engage local communities and create ownership. Furthermore, localisation of an energy storage supply chain will be needed with local manufacturing, local technicians and operators, and opportunities for local recycling.

5. Environment

The current challenges for expanding India's transmission and distribution networks are often due to concerns about environmental impacts. It is therefore crucial that energy storage systems – an alternative to grid expansion in some cases – is environmentally benign. This means that there standards are needed regarding safety, toxicity, and recycling of electricity storage systems.

6. Not storage because of storage

It is important that India develops a political framework for energy storage that is holistic. On the one hand side, this means that energy storage should be considered alongside other methods that can support the integration of renewables into the grid infrastructure, such as prevailing power quality, load shedding, time of use and time of the day pricing etc. When assessed in such a comprehensive manner often the hidden benefits of energy storage will be brought out due to its synergistic use and create monetary value that otherwise may not exist or may be too meager to make a business case for energy storage use. On the other hand, energy storage should not only be considered as a tool for the integration of renewables. Energy storage can also be an important tool to support India's grid infrastructure by increasing efficiency, reducing losses, and creating advanced ways of managing distribution networks.

7 References and additional resources

Business Standard (2014), "North Eastern Region Power System Improvement project for six States (Assam, Manipur, Meghalaya, Mizoram, Tnapura and Nagaland) for strengthening of the Intra-State Transmission and Distribution System", New Delhi, 20 November 2014, accessed in Feb 2015: http://www.business-standard.com/article/government-press-release/north-eastern-region-power-system-improvement-project-for-six-6-states-114112001427_1.html.

CEA (Central Electricity Authority) (2013), "Large Scale Grid Integration of Renewable Energy Sources – Way Forward", November, 2013, accessed at: http://www.cea.nic.in/reports/powersystems/large_scale_grid_integ.pdf

FICCI (Federation of Indian Chambers of Commerce and industry) (2013), "Power Transmission: The Real Bottleneck. An overview of the Indian power transmission sector, its challenges and recommendations", September 2013, accessed at: http://www.ficci.com/spdocument/20311/power-transmission-report_270913.pdf

IESA (Indian Energy Storage Alliance) (2014), "Energy storage technologies for ancillary services in India. Improving power quality and reliability of the Indian grid.", IESA, Customized Energy Solutions, Shakti Sustainable Energy Foundation,

GIZ (2013), "Analysis of System Stability in Developing and Emerging Countries. Country Chapter: India", GIZ, accessed: http://www.giz.de/fachexpertise/downloads/giz2013-en-power-system-stability-india.pdf

Lall, R. (2012), "The distribution and infrastructure challenge: Improving India's grid network and rural connectivity", in: Empowering Growth: Perspectives on India's energy future, A report from the Economist Intelligence Unit, 2012, accessed at: http://www.economistinsights.com/sites/default/files/downloads/Empowering_Growth.pdf

MoP (Ministry of Power) (2012), "Report of The Working Group on Power for Twelfth Plan (2012-2017)", Ministry of Power, Government of India, New Delhi, January 2012, accessed at: http://planningcommission.gov.in/aboutus/committee/wrkgrp12/wg_power1904.pdf

MoP (2013), "Guidelines for Village Electrification through Decentralized Distributed Generation (DDG) under Rajiv Gandhi Grameen Vidyutikaran Yojana in the XI Plan – Scheme of Rural Electricity Infrastructure and Household Electrification, New Delhi, 1 April 2013, accessed: http://powermin.nic.in/upload/Amendment_to_DDG_Guidelines_dated_01042013_July2013.pdf

MoP (2014c), "Perspective Transmission Plan for Twenty Years (2014-2034)", Ministry of Power, Central Electricity Authority, PGCIL, POSOCO, August 2014, accessed at: http://www.cea.nic.in/reports/powersystems/sppa/scm/allindia/notices/3rd_report.pdf

MoP (Ministry of Power) (2014b) "Integrated Power Development Scheme" (IPDS), Office Memorandum, No. 26/1/2014-APDRP, 3 December 2014, accessed at: http://powermin.nic.in/upload/pdf/Integrated_Power_Development_Scheme.pdf

MoP (2014c) "Deendayal Upadhyaya Gram Jyoti Yojana" (DDUGJY), Office Memorandum, F. No. 44/44/2014-RE, 3 December 2014: accessed at: http://rggvy.gov.in/rggvy/rggvyportal/memo/DDUGJY-OM.pdf

MoP (2015), "Status of Rural Electrification (RE) under DDUGJY", Ministry of Power, accessed on Feb. 2015: http://powermin.nic.in/Rural-Electrification

NITI Aayog (National Institution for Transforming India) (2015), "Report on India's Renewable Electricity Roadmap 2030. Towards Accelerated Renewable Electricity Deployment", NITI Aayog, Government of India, February 2015, accessed at: http://shaktifoundation.in/wp-content/uploads/2014/02/Report-on-Indias-RE-Roadmap-2030-full-report-web2.pdf

PGCIL (Power Grid Corporation of India Ltd) (2012), "Transmission Plan for Envisaged Renewable Capacity. A Report. Volume 1", PGCIL, July 2012, accessed at: http://www.powergridindia.com/_layouts/PowerGrid/WriteReadData/file/ourBusiness/SmartGrid/Vol_1.pdf

POSOCO (Power System Operation Corporation Limited) (2014), " Annual report 2013-2014", accessed at: http://posoco.in/uploads/Annual%20Report_13-14.pdf

TERI (2013) "Policy and regulatory issues in the context of large scale grid integration of renewable energy in Gujarat", Project Code 2011RT05, Shakti Foundation, January 2013, accessed at: http://shaktifoundation.in/wp-content/uploads/2014/02/Gujarat-Grid-Study_Final-Report_TERI-PDF.pdf

Vashuda Foundation (2013), "Current Status of Rural Electrification and Electricity Service Delivery in Rural Areas of India", accessed at: http://www.vasudha-foundation.org/wp-content/uploads/2)%20Reader%20Friendly%20Paper%20for%20USO_Status%20of%20Rural%20electrification%20status%20in%20India.pdf

WB (World Bank (2014), "More Power to India: The Challenge of Electricity Distribution", Directions in Development, Energy and Mining, the World Bank, accessed at: https://openknowledge.worldbank.org/bitstream/handle/10986/18726/889060PUB0978100Box385252B00PUBLIC0.pdf?sequence=1