SAARC
ENERGY
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# STUDY ON THE POTENTIAL FOR ENERGY STORAGE TECHNOLOGIES (ESTES) IN THE ELECTRICITY SECTOR OF SAARC MEMBER STATES

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# Contents

## Foreword

Upgrading electric system will help nations to meet the challenge of handling projected energy needs—including addressing climate change. Advances to the electric grid must maintain a robust and resilient electricity delivery system, and energy storage can play a significant role in meeting these challenges. Energy storage has gained the potential to change the way electricity is generated and used. Grid connected energy storage can also support energy efficiency through demand side management and higher penetration of variable renewable energy sources like solar and wind energy.

SAARC Member States must consider a transition to power systems based on renewables with energy storage options for supporting a reliable, efficient, cost-effective and sustainable power sector. In order to highlight the importance of energy storage, SAARC Energy Centre (SEC) initiated this short term, Study on the "Potential for Energy Storage Technologies in Electricity Sector of SAARC Member States" through its Action Program FY 2016.

Considering the importance, the study was outsourced through a competitive yet transparent process; to a team of experts led by Prof. Dr. Tahir Nadeem Malik and other members including Mr. A. Mohan Menon (India), Mr. Omair Khalid, Mr. Jorge Jaramillo (U.K) and Mr. Mansoor Ashraf. The effort was supported by Mr. Ihsanullah Marwat (Research Fellow – Energy Efficiency), who as Program Coordinator, provided overall guidance for the study including improvement in the process of hiring external experts and its application in outsourcing this study. Dr. Shoaib Ahmad (Deputy Director Coordination) gave a new dimension of developing "Proposed Minimum Contents of the Study" before floating the study, as a broader outline to support Terms of Reference (TORs). The contributions of Mr. Salis Usman (Program Leader – Energy Trade) and Mr. Hassan Zaidi as Peer Reviewer are highly appreciated; their critique and experienced remarks helped in definite value addition and refining the overall conclusions of this study.

The basic purpose of this study was to provide a food for thought to SAARC Member States with a set of viable options with respect to energy storage technologies in the perspective of success stories from the region and beyond. And to explore potentials of commercial application of electricity storage in remote electricity systems, Distribution utility support, Grid stability, residential and commercial storage systems using storage technologies such as Batteries, Flywheels, Compressed Gas, and Pumped Hydro etc.

SEC looks forward to the comments and suggestions from the professionals to add further value to the Study report besides seeking proposals for future interventions to be undertaken by the SEC especially in the perspective of Smart Grids and regional connectivity.

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## Abbreviations and Acronyms

| BHEL | Bharat Heavy Electricals Limited. |
|---|---|
| CEA | Central Electricity Authority |
| CSTEP | Centre for Study of Science, Technology and Policy |
| ESTES | Energy Storage Technologies in Electricity Sector |
| EV | Electric Vehicle |
| Exim Bank | Export Import Bank of India |
| FAME | Faster Adoption and Manufacturing of Electric Vehicles |
| FDI | Foreign Direct Investment |
| FiT | Feed-in Tariff |
| GBI | Generation Based Incentive |
| GST | Goods and Services Tax |
| IESA | India Energy Storage Alliance |
| INDC | Intended Nationally Determined Contribution |
| IREDA | Indian Renewable Energy Development Agency |
| MNRE | Ministry of New and Renewable Energy, Government of India |
| MoP | Ministry of Power, Government of India |
| NCL | National Chemical Laboratory |
| NEMM | National Electric Mobility Mission |
| NESM | National Energy Storage Mission |
| NITI Aayog | National Institution for Transforming India |
| NSGM | National Smart Grid Mission |
| NSM | National Solar Mission |
| NTPC | National Thermal Power Corporation Limited |
| PACE | Partnership to Advance Clean Energy |
| POSOCO | Power System Operation Corporation Limited |
| SECI | Solar Energy Corporation of India Limited |
| SEC | SAARC Energy Centre |

## Executive Summary

1. This study was envisioned by the SAARC Energy Centre in the light of energy storage globally emerging as a potential means to support existing electricity networks, facilitate the efficient operation of electricity markets, improving grid stability and meeting energy requirements of residential and commercial customers amongst some of the applications.
2. Several different energy storage technology types were investigated and have been discussed in the study including Pumped-Hydro, Flywheels, and battery based storage etc.
3. The approach of the study was application driven i.e. looking into what applications are, the technologies relevant for, and the need of that application area for each SAARC member state to understand the potential for each technology.
4. For each of the SAARC Member States, a sector assessment summary based on research was performed to highlight the important underlying enablers and gaps for energy storage technologies and to discover the priority for the different application areas of storage technologies as relevant to each country.
5. In the overall SAARC Region, the need for storage is driven by factors such as increasing renewable energy integration, low reserve margins, rural-electrification plans, stress on transmission and distribution networks etc.
6. Globally, Energy Storage Applications are positioning themselves as one of the most important technologies for more reliable and sustainable energy systems in the future.
7. To outline a more comprehensive structure for ESTES deployment, an international assessment on the main global players was also performed. This assessment debriefs the key takeaways and describes specific efforts as positive lessons for the growth of ESTES.
8. Among the country profiles reviewed, the United States, China, and Japan are the most relevant candidates to be a subject of further analysis and consideration. These three nations have been in the loop of energy storage deployment as well as with many other services within the industry since the late 90s. Moreover, the three, together, account for more than 70% of this profitable global market
9. Based on the evidence assessed during the study it was found that as SAARC Member States consider developing their power systems, energy storage options show potential of benefitting the region based on learning from international experiences and an assessment of local conditions and requirements of the power sector in the SAARC region.

10. Recommendations for the sector have been provided which cover areas of:
    - Political and Institutional Preconditions
    - Legislation and Policy Regime
    - Human Resource and Academia Involvement
    - Infrastructure and Mass Awareness
    - Regional Cooperation, Institutional Partnership in capacity building

11. The success of any endeavour as humongous and widespread as the deployment of energy storage depends very much on the support that it receives from the political level.
12. Subordinate legislation would also need to be brought in to ensure the setting of continually updated standards for design, manufacture, testing and operation of energy storage devices, besides safety standards. While finalizing subordinate legislation in the form of storage regulations, electricity regulators need to assess the fit that the various storage technologies may have with the planned energy mix. Regulators also need to consider the policies that will enable and incentivise storage adoption within their jurisdiction.
13. Government support through financial contributions, tax credits, standard setting and market creation is important for effective technology development, innovation and deployment.
14. It is therefore very clear that strong institutional mechanisms need to be set up and for a nascent component like energy storage; even the very institutions would need to be specifically identified or created.
15. Commercial requirements for energy storage systems need to keep in mind the future market needs, industry capability, and the best use of storage in as many situations as feasible.
16. Integrating energy storage will necessitate significant skill development in some areas and partial re-skilling in others. A key challenge therefore will be the development of adequate trained human resources. While this will help in expansion of manufacturing as well as research and development, it would also create considerable value for the economy while supporting and sustaining a vibrant energy storage sector.
17. Some of the valuable contributions of academia involvement would include the following:
    - Accelerate R&D efforts focused on optimising the integration of energy storage technologies in the energy system
    - Work on efficiency and reliability of existing systems

- o Push technologies beyond their current limits in order to bring down their costs and/or widen their potential applications
- o Work on improving storage management systems through integration of academic research and feedback from industry
- o Provide an overarching and non-partisan voice in industry debates without being bogged down by corporate loyalties or commercial gain

18. A well planned and sustained mass awareness campaign is therefore necessary to set out the benefits of energy storage systems before the people and also the elected representatives. It is necessary to get the storage story out to more people and help push the policy conversation in a direction that creates opportunities for storage to provide flexibility, reliability and renewables integration to the grid.
19. However, energy storage should not be considered an end in itself. Rather, it provides one of the options for supporting a reliable, efficient, cost-effective and sustainable power sector.
20. Future work on this sector is recommended to include energy storage technologies when developing Integrated Energy Models and Power Sector Master Plans as well as including energy storage as a factor during Power System Studies as system studies form the fundamental analysis block power sector planning.

Chapter 1

# INTRODUCTION

# Chapter 1: Introduction

## Background and Purpose of the Study

This study was envisioned by the SAARC Energy Centre in the light of energy storage globally emerging as a potential means to support existing electricity networks, facilitate efficient operation of electricity markets, improving grid stability and meeting energy requirements of residential and commercial customers as well as supporting electric transport systems. With technical advances, energy storage has gained the potential to change the way electricity is generated and used. Grid connected energy storage can also support energy efficiency through demand side management and higher penetration of variable renewable energy sources like solar and wind energy. The policy and regulatory frameworks for grid connected energy storage is also evolving.

Energy storage is not a new concept in the electricity sector. Utilities across the world have built a number of energy storage facilities in the last few decades. These storage systems have been used for load levelling, frequency response, and voltage control. Likewise, storage facilities based on other technologies such as batteries have been installed by a number of utilities to fulfil a variety of functions. At a different scale, energy storage is also commonly used at the user level to ensure reliability and power quality to customers with sensitive equipment. Another traditional application is the electrification of off-grid networks and remote telecommunications stations, mostly in connection with renewable sources.

In future, as SAARC Member States consider a transition to power systems based on renewables, energy storage options may become highly relevant. However, energy storage should not be considered an end in itself. Rather, it provides one of the options for supporting a reliable, efficient, cost-effective and sustainable power sector.

SAARC Energy Centre proposed this study for Energy Storage Technologies in the Electricity Sector (ESTES) under its thematic area of Programme on “Integrated Assessments of Energy, Transport, and Environment (PETREN)”. This report is the culmination of the research that the study team took and is presented in the sections that follow.

## Objectives of the Study

The objectives of the study were set by the SAARC Energy Centre as:

"Outcome of this study shall provide SAARC Member States with a set of viable options with respect to energy storage technologies in the perspective of success stories from the region and beyond. The proposed study may review the existing policy options and regulatory framework of energy storage technologies in electricity sector (specifically utility scale and consumer applications) globally and consider these in the context of SAARC Member States. The study will review specific barriers (technical, economical, regulatory issues) which hinder the implementation of an effective and economical energy storage solution(s) for electricity sector in all SAARC Member States.

The study will also explore commercial application potentials of electricity storage in remote electricity systems, Distribution utility support, Grid stability, residential and commercial storage."

## Scope of the Study

The scope of the study was set by the SAARC Energy Centre in its Terms of Reference. Thus, the study was to cover the following aspects:

- Assess the energy storage market for all applicable areas in SAARC region
- Review best practices of energy storage systems deployed on utility and commercial scale outside the SAARC Region
- Identify barriers and suggest measures for promotion and adoption of Energy Storage Technologies/ Projects in SAARC Member States
- Explore financial aspects of energy storage options in electricity sector of SAARC Member States
- Suggest measures for creating the enabling environment for application of the Energy Storage Technologies in electricity sector of all SAARC Member States
- Suggest facilitation for relevant regional cooperation and institutional partnerships in capacity building
- Explore commercial application potentials of electricity storage in remote electricity systems, distribution utility support, grid stability, residential and commercial storage systems using storage technologies such as batteries, flywheels, compressed gas, pumped hydro etc.
- Propose a brief action plan for successful implementation of Energy Storage Policy and market development in SAARC Region.

## Methodology Adopted in the Study, Approach Considerations and Limitations

From an overarching perspective, the study was done on the basis of research on industry, academic and policy level data available for the SAARC Region. The steps that have been taken are as follows:

1. Developing an understanding of the Energy Storage Technologies for the Electricity Sector (ESTES)
2. Creating an international perspective to evaluate where energy storage technologies are being deployed
3. Deeper understanding of the application areas of ESTES
4. Generating a SAARC Member State power sector assessment profile to understand the extent to which each application area is relevant to a country
5. From the power sector profile assessing the gaps present in the sector
6. Formulating recommendations for the SAARC Region in the light of the findings for the ESTES Potential

The starting point for the SAARC Region country level analysis was generating a country level power see through research. Since the assessment of the potential based on application and the gaps are both based on the underlying sector profile assessment that was generated, these two elements of the scope have been presented together rather than as separate chapters for reasons of logical flow.

Given the overall nascent state of ESTES in the SAARC Region compared to the advanced countries, it was found that the recommendations generated were applicable to the overall region and hence have been presented as such. Categorizing them in individual countries would have merely resulted in the recommendations being repeated.

It is important to note that there are fundamental differences in the SAARC Region in terms of the power sector among Member States. Although for most of these Member States, these differences are treatable within a single broad framework, the case for India was found to be significantly different. This is because of the sector reaching a higher degree of liberalization compared to peers in the South Asian region and elements such as the development of Power Exchanges and the associated energy trading that has the potential to act as a major enabler and route-to-market for energy storage technologies. Due to this, the evaluation of India has been presented separately as a case study.

Although the following does not quality as a limitation to the study, but it is important to note that the assessment has been done from a technology strategy and policy perspective and as such is primarily qualitative in nature.

A quantitative assessment of Energy Storage deployment cannot be done in isolation from other generation technologies and the overall economy of the country and requires both the building of Integrated Energy Models and Power System Planning Studies to assess the quantity that can be deployed in a certain network and the overall cost levels associated with the deployment.

Such models are sophisticated and require significant input and specialized software tools to be developed for each Member State and as such are well outside the scope of the study as these models would be built for answering questions about an entire country's power system and not just to look at storage.  The development of these models can be considered appropriate as future extension work for this study and may be undertaken at a stage where Power Sector Master Plans are being developed for the countries.

# Chapter 2

# SETTING THE PERSPECTIVE

# Chapter 2: Setting the Perspective

## 2.1. Electrical Power System

The power system planners and engineers are faced with the challenging task of planning and successfully operating one of the most complex systems of today's civilization. The efficient planning and optimum economic operation of power system have always been considered critical in the electric power industry.

A typical Electrical Power System (EPS) comprises of three main elements. Firstly, the generating plants with different types, capacities and location. Secondly, there is transmission network to transport the power from generation to load centres. Thirdly, there are consumers, whose requirements of electrical energy have to be served by electrical power system.

In historical perspective, until the beginning of the twentieth century, energy generation was based on combustion of fuel at the point of energy use. However, thanks to Thomas Edison, a new industry was born when the first electric power station, Pearl Street Electric Station in New York City, went into operation in 1882. The electric utility industry developed rapidly, and generating stations spread across the entire country. [1, 2]

There are several reasons for the rapid increase in demand for electrical energy. The fundamental rationale may be the fact that electrical energy, in many ways, remains the most convenient and cleanest energy form (from user perspective), which can be converted into other useful forms. It can be transported by wire to the point of consumption and then transformed into mechanical work, heat, radiant energy, light, or other forms.

### 2.1.1 Elements of Power System

#### Sources of Electric Energy - Generation System

Electricity is the odd man out in the energy market. It cannot be mined or bored from wells, as it is not a primary energy source. It must be produced by some conversion process from a primary source. The primary sources of energy can be divided into two groups, renewable and non-renewable energy sources. The main non-renewable sources of energy are Oil, Gas and Coal, whose stored chemical energy is released by combustion, whereas in the nuclear fuel, the stored atomic energy is released by fission process [3].

Many renewable sources have been identified such as hydro, solar, wind, and tidal, however, the hydroelectric power is utilized to a great extent. Other renewable sources are thus grouped as non-conventional sources of electric power. Now we will discuss very briefly, the broad categories of power generating types.

Electricity generation system is one which transforms the energy from an energy source into electrical energy. This is usually accomplished by converting the energy in the fuel to heat energy and then using this heat energy to produce steam to drive a steam turbine, which in turn drives a generator to produce electrical energy. There are certain other possible energy conversion methods.

There are a number of ways to produce electricity, the most common commercial way being the use of a synchronous generator driven by a rotating turbine. The combination is called a turbine–generator.

The most common types of turbine–generators are those in which a fossil fuel is burned in a boiler to produce heat to convert water to steam, which drives a turbine. The turbine is coupled to the rotating shaft (armature or rotor) of a synchronous generator in which the rotational energy is transformed to electrical energy. In addition to the use of fossil fuels to produce the heat for changing the water to steam, there are turbine–generators that rely on the fission of nuclear fuel to produce the heat. Other types of synchronous generators are those in which turbines are driven by moving water (hydro turbines) and gas turbines that are turned by the exhaust of a fuel burned in chamber containing compressed air.

For each type of system, there are many variations incorporated in a power plant in order to improve the efficiency of the process. Hybrid systems are also in use; an example is a combined-cycle generator in which the exhaust heat from a gas turbine is used to help provide heat for a steam-driven turbine. Typically, more than one of these generating facilities are built at the same site to take advantage of common infrastructure facilities such as fuel delivery systems, water sources, and convenient points to connect to the delivery system.

A small but not insignificant segment of the electric generation in the country includes technologies that are considered more environmentally benign than traditional sources, such as geothermal, wind, solar, and biomass. In many of these technologies, Direct current (DC) power is produced and inverters are used to change the DC to the alternating current (AC) needed for transmission and use.

Generators are selected, sized, and built to supply different parts of the daily customer load cycle. One type of generator might be designed to operate continuously at a fixed level for the entire day. This is a base-loaded generator. Another generator might be designed to run for a short period at times of peak customer demand. This is a peaking generator. Others might be designed for intermittent service.

One important aspect of the selection of a particular generator is the trade-off between its upfront and operating costs. Base-loaded generators have much higher upfront costs per unit of capacity than peaking generators but offer much better efficiency and lower operating costs. The decision is also effected by the availability and projected cost of fuel.

Best utility practices used to have enough generation available to meet the forecast customer seasonal peak demand plus an adequate reserve margin. Reserve margins were determined by conducting probability studies considering, among other things, the reliability of the existing generation and potential future loads.

### Transmission System

Second main component of an EPS is the transmission system which transmits the bulk electrical energy from the generation system, where it is produced, to main load centres where it is to be distributed through distribution network.

The primary function of transmission is to transmit bulk power from sources of desirable generation to bulk power delivery points. Benefits have traditionally included lower electrical energy costs, access to renewable energy such as wind and hydro, locating power plants away from large population/load centres, and access to alternative generation sources when primary sources are not available. [4]

In the past, transmission planning and its construction used to carry out by individual utilities with a focus on local benefits. However, proponents of nationwide transmission policies now consider the transmission system as an “enabler” of energy policy objectives, even at national level.

In general, transmission lines have two primary objectives: (1) to transmit electrical energy from the generators to the load centres within a single utility, and (2) to provide paths for electrical energy to flow between utilities. The latter lines are called “tie lines” and enable the utility companies to operate as a team to gain benefits that would otherwise not be attainable.

Interconnections, or the installation of transmission circuits across the utility boundaries, influence both the generation and transmission planning of each utility involved. According to Morrow and Brown[5], this view is reasonable since a well-planned transmission grid has the potential to provide for the following:

1. Hedge against generation outages: The transmission system should typically permit access to alternative economic energy sources to replace lost sources.

2. Efficient bulk power markets: Bulk power needs should be met by the lowest cost generation, instead of by higher-cost electricity purchases to prevent violation of transmission loading constraints.
3. Operational flexibility: The transmission system should be flexible to accommodate the economic scheduling of maintenance outages and for the economic reconfiguration of the grid when unforeseen incidence takes place.
4. Hedge against fuel price changes: The transmission system should facilitate purchases to economically access generation from diversified fuel resources as a hedge against fuel disruptions due to various causes.
5. Low-cost access to renewable energy: The transmission system should usually permit developers to build renewable energy sources without the need for expensive transmission upgrades.

### Distribution System

Third tier of an EPS is the Distribution System. Transmission facility delivers electricity from generators to substations which supply distribution facilities. Distribution facilities deliver the electricity to the customers. A system of overhead wires, underground cables and submarine cables is used to deliver the electric energy from the transmission system (power grid) to the customers. This delivery system, which electrically operates as a three-phase, alternating current system, has two major parts: primary distribution and secondary distribution [6].

The characteristic that differentiates the two parts of the delivery system from one another is the voltage at which they operate. Primary distribution operates at the higher voltages as compared to secondary distribution.

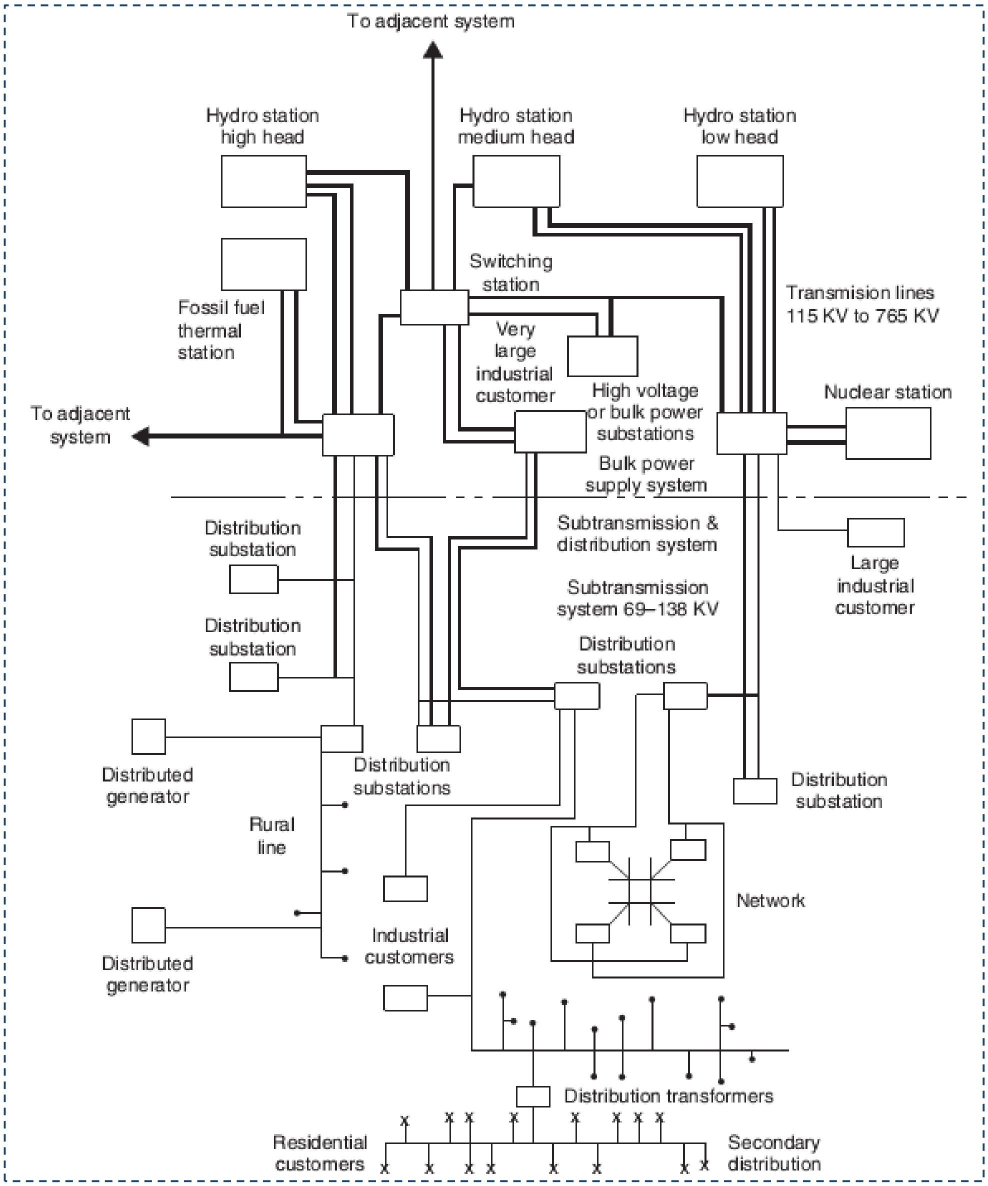



Figure 0.1 A typical power system

## Customers

Customer usage is typically referred to as customer demand, customer load, or "the load." Industry practice has been to group customers by common usage patterns. Typically, these customer classes (or groups) are as follows:

1. Residential customers
2. Commercial customers
3. Industrial customers
4. Agricultural customers

5. Governmental customers
6. Traction/railroad customers

The peak usage, usually measured over an hour, a half hour, or 15 minutes (peak demand) is measured in either kilowatts or megawatts. The energy used by a typical residential or small commercial customer is measured in kilowatt-hours whereas energy used by larger customers is measured in megawatt-hours.

A reason for delineating customer types is to recognize the costs that each customer class causes in the provision of electric service since different customer classes have different usage patterns with diversified impacts on the capital and operating costs. In a regulated environment, in which customers are charged for their usage of electricity based on the cost of that supply, these classifications allow different menus of charges (rates) to be developed for each customer class.

In order to establish schedules of charges (rates) for each class of customer, utilities perform studies of the contributions of the various classes to the utility's costs; these are called cost-of-service studies.

Analysing different customer types also facilitates forecasting changes in customer's electric requirements. These forecasts are required for long-range planning and short-range operating purposes.

Individual customer requirements vary by customer type and by hour during the day, by day during the week, and by season as well. For example, a residential customer's peak hour electricity consumption will normally occur in the evening during a hot summer day when the customer is using air-conditioning, lighting, and perhaps a TV, computer, or other appliances. A commercial customer's peak hour consumption might also occur during the same day but during afternoon hours when workers are in their offices.

The time of day when a system, company, or geographic area peak occurs depends on the residential, commercial, and industrial customer mix in that area. The aggregate customer annual peak demand usually occurs during a hot summer day or a cold winter day, depending on the geographic location of the region and the degree of customer use of either air conditioning or electric heating. The electric system is built to meet the maximum aggregate system and local area peak customer demand for each season There are seasonal variations in SAARC member states affecting peak to occur in summer in some countries and in winter in some other countries in SAARC region

Diversity refers to differences in the time when peak load occurs. For example, if one company's area is heavily commercial and another's is heavily residential, their peaks may occur at different times during the day or even in different seasons. This timing difference gives the supplying company the ability to achieve savings by reducing the total amount of capacity required. Within the SAARC member states there is difference in terms of time related to occurrence of peak in different member states.

The types of electric devices customers use, also have an important bearing on the performance of the electric system during times of normal operation and times when electrical disturbances occur, such as lightning strikes, the malfunctioning and loss of generating resources, or damage to parts of the delivery system. Some types of customer equipment, such as large motors, can require that devices be installed to provide extra support to maintain the power system's voltage.

The electric system has metering equipment to measure and record individual customer electric usage and systems to bill and collect appropriate revenues. For most customers, the meters measure an aggregate energy usage. For larger customers (usually commercial and industrial), meters also are used that record peak demand.

## Delivery System

The connection point between the transmission system or the sub transmission system and the primary distribution system is called a distribution substation.

Depending on the size of the load supplied, there can be one or more transmission or sub transmission lines supplying the distribution substation. A distribution substation supplies a number of primary distribution feeders. These distribution feeders can supply larger customers directly or they connect to a secondary distribution system through a transformer affixed to the top of a local utility pole or in a small underground installation.

Depending on the magnitude of their peak demand, customers can be connected to any of the four systems. Typically, residential customers will be connected to the secondary distribution system. Commercial customers such as a supermarket or a commercial office building will normally be connected to the primary distribution system. Very large customers such as steel mills or aluminium plants can be connected to either the sub transmission or transmission system.

The resulting transmission system is not a linear arrangement of lines fed from a single generating station and tied to a single primary distribution system but something much more complex. Generating units are located at a number of sites, as are the distribution substations. The generating sites are often electrically directly connected by transmission lines (some short and some long in length) to nearby substations where transmission lines also connect. Other transmission lines connect substations together and also connect to distribution substations where there are connections to lower voltage facilities. From some of the substations, there are interconnections to other companies.

Taken together, this arrangement of transmission lines tied together at various substations provides a degree of redundancy in the delivery paths for the electric energy.

Power engineers have coined the terms “the grid,” the “bulk power system,” and “the interconnection” to describe the delivery system.

## 2.2 Introduction to ESTES

Energy and environment have been forecasted to become two of the most challenging and major issues of the world in the future [7]. Energy storage thus becomes a key element in achieving goals of energy sustainability that lead to energy and cost savings.

Electrical Energy Storage (EES) refers to a process of converting electrical energy from a power network into a form that can be stored for converting back to electrical energy when needed [7]. Such a process enables electricity to be produced at times of either low demand, low generation cost or from intermittent energy sources and to be used at times of high demand, high generation cost or when no other generation means is available. EES has numerous applications including portable devices, transport vehicles and stationary energy resources [8].

Storing energy allows the following features: [9]

- To meet short-term, random fluctuations in demand and so avoid the need for frequency regulation by the main plant. It can also provide ‘ride through’ for momentary power outages, reduce harmonic distortions, and eliminate voltage sags and surges
- To eliminate the need for part-loaded main plant which is held in readiness to meet sudden and unpredicted demands, as well as power emergencies which arise from the failure of generating units and/or transmission lines
- To accommodate the minute/ hour peaks in the daily demand curve
- To store the surplus electricity, generate overnight (i.e. during off-peak hours) to meet increased demand during the day
- To store the electricity generated by renewable so as to match the fluctuating supply to the changing demand

### 2.2.1 Historical background

The value of energy storage on electric power systems has been recognized for more than half a century. In the 1960s, some anticipated the United States paying exorbitant prices for foreign oil in the future to produce electricity during the daytime, while base-load coal and nuclear generation that could have supplied this energy was not being used at night. It was obvious that if storage were available to store the coal and nuclear produced energy during the nights, it would create significant savings. In spite of these potential advantages and considerable research, the only significant energy storage system developed for electric power systems was pumped storage plants.

Fifty years ago, energy storage was restricted to base-load nuclear and coal generation. Now, the emphasis is on development and use of renewable technologies, such as wind and solar, technologies that often do not produce power when it is needed. The net result is that the significant portion of the generating capacity in the wind and solar generation has to be duplicated on the power system with some form of peaking generation that can be operated to provide the reliability needed by the system. It is becoming increasingly evident that energy storage could be an alternative to this peaking capacity and become the “handmaiden” of solar and wind power as well as enabling the utilities to fully utilize base-load nuclear and coal capacity, where available.

Additional studies and research are underway to determine the role of the specific types of storage, since each type may have different characteristics, and the amount of storage that is feasible varies in various situations. This requires analysis of the duty cycle required for the storage as increasing amounts of wind and solar power are installed. Key factors in determining the usefulness of energy storage are the shape of the system load requirements and the characteristics of the other generating capacity available. In future, the time and magnitude of system loads could change. For example, the large-scale development of plug-in hybrid electric vehicles and the electrification of more railroads and rapid transit systems will undoubtedly cause changes in the characteristics that may help improve the capacity value of renewable resources.

### 2.2.2 Benefits of Energy Storage Systems to EPS

Energy storage applications offer potential benefits to the transmission and distribution system because of the ability of modern power electronics, and some electro-chemistries, to change from full discharge to full charge, or vice versa, extremely rapidly. These characteristics enable energy storage to be considered as an option for improving transmission grid reliability or increasing effective transmission capacity. At the distribution level, energy storage can be used in substation applications to improve system power factors and economics. It can also be used as a reliability enhancement tool and a way to defer capital expansion by accommodating peak load conditions.

Energy storage can also be used to alleviate congestion patters and, in effect, store energy until the transmission system is capable of delivering the energy to the location where it is needed.

Other technical applications of electric energy storage include:

- Grid stabilization
- Grid frequency support
- Grid reserves
- Grid voltage support
- Black start

Storage technologies were predominantly installed as an investment that could take advantage of dispatch-able supply resources and variable demand. Today, increasing emphasis on energy system decarburization has drawn awareness to the ability for storage technologies to increase resource use efficiency (e.g. using waste heat through thermal storage technologies) and to support increasing use of variable renewable energy supply resources. Moving forward, it is important that energy storage be considered from a system's point of view with a focus on the multiple services that it can provide in bulk, small-scale (e.g. off-grid) and other applications. [10]

Looking forward, the most important drivers for increasing use of energy storage will be:

1. Improving energy system resource use efficiency
2. Increasing use of variable renewable resources
3. Rising self-consumption and self-production of energy (electricity, heat/cold)
4. Increasing energy access (e.g. via off-grid electrification using solar photovoltaic (PV) technologies)
5. Growing emphasis on electricity grid stability, reliability and resilience
6. Increasing end-use sector electrification (e.g. electrification of transport sector).

## 2.3 Energy Storage as a Structural Unit of a Power System

Power system planning becomes complex due to the diversity of applications of electricity and particularly the fact that some of its uses, such as lighting and space heating, are subject to substantial seasonal variation. Generation itself cannot, in any case, be constant because of fluctuations mainly in hydroelectric generation and intermittency of renewable sources.

There should therefore be an intermediate unit between producer and customer that can coordinate them. This unit has to provide the following two possibilities:

- For producers, to transfer generation or production capacity from off-peak to peak load hours to supplement the development of specific peak-production means
- For distributors or customers, to encourage customers to shift peak hour consumption requirements to off-peak times. (Incidentally, the customer can also alter his/her habits.)

This intermediate unit therefore has to be able to separate partly or completely the processes of energy generation and consumption in the power system. We will call this unit secondary energy storage. Secondary energy storage in a power system is any installation or method, usually subject to independent control, with the help of which it is possible to store energy, generated in the power system, keep it stored and use it in the power system when necessary.

Secondary energy storage is an installation specially designed to accept energy generated by the power system, to convert it into a form suitable for storage, to keep it for a certain time and to return as much of the energy as possible back to the power system, converting it into a form required by the consumer.

Secondary energy storage method is a load management strategy that helps utilities to reduce peak load and to shift some of the required energy to base load power plants.

According to the above definition, energy storage may be used in a power system in three different regimes:

- Charge
- Store
- Discharge

In each of these three regimes a balance between power and energy in the power system has to be maintained so the energy storage has to have the appropriately rated power and energy capacity. The duration of each regime, its time of reverse (switching time) and storage efficiency are subject to power system requirements. In order to fulfill the requirements given in this definition, any complete energy storage unit must contain three parts:

- Power transformation system (PTS)
- Central store (CS)
- Charge-discharge control system (CDCS)

The PTS has to couple the power system and the CS. It also acts as a power conditioning system and controls energy exchange between CS and the power system. Basically there are three different types of PTS, namely thermal, electro-mechanical and electrical.

There are two possible ways to couple energy storage to power system: parallel connection and series connection. In the case of series connection, energy storage also has to act as a transmission line, so its rated power has to satisfy the system requirements for these lines: all the generated energy passes through its PTS. For parallel connected energy storage, the power exchange between the CS and the power system passes through the PTS, so the rated power of the latter element has to satisfy the power system requirement for the energy storage power capacity Ps. For the same reason, the variable characteristic of the PTS has to satisfy the power system's requirement for the time of reverse $t_{rev}$.

The CS comprises two parts: storage medium and medium container. There are the following types of CS:

- Thermal, using sensible or latent heat of the relevant storage medium;
- Mechanical, using gravitational, kinetic or elastic forms of energy;
- Chemical, using chemically bound energy of the storage medium; and
- Electrical, using electromagnetic or electrostatic energy of the relevant storage media

The CS is only a repository of energy from which energy can be extracted at any power rate within the PTS installed capacity margins until it is discharged. The CS should be capable of charge (discharge) up to a predetermined power level throughout the entire charge (discharge) period $t_w$. In practice, this means that a certain part of the stored energy must be kept in the CS to ensure the ability of the PTS to work at a required power level. It should be mentioned here that no single type of CS allows the full discharge of stored energy without damage to the whole installation.

The CDCS controls charge and discharge power levels in accordance with the requirements of the power system's regime. It is an essential part of any storage device and usually comprises a number of sensors placed in certain nodes of the power system, in the PTS and in the CS. The information from these sensors has to be collected and used in a computer-based controller which, using relevant software, produces commands for power flow management in the PTS.

Different types of storage equipment use different physical principles, for which reason direct comparison of storage systems tends to be very complex. Therefore, it would be reasonable to select a number of energy storage characteristics common to any type of equipment and make a comparison using these. The following general features are the key parameters for comparison when discussing storage systems:

- Energy density per mass and volume
- Cycle efficiency
- Permissible number of charge–discharge cycles
- Lifetime
- Time of reverse and response time level
- Optimal power output
- Optimal stored energy
- Siting requirements

Before installing any device in a power system, a planning engineer should decide in what way the utility is going to use it. Energy storage could be deployed for one or more of the following reasons:

- To secure power system generating capacities optimal remix
- To improve the efficiency of a power system operation
- To reduce primary fuel use by energy conservation
- No alternative energy source available
- To provide security of energy supply

There are two different types of energy systems – hybrid and combined systems. A system with one kind of energy output and two or more energy sources as input is termed as hybrid system. The combined system, in contrast, has one primary source as input and two or more different kinds of energy output.

The hybrid system has been used in the transport sector. The combined system has been widely used in combined heat and power generation, where a power station utilizes the waste heat from electricity production as district heating. Energy storage usage is possible in both these systems.

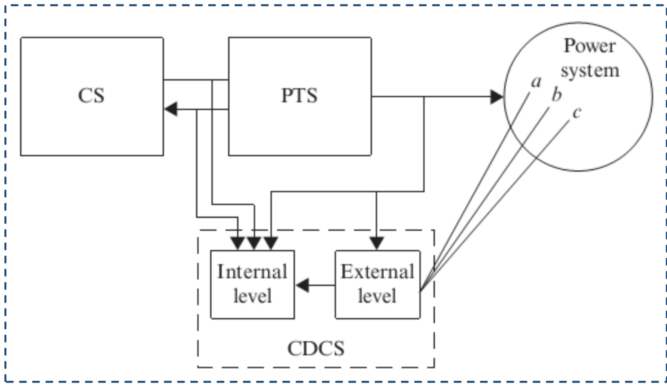



*Figure 0.2 Schematic structure of energy storage*

## 2.4 Types of ESTES

Different energy storage technologies coexist because their characteristics make them attractive to different applications. In general, energy storage systems can be described as mechanical, electrical, chemical or thermal. The principal technologies are:

1. Mechanical Energy Storage
    a) Compressed Air Energy Storage (CAES)
    b) Flywheel Energy Storage (FES)
    c) Pumped Hydro Storage (PHS)
2. Electrical Energy Storage
    a) Battery Energy Storage (BES)
        - Lead Acid Battery
        - Nickel Battery
        - Sodium-Sulfur Battery
        - Lithium Battery
        - Metal Air Battery
    b) Flow Battery Energy Storage (FBS)
    c) Superconducting Magnetic Energy Storage (SMES)
    d) Super capacitor Energy Storage (SCES)
3. Chemical Energy Storage

4. Thermal Energy Storage
    a) Sensible Heat Storage (SHS)
    b) Latent Heat Storage (LHS)
    c) Thermo-Chemical Energy Storage (TCES)

## 2.5 ESTES - Working Philosophy

## 2.5.1 Mechanical Energy Storage

### Compressed Air Energy Storage (CAES)

Compressed air (compressed gas) energy storage is a technology known and used since the 19th century for different industrial applications. Air is used as storage medium due to its abundant availability. Electricity is used to compress air and store it in either an underground structure or an above-ground system of vessels or pipes. When needed, the compressed air is mixed with natural gas, burned and expanded in a modified gas turbine. Typical underground storage options are caverns, aquifers or abandoned mines. If the heat released during compression is dissipated by cooling and not stored, the air must be reheated prior to expansion in the turbine. This process is called diabatic CAES and results in low round-trip efficiencies of less than 50%. Diabatic technology is well-proven; the plants have a high reliability and are capable of starting without extraneous power. Major advantage of CAES is its large capacity; disadvantages are low round-trip efficiency and geographic limitation of locations. [11]

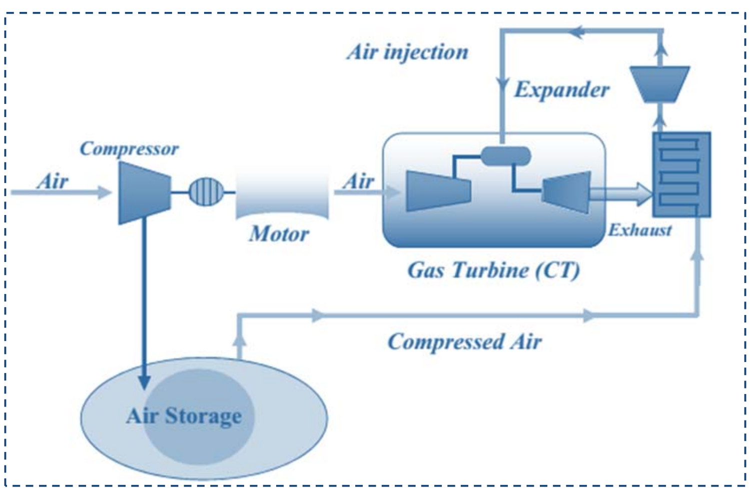



*Figure 0.3 Compressed air energy storage*

## Flywheel Energy Storage (FES)

In flywheel energy storage, rotational energy is stored in an accelerated rotor, a massive rotating cylinder. The main components of a flywheel are the rotating body/cylinder (comprised of a rim attached to a shaft) in a compartment, the bearings and the transmission device (motor/generator mounted onto the stator). The energy is maintained in the flywheel by keeping the rotating body at a constant speed. An increase in the speed results in a higher amount of energy stored.

For accelerating the flywheel, electricity is supplied by a transmission device. If the flywheel's rotational speed is reduced, electricity may be extracted from the system by the same transmission device.

Flywheels of the first generation, available since about 1970, use a large steel rotating body on mechanical bearings. Advanced FES systems have rotors made of high-strength carbon fi laments, suspended by magnetic bearings, and spinning at speeds from 20,000 to over 50,000 rpm in a vacuum enclosure. The main features of flywheels are the excellent cycle stability and a long life, little maintenance, high power density and the use of environmentally inert material. However, flywheels have a high level of self-discharge due to air resistance and bearing losses and suffer from low current efficiency.

Today flywheels are commercially deployed for power quality in industrial and UPS applications, mainly in a hybrid configuration. Efforts are being made to optimize flywheels for long-duration operation (up to several hours) as power storage devices for use in vehicles and power plants. [11]

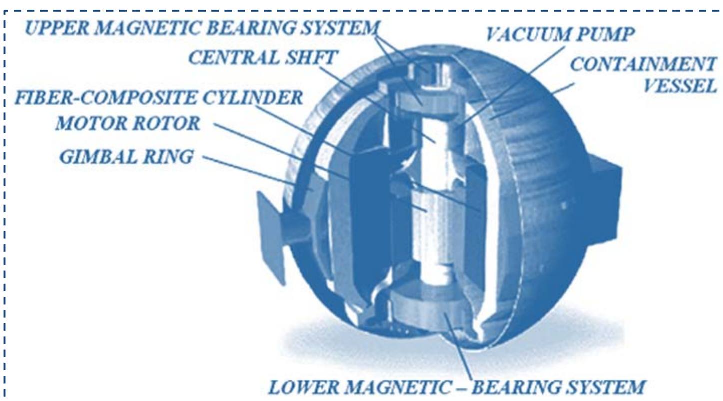



*Figure 0.4 Flywheel energy storage*

## Pumped Hydro Storage (PHS)

Conventional pumped hydro storage systems use two water reservoirs at different elevations to pump water during off-peak hours from the lower to the upper reservoir (termed as charging). When required, the water flows back from the upper to the lower reservoir, powering a turbine with a generator to produce electricity (termed as discharging). There are different options for the upper and lower reservoirs, e.g. high dams can be used as pumped hydro storage plants. For the lower reservoir flooded mine shafts, other underground cavities and the open sea are also technically possible. [11]

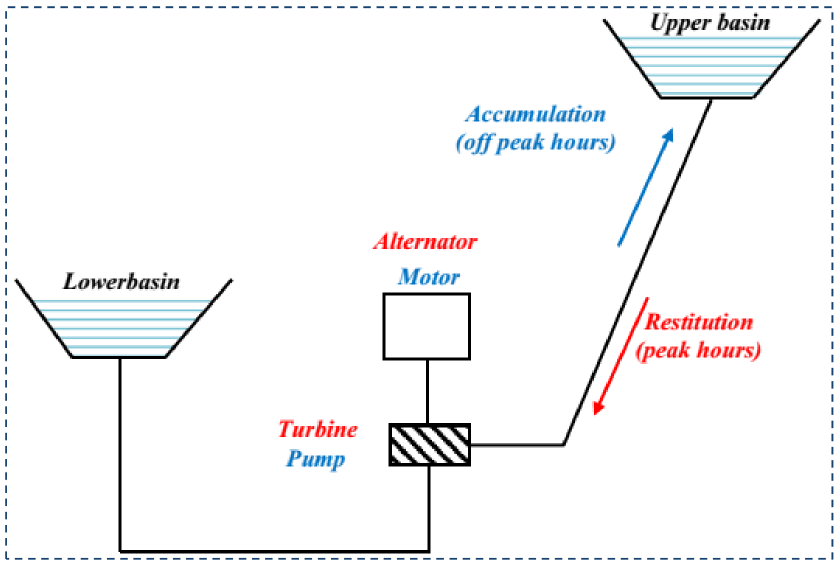



Figure 0.5 Pumped hydro storage system

## 2.6.1 Electrical Energy Storage

### Battery Energy Storage (BES)

- Lead Acid Battery

Lead–acid battery is the most mature and the cheapest energy storage device of all the battery technologies available. Lead–acid batteries are based on chemical reactions involving lead dioxide (which forms the cathode electrode), lead (which forms the anode electrode) and sulfuric acid which acts as the electrolyte. There are two major types of lead–acid batteries: flooded batteries, which are the most common topology, and valve-regulated batteries, which are subject of extensive research and development. [9]

- Nickel Battery

The nickel based batteries are mainly the nickel–cadmium (NiCd), the nickel-metal hybrid (NiMH) and the nickel-zinc (NiZn) batteries. All three types use the same material for positive electrode and the electrolyte which is nickel hydroxide and an aqueous solution of potassium hydroxide with some lithium hydroxide, respectively. As for the negative electrode, the NiCd type uses cadmium hydroxide, the NiMH uses a metal alloy and the NiZn uses zinc hydroxide. Nickel–cadmium batteries compete with lead–acid batteries because they have a higher energy density, a longer life cycle (more than 3500 cycles) and lower maintenance requirements. [9]

- Sodium Sulfur Battery

NaS battery is one of these types and it has already been employed in power systems for more than 20 projects in Japan and many other worldwide constructions since 1980s. A NaS as shown in figure consists of liquid (molten) Sulfur at the positive electrode and liquid (molten) sodium at the negative electrode as active materials separated by a solid beta alumina ceramic electrolyte. NaS battery cells are usually designed in a tubular manner where the sodium is normally contained in an interior cavity formed by the electrolyte. [9]

- Lithium Battery

Lithium-based batteries are widely used in small applications, such as mobile phones and portable electronic devices; therefore, the annual gross production is around 2 billion cells. A Lithium technology battery consists of two main types: lithium-ion and lithium–polymer cells. The high energy and power density of lithium-ion cells make them attractive for wide range of applications, from portable electronics to satellite applications. [9]

- Metal Air Battery

Metal-air battery is the most compact and potentially the cheapest battery available in the market. Instead of an aqueous solution as its electrolyte; the battery uses ionic liquids. The most advanced metal-air systems developed to date are the zinc-air and lithium-air batteries, although other metal electrodes have a higher theoretical energy density. Between the two; Li-air batteries have a higher limit of specific energy. However, Zn-air batteries have an advantage over the Li-air battery systems due to their inexpensive material and are environmentally safer. [8]

### Flow Battery Energy Storage (FBS)

Similar to a conventional battery, flow battery converts chemical energy directly into electrical energy by chemical reactions. However, the electro-active material is stored externally in two tanks of electrolysis and produces the energy by reversible electrochemical reaction between two electrolytes. These systems have quoted efficiencies varying from 70% (cerium zinc) to 85% (vanadium redox). There are four types of flow battery currently being produced or in the late stages of development; zinc bromine, vanadium redox (VRB), polysulphide bromide and cerium zinc. [8]

### Superconducting Magnetic Energy Storage (SMES)

Superconducting Magnetic Energy Storage (SMES) utilizes the magnetic field to store the energy which has been cryogenically cooled to a temperature below its superconducting critical temperature. The idea of this technology appeared in 1970s to improve the load of French electricity network [103]. However, due to immature technology and cryogenic problems, the plant just operates for one year. In the typical application of SMES, the system consists of three parts namely superconducting coil/magnet, power conditioning system and cryogenically cooled refrigerator. [8]

### Super capacitor Energy Storage (SCES)

Super capacitor, ultra-capacitors or double-layer capacitors (DLCs) as they are also known is an electrochemical capacitor with relatively high energy density, approximately hundreds of times greater than conventional electrolytic capacitors. The energy stored between a pair of charged plates. Compare to conventional capacitor, super capacitors comprise a significantly enlarged electrode surface area, a liquid electrolyte and a polymer membrane. Apart from that, super capacitor also offers great advantages over batteries such as the ability to be charged and discharged continuously without degrading. [8]

## 2.6.2 Chemical Energy Storage

Chemical energy storage is receiving world attention due to its potential to replace petroleum products and reduce greenhouse gas emission significantly. One of the most popular chemical energy storage is hydrogen energy storage. This hydrogen energy storage offers zero emission when it coupled with renewable energy source or low carbon technology. The important components of a hydrogen storage system comprise an electrolyser unit, the storage component and an energy conversion. [8]

## 2.6.3 Thermal Energy Storage

### Sensible Heat Storage (SHS)

Sensible heat storage (SHS) method is carried out by adding energy to a material to increase its temperature without changing its phase. In sensible heat storage, the quantity of stored heat depends on the temperature change, the heat capacity of the material, and the amount of storing material. In this type of heat storage, a solid or a liquid material is used as a storage medium. The storage medium can be water, bricks, sand, rock beds, oil or soil. Together with a container, and input/output device is attached to it to provide thermal energy for any intended application. [8]

### Latent Heat Storage (LHS)

Latent heat storage (LHS) is based on the heat release or heat absorption during phase change of a storage material from solid to liquid or liquid to gas or vice versa. The phase change process of the material is adapted to store the latent heat thermal energy. There is a visible advantage of PCMs (paraffin wax, salt hydrates, and fused salts) over sensible heat storage materials. [8]

### Thermo Chemical Energy Storage (TCES)

In thermo-chemical energy storage system, the energy is stored after a breaking or dissociation reaction of chemical bonds at the molecular level which releases energy and then recovered in a reversible chemical reaction. Similar to the other type of thermal energy storage systems, thermo-chemical heat storage system may also undergo charging, storing and discharging processes. [8]

## 2.7 Potential Areas and Challenges with Respect to ESTES Application

Each storage technology has unique characteristics and is different in terms of its appropriate application field and energy storage scale. A comprehensive analysis of each storage technology needs to be performed before a decision can be made about the storage technology that is most suitable. From a user point of view, there are both technical and commercial criteria for selecting the most suitable technology. [9]

- Energy and power density
- Self-discharge
- Response time
- Cost and economics of scale
- Life time
- Storage capacity
- Monitoring and control equipment
- Efficiency
- Operating constraints

Mechanical and thermal based energy storage systems including PHS, CAES, flywheel, and TES have a long-life cycle. The life cycle such as flow batteries and fuel cells are not as high as other systems owing to chemical deterioration with the elapsed time. In terms of environmental criteria, PHS, CAES, batteries, flow batteries, and SMES have negative influences on the environment due to different reasons:

- The construction of PHS could change the local ecological system, which may have environmental consequences.
- CAES is based on conventional gas turbine technology and involves combustion of fossil fuel hence emissions can be an environmental concern.
- Batteries have been suffering from the toxic remains/wastes for long time.
- Flow batteries have similar issues as other batteries
- The strong magnetic field of SMES can be harmful to human health.

It is also evident that while a few technologies such as PHS and lead–acid battery have widely used for decades, much research on new technologies has led to significant improvements during the recent years. Major technical barriers include high manufacturing costs, high material costs, and a lack of storage capacity of certain technologies.

There are three key barriers to the expanding energy storage technology as addressed by Elkind [12], namely: [8]

- Regulations and utility processes that disfavour energy storage
- Costs
- Lack of awareness of energy storage benefits

Table 2.1 Comparison of technical characteristics of energy storage systems

| | Efficiency (%) | Capacity (MW) | Energy density (Wh/kg) | Capital ($/kW) | Capital ($/kWh) | Response time | Life time (yrs) | Maturity | Environmental Impact |
|---|---|---|---|---|---|---|---|---|---|
| **TES** | 30-60 | 0-300 | 80-250 | 200-300 | 3-50 | - | 5-40 | Developed | Small |
| **PHS** | 75-85 | 100-5000 | 0.5-1.5 | 600-2000 | 5-100 | Fast (ms) | 40-60 | Mature | Negative |
| **CAES** | 50-89 | 3-400 | 30-60 | 400-2000 | 2-100 | Fast | 20-60 | Developed | Negative |
| **Fly wheel** | 93-95 | 0.25 | 10-30 | 350 | 5000 | Very fast (<ms) | ~15 | Demonstration | Almost |
| **Pb-acid battery** | 70-90 | 0-40 | 30-50 | 300 | 400 | Fast 5-15 | 5-15 | Mature | Negative |
| **Ni-Cd battery** | 60-65 | 0-40 | 50-75 | 500-1500 | 800-1500 | Fast 10-20 | 10-20 | Commercial | Negative |
| **Na-S battery** | 80-90 | 0.05-8 | 150-240 | 1000-3000 | 300-500 | Fast 10-15 | 10-15 | Commercial | Negative |
| **Li-ion battery** | 85-90 | 0.1 | 75-200 | 4000 | 2500 | Fast | 5-15 | Demonstration | Negative |
| **Fuel cells** | 20-50 | 0-50 | 800-10000 | 500-1500 | 10-20 | Good (<1 s) | 5-15 | Developing | Small |
| **Flow battery** | 75-85 | 0.3-15 | 10-50 | 600-1500 | 150-1000 | Very fast | 5-15 | Developing | Negative |
| **Capacitors** | 60-65 | 0.05 | 0.05-5 | 400 | 1000 | Very fast | ~5 | Developing | Small |
| **Super capacitors** | 90-95 | 0.3 | 2.5-15 | 300 | 2000 | Very fast | 20+ | Developing | Small |
| **SMES** | 95-98 | 0.1-10 | 0.5-5 | 300 | 10000 | Very fast | 20+ | Demonstration | Benign |

## 2.8 ESTES - Options for the SAARC Region

The SAARC Member States include Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka. Most of these countries are facing severe energy crisis especially electricity. Due to which, the countries are being tremendously affected in terms of progress in industry, electricity sector, exports and GDP, etc. There is need to discover new power generation sources besides conventional sources, such as renewable energy resources. Under this situation, it is high time to focus on the energy storage option for South Asia to offset the electricity demand and supply gap. This study is a small step in this direction but it is highly likely to fetch huge results in the coming times for a brighter South Asia.

Chapter 3

# ELECTRICAL ENERGY STORAGE TECHNOLOGIES (ESTES)

# Chapter 3: Electrical Energy Storage Technologies (ESTES)

## 3.1 Pumped Hydro Storage

Hydro power became cheaper than gas for public lighting as early as 1881 when the world's first public electricity supply system was built for Godalming in Surrey, UK. As soon as hydroelectric power systems became widespread associated developments for energy storage, using pumping water, followed in Italy and Switzerland in the 1890s. We have more than a century of experience in the storage of natural inflows as an essential feature of the exploitation of potential hydraulic energy. Reservoirs can be used to store artificial inflows obtained by utilizing the energy available in power systems during demand troughs from generating capacity that is not fully loaded.

At the start of the last century, all hydroelectric plants with reservoirs were equipped with certain pumping mechanisms in order to supplement the natural inflow to the upper reservoir; the main idea was to create seasonal storage in a hydroelectric power system [1].

Only in the second phase of evolution, and predominantly in thermoelectric systems, were special hydroelectric plants built with inflows from pumping alone. These so-called pure pumped-storage plants were designed mainly for daily or weekly storage.

Pumped hydro storage is the only large energy storage technique widely used in power systems. For decades, utilities have used pumped hydro storage as an economical way to utilize off-peak energy, by pumping water to a reservoir at a higher level. During peak load periods the stored water is discharged through the reversible pump-turbines to generate electricity to meet the peak demand. Thus, the main idea is conceptually simple. Energy is stored as hydraulic potential energy by pumping water from a lower level to a higher-level reservoir. When discharge of the energy is required, the water is returned to the lower reservoir through turbines that drive electricity generators.

Pumped hydro storage usually comprises the following parts: an upper reservoir, waterways, a pump, a turbine, a motor, a generator and a lower reservoir, shown schematically in figure. In pumped hydro storage, water is pumped from a lower to a higher elevation. The water at the higher elevation can be stored and used to generate electricity for later utility use when it flows down through a hydro turbine to drive an electric generator. Pumping and generation may also be accomplished with a reversible pump–turbine connected to a motor–generator. The reservoirs needed for the pumped storage operation may be natural bodies of water, reservoirs of existing hydro plants or of water storage systems, especially constructed surface reservoirs, under-ground caverns, or a combination of these. Typical efficiency of this process is about 70%, with 30% used in the pumping–generating cycle. More than 20,000 MW of pumped storage capacity exists in the United States [2].

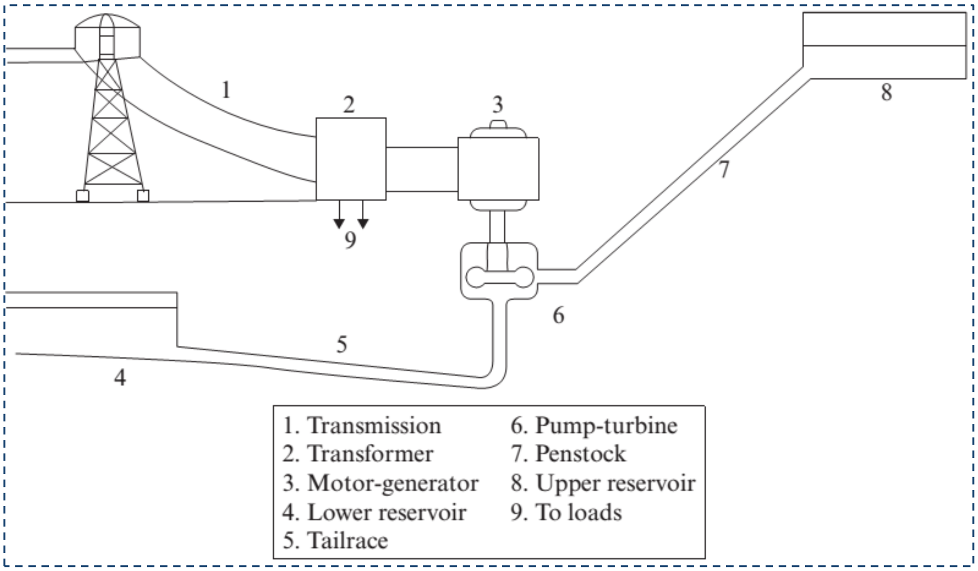



*Figure 0.1 Schematic diagram of pumped hydro storage*

The major barriers to widespread use of conventional pumped storage are siting, geological factors, environmental and space constraints because of the large size of commercially feasible installations, and long construction times. The uncertainty and potential high costs of underground construction costs are believed to be the reason that no underground projects have been pursued to actual construction.

In underground pumped storage, the lower reservoir and power plant are located in deep underground caverns and the upper reservoir is at the surface. By being free of surface topo-graphical restrictions, the siting of these underground plants should be considerably easier than the siting of conventional pumped storage facilities. The underground reservoir and power plant could use naturally occurring caverns, abandoned mines, or a mined-out cavern consisting of a tunnel labyrinth excavated specifically for the pumped storage reservoir. In existing mine sites, first-hand knowledge of the subsurface rock formations is available, and existing shafts can be used. With the elevation difference (head) between the upper and lower reservoirs now a variable parameter not limited by surface topography, the major de-sign restrictions are equipment capability and rock conditions. If very high heads are used, there may be cost penalties associated with very deep mining; nevertheless, mining costs per unit of energy storage capacity should decrease with depth because of proportional reductions in the volume of the reservoir.

*Figure 0.2 Pumped hydro storage*

Underground construction and mining technologies are avail-able and can be adapted for this system. The largest uncertainty is construction of the underground reservoir: its cost, durability with pressure cycling, and the rate of water leakage into the lower reservoir. Costs are heavily dependent upon suitability of the site and local labor conditions. The economics of scale in pumped hydro dictates sizes in the range of 1000 to 2000 MW.

*Figure 0.3 Pumped hydro energy*

## 3.2 Compressed Air Energy Storage (CAES)

In this case, compressed gas is a medium that allows us to use mechanical energy storage. When a piston is used to compress a gas, the energy is stored in it. This energy can be released when necessary to perform useful work by reversing the movement of the piston. Pressurized gas therefore acts as an energy storage medium.

Compressed air storage uses a modified combustion turbine (split Brayton cycle), uncoupling the compressor and turbine so that they can operate at different times and incorporating the intermediate storage of compressed air. During off-peak load periods, the turbine is disengaged and the compressor is driven by the generator, which is now used as a motor and takes its power from other generating units through the system's interconnections. The stored compressed air is subsequently used during peak load periods when it is mixed with fuel in the combustion chamber, burned, and expanded through the turbine. During that period, the compressor is disengaged and the entire output of the turbine is used to drive the generator.

Since in normal operation the compressor consumes about two-thirds of the power output of the turbine, the rating of the combustion turbine operating from the stored compressed air is increased roughly by a factor of three. This permits redesign of the compressors, the combustion process, and the combustion turbine, free from the aerodynamic and thermodynamic restrictions inherent in designs of conventional combustion turbines. Current estimates for the heat rate of the combustion turbine operating from stored compressed air are in the range of 4000 Btu/kW-hr. A compression/generation energy ratio in the range of 0.65–0.75should be readily available. The variable maintenance cost should not be any greater than that for a conventional combustion turbine.

The compressed air may be stored in naturally occurring reservoirs (caverns, porous ground reservoirs, and depleted gas or oil fields) or manmade caverns (dissolved-out salt caverns, abandoned mines, or mined hard-rock caverns). Air storage may be accomplished at variable pressure or, through the use of a hydrostatic leg, at constant pressure. Each approach has its advantages and all are applicable to different underground geologies and reservoir designs. Designs of plants in the 50–250 MW range and larger have been explored.

Compressed air storage is an old concept. Considerable interest in this concept has been expressed in Sweden, Finland, Den-mark, Yugoslavia, France, and the United States. However, only two commercial units have been built: a 220 MW unit in 1977 in Huntorf, Germany and 110 MW unit with a 28-hour discharge capability in Alabama in 1991.

Research is required to investigate: (a) geological conditions for underground storage, (b) new approaches to underground cavern construction, (c) energy losses storing and moving air, (d) alternative concepts of air storage, and (e) corrosion effects on turbines from air contamination. The major uncertainties include the cost of the air storage facilities, the performance and durability of the storage facility with pressure and thermal cycling, and leakage from the storage reservoir. Also, additional geological survey work to identify the availability and number of possible sites is necessary before the future role of compressed air storage may be assessed. With the high costs of fuel and the needs of intermittent renewable resources, renewed interest in compressed air storage has developed and a concept that uses high-pressure storage in buried pipes for smaller installations is being explored.

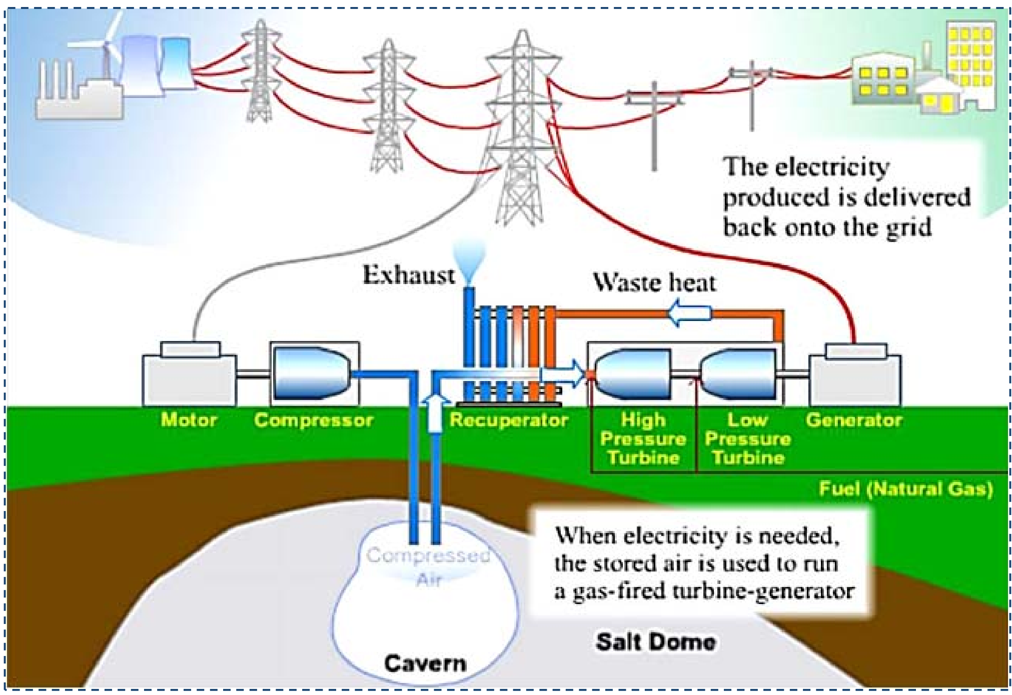



*Figure 0.4 CAES schematic diagram*

## 3.3 Flywheel Energy Storage (FES)

Storing energy in the form of mechanical kinetic energy (for comparatively short periods of time) in flywheels has been known for centuries, and is now being considered again for a much wider field of utilization, competing with electrochemical batteries.

In inertial energy storage systems, energy is stored in the rotating mass of a flywheel. In ancient potteries, a kick at the lower wheel of the rotating table was the energy input to maintain rotation. The rotating mass stored the short energy input so that rotation could be maintained at a constant rate. Flywheels have been applied in steam and combustion engines for the same purpose since the time of their invention. The application of flywheels for longer storage times is much more recent and has been made possible by developments in materials science and bearing technology.

The energy capacity of flywheels, with respect to their weight and cost, has to date been very low, and their utilization was mainly linked to the unique possibility of being able to deliver very high power for very short periods (mainly for special machine tools).

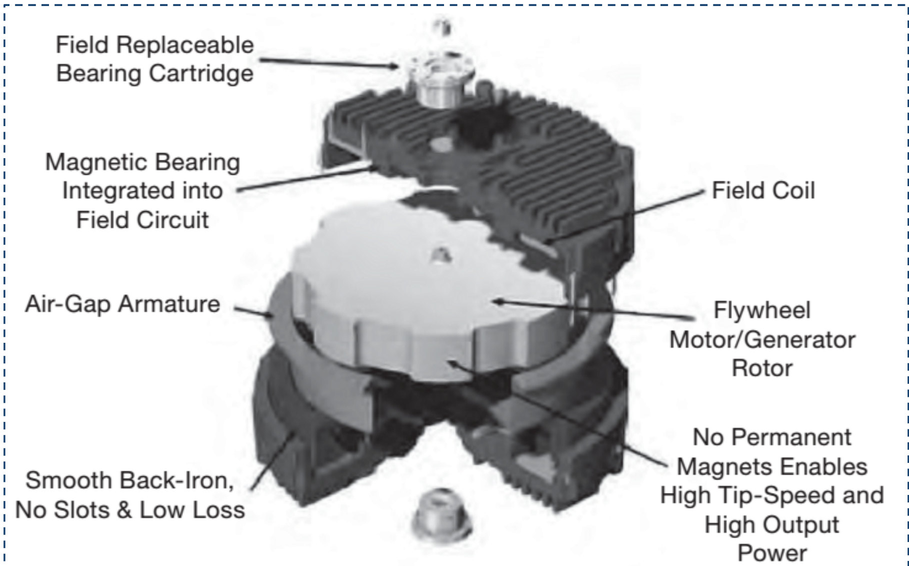



*Figure 0.5 Flywheel energy storage*

Flywheels store energy in the form of the kinetic energy of a rotating mass and have been used since the beginning of the industrial age. In recent years, the commercial application of flywheels to power quality and interruptible power supplies has become a commercial reality. Technological advances in rotating machinery and high-strength materials achieved since then hold promise for longer periods and greater capacity of energy storage, which raises the possibility of new applications.

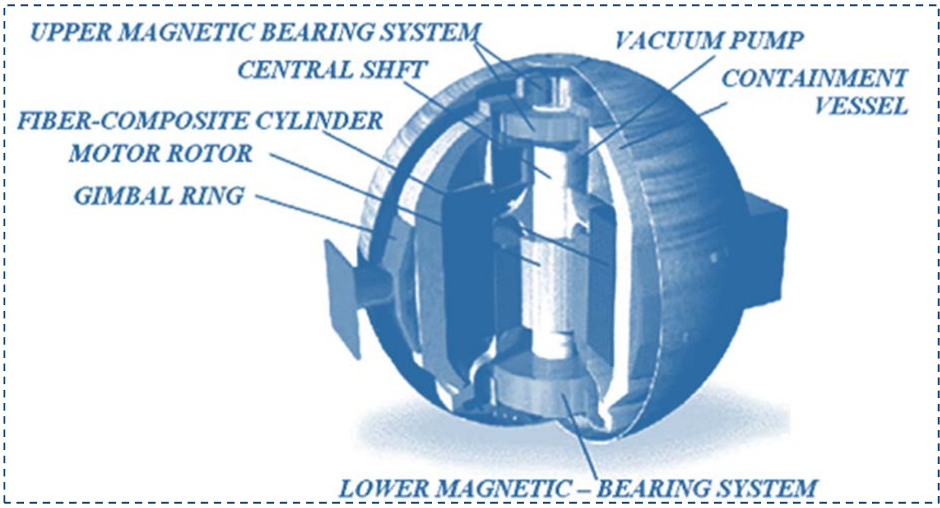



*Figure 0.6 Flywheel storage system*

Utility system applications have been restricted to special-purpose uses for smoothing pulsed power needs or for short-duration power quality needs. Although advanced composite materials have been experimented with in test facilities and proposed for commercial application, the metal flywheel has been the one approach that is in general use. Proposed super flywheel designs deal primarily with the wheel itself, without treating the full energy storage system in sufficient detail. The large wheels once pro-posed for utility applications appear to be outside the size of current, state-of-the-art, cost-effective designs. Commercial applications have used steel wheels and various electromechanical machinery designs, including variable frequency converters.

## 3.4 Battery Energy Storage (BES)

In “storage” batteries, the conversion from electrical to chemical energy (charging) and the reverse process (discharging) are per-formed by electrochemical reactions. The electric form of input and output energy, compactness, and the modular characteristics common to electrochemical devices make batteries potentially the most useful among advanced energy storage methods.

Many different electrochemical systems have been developed, or offer prospects for development, into practical storage batteries.

For more than thirty years, efforts have been underway to develop and commercialize various battery systems for use by electric utilities at the scale of distributed energy storage in the size range of megawatts to tens of megawatts; several applications of lead acid batteries have actually been operated for extended periods and more advanced systems proposed and demonstrated.

Today, great interest and very substantial funding is being in-vested in lithium battery systems that operate at ambient temperatures and are targeted primarily for mobility and portable power, including especially the plug-in hybrid vehicle. If this current effort is successful and the promise of lower costs in large volume production is realized, practical battery energy storage may be-come a practical reality on a large scale, although each individual installation may be only the tens of kilowatt hours needed for the personal vehicle applications.

### 3.4.1 Lead Acid Battery

Lead-acid batteries, the oldest and most developed battery, are a rechargeable battery types and composed of a sponge metallic lead anode, a lead-dioxide cathode and a sulfuric acid solution electrolyte [3]. Having a lot of advantages such as relatively low cost, simplicity of manufacture, quick electrochemical reaction kinetics and good cycle life under measured conditions made them quite attractive and dominate the market [4]. However, the use of heavy metal component is the main drawback of this type of battery which makes them toxic and hazardous to the environment. On the other hand, the utilization of static lead-acid batteries for large-scale application is not favourable and is considered not suitable due to higher cost, limited life span, and practical difficulties in construction. Additives such as calcium, selenium and antimony have also been used by battery manufacturers to improve the performance of lead-acid batteries. Various types of lead-acid battery have been developed namely, Lead Antimony Batteries, SLI Batteries (Starting Lighting and Ignition), Valve Regulated Lead Acid (VRLA) Batteries, Lead Calcium Batteries, AGM Absorbed Glass Mat Battery, Gel Cell, and Deep Cycle Batteries.

The problems with static lead-acid batteries lay in the balancing of power consumption and power generation, i.e. load levelling and peak shaving which can be solved using lead-acid flow batteries. These relatively new energy storage devices may be coupled with solar and wind energy harvesters that have very unpredictable behaviours due to weather element.

### 3.4.2 Nickel Battery

Rechargeable Nickel batteries are classified as secondary batteries and made of active material–nickelous hydroxide as the positive electrode. Among all types of Nickel based battery, Ni–Cd and Ni–MH are the most developed. The other types including that currently available or under development including Nickel–Zinc (Ni–Zn), Nickel–Cadmium (Ni–Cd), Nickel–Metal Hydride (Ni–MH) and Sodium–Nickel Chloride (Na–$NiCl_2$). Even though Ni–MH and Ni–Cd are widely used in the market, they offer the lowest efficiency compared to others. Compared to Ni–Zn batteries and Na–$NiCl_2$ which offer efficiency of 80% and 90% respectively, they only offer 70% of efficiency [4].

Ni–Cd batteries use nickel oxy-hydroxide and metallic cadmium as the electrodes. This battery dominates the rechargeable battery segment by the 1990s. Ni–Cd battery come with two designs, sealed and vented. Comparatively inexpensive, fast recharge, long cycle life and capable to withstand deep discharge rates with no damage or loss of capacity are a plus point of this type of battery. Cadmium used within them, although recyclable, is highly toxic and can harm the environment if not treated properly.

### 3.4.3 Sodium Sulfur Battery

Sodium Sulfur (NaS) battery is an advanced secondary battery has been pioneered in Japan since 1983 by the Tokyo Electric Power Corporation (TEPCO) and NGK. A Na–S battery consists of molten sodium and molten Sulfur (þ) as active materials parted by a solid beta alumina ceramic electrolyte. It is the most developed type of high temperature battery, though relatively new in power system applications. Due to its outstanding energy density, high efficiency of charge/discharge, zero maintenance, fabricated from inexpensive materials and long life cycle of up to 15 years made it attractive for use in relatively large scale battery energy storage system applications.

However, it is reported that there are several conditions that limit the applications to large scale stationary systems. High temperature condition that require to maintain the Sulfur in its molten form addressed as small threat to the operators and environment. Moreover, the system must be protected from reacting with atmosphere as pure sodium explodes instantly in contact with air. In addition, the endurance in the harsh chemical environment causes corrosion in insulators thus the battery became conductive and the self-discharge rate increased.

### 3.4.4 Lithium Battery

Lithium-based batteries are widely used in small applications, such as mobile phones and portable electronic devices; therefore, the annual production gross is around 2 billion cells. Some battery manufactures (SAFT, Shin-Kobe, Japan Storage, Avestor) are developing lithium-based batteries in both high energy and high power configurations for electric vehicles and hybrid electric vehicles. A Lithium technology battery consists of two main types: lithium-ion and lithium–polymer cells. The high energy and power density of lithium-ion cells make them attractive for wide range of applications, from portable electronics to satellite applications. The even growing demand for energy storage requires further researches to improve the performance of this type of power resource. Most commercial lithium-ion cells manufactured today consists of a carbon based negative electrode, a layered oxide positive electrode and an electrolyte based on a solution of a lithium salt in a mixture of organic solvents.

Numerous researches have been carried out on electrode materials and electrolyte showing the importance of the choice of these components of the battery. For lithium-ion batteries, self-discharge rate is very low at maximum 5% per month and battery lifetime can reach more than 1500 cycles. However, the lifetime of lithium-ion battery is temperature dependent, with aging taking its toll much faster at high temperatures, and can severely shortened due to deep discharges. This makes lithium-ion batteries unsuitable for use in back-up applications where they may become completely discharged. Although Li-ion batteries take over 50% of the small portable devices market, there are some challenges for making large-scale Li-ion batteries. The main hurdle is the high cost (4$600/kWh) due to the special packaging and internal overcharge protection circuits. Lithium–polymer battery lifetime can only reach about 600 cycles. Regarding its self-discharge, this is much dependent on temperature but it has been reported to be around 5% per month [5]. Compared to the Li-ion battery, the lithium–polymer battery operational specifications dictate a much narrower temperature range, avoiding lower temperatures. However, lithium–polymer batteries are lighter, and safer with minimum self-inflammability.

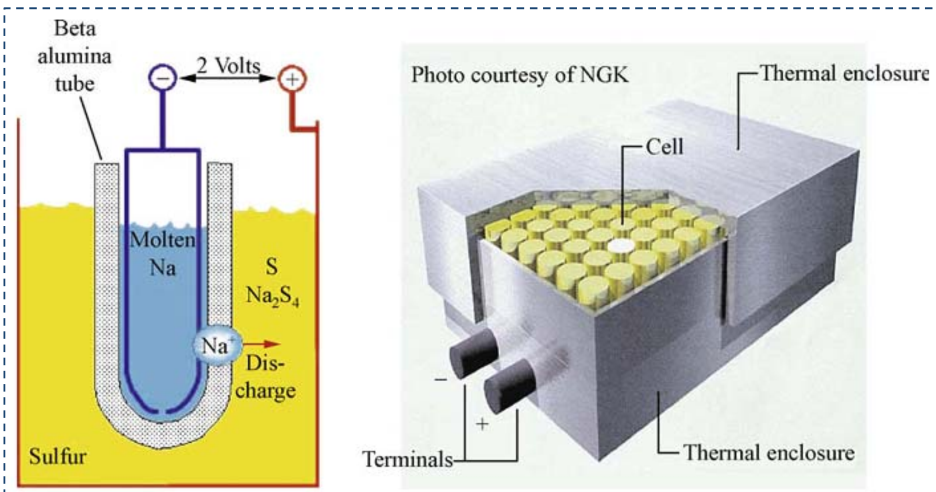



*Figure 0.7 Sodium Sulfur battery*

## 3.5 Hydrogen Based Energy Storage

Hydrogen energy storage represents the best-known example of advanced chemical energy storage. Several approaches have been proposed and explored for each of the required subsystems—hydrogen generation, storage, and reconversion—which can be combined in various ways into overall energy conversion and storage systems. For hydrogen generation from water, electrolysis is the only established industrial process. Current electrolysis technology is handicapped by high capital costs, but considerable potential appears to exist for development of more efficient, lower-cost electrolysers. At present, there is little commercial incentive to develop such technology.

Closed-cycle thermochemical processes are being proposed for hydrogen production via water splitting, but current work is still in the conceptual and early laboratory stages. The incentive to develop such processes derives from the potential for efficiencies and economics that might be superior to those offered by electrolysis, particularly if sources of high-temperature heat, such as high-temperature, gas-cooled reactors or, perhaps, focused solar heat, become available. Integration of these processes with nuclear heat sources and commercialization of the entire hydrogen production system are likely to require many years and large capital investments. [2]

Hydrogen storage, the second major subsystem of hydrogen energy storage systems, can take several different forms. Storage of compressed hydrogen is technically feasible now, as is storing hydrogen in more concentrated forms as a cryogenic liquid or chemically bound in metal hydrides, and logistically attractive. However, cryogenic storage of hydrogen carries a significant efficiency penalty that is unacceptable for large-scale energy storage on utility systems, and capital cost, logistics, and safety are likely to present problems for mobile applications. The outlook is better for metal hydride storage, but development efforts are still required to establish the technical and economic characteristics of this method for hydrogen storage. Reconversion of hydrogen to electric energy can be done in fuel cells or in combustion devices (gas fired boilers or gas turbines). The fuel cell approach offers potential for high efficiency, with 60% as a target for pure hydrogen fuel.

Hydrogen has unique potential for utilization of primary energy sources and flexible use of the stored energy. However, unless major advances result from current research and development on hydrogen production, storage, and conversion technologies, relatively low efficiency and high capital costs will be major barriers to the introduction of hydrogen energy storage systems.

Hydrogen is one of the most efficient, cleanest and lightest fuels; however, it is not found naturally and must be produced from primary energy sources. It is expected to play a major role in future energy systems. Like electricity, it must be produced and transported. Although hydrogen has one additional advantage: it can be stored. Electricity must be used as it is produced; it can be stored only if converted to another energy form. Currently there are four main technologies for hydrogen storage out of which two are more mature and developed. These are the hydrogen pressurization and the hydrogen adsorption in metal hydrides. The remaining two technologies that are still in research and technological development phase are the adsorption of hydrogen on carbon nanofibers and the liquefaction of hydrogen. For a comprehensive review of hydrogen production technologies the reader is referred to Goswami et al. [6]. When hydrogen is produced, it can be stored in order to be used directly in fuel cells, or transported to users to produce electricity. A hydrogen fuel cell uses hydrogen and oxygen to produce electricity and water as shown in figure, and a reversible hydrogen fuel cell could also use electricity and water to produce hydrogen and oxygen. The essential elements of a hydrogen fuel cell comprise an electrolyser unit, to convert the electrical energy input into hydrogen, the hydrogen storage system itself and a hydrogen energy conversion, to convert the stored chemical energy in the hydrogen back to electrical energy.

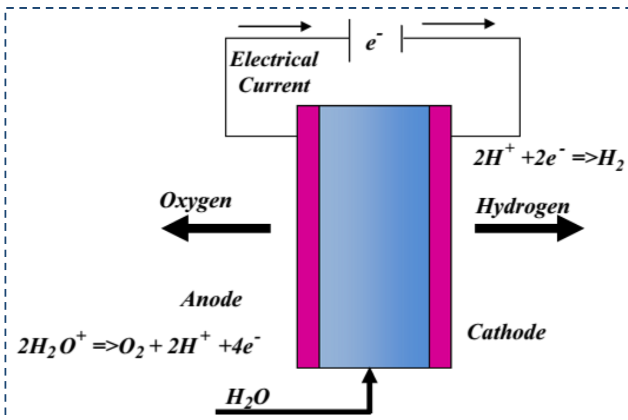



Figure 3.8 Hydrogen based fuel cell

## 3.6 Capacitors

Capacitors store energy as electric charge between two plates metal or conductive separated by an insulating material known as a dielectric when a voltage differential is applied across the plates. When one plate is charged with electricity from a direct current source, the other plate will have induced in it a charge of the opposite sign. The factors that determine the capacitance are the size of the plates, the separation of the plates, and the type of material used for the dielectric. The energy stored in the capacitors is directly proportional to their capacity and the square of the voltage between the terminals of the electrochemical cell, while the capacity is proportional to the distance between the electrodes. Capacitors are already used in many utility power control applications. The advantages of capacitors for small energy storage and short discharge are long cycle life and immediate recharge capability. However, the main problem presented by capacitors is the low energy density. If a large capacity is required, the area of the dielectric must be very large. This fact makes the use of large capacitors uneconomical and often cumbersome. [3]

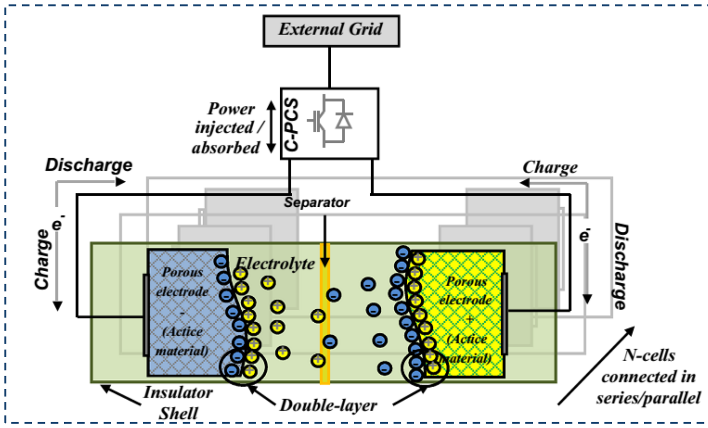



Figure 0.9 Capacitor energy storage

### 3.6.1 Double Layer Capacitor

Electrochemical double-layer capacitors (DLC), also known as super capacitors, are a technology which has been known for 60 years. They fill the gap between classical capacitors used in electronics and general batteries, because of their nearly unlimited cycle stability as well as extremely high power capability and their many orders of magnitude higher energy storage capability when compared to traditional capacitors. This technology still exhibits a large development potential that could lead to much greater capacitance and energy density than conventional capacitors, thus enabling compact designs.

The two main features are the extremely high capacitance values, of the order of many thousand farads, and the possibility of very fast charges and discharges due to extraordinarily low inner resistance which are features not available with conventional batteries.

Still other advantages are durability, high reliability, no maintenance, long lifetime and operation over a wide temperature range and in diverse environments (hot, cold and moist). The lifetime reaches one million cycles (or ten years of operation) without any degradation, except for the solvent used in the capacitors whose disadvantage is that it deteriorates in 5 or 6 years irrespective of the number of cycles. They are environmentally friendly and easily recycled or neutralized. The efficiency is typically around 90 % and discharge times are in the range of seconds to hours. They can reach a specific power density which is about ten times higher than that of conventional batteries (only very-high-power lithium batteries can reach nearly the same specific power density), but their specific energy density is about ten times lower. Because of their properties, DLCs are suited especially to applications with a large number of short charge/discharge cycles, where their high-performance characteristics can be used. DLCs are not suitable for the storage of energy over longer periods of time, because of their high self-discharge rate, their low energy density and high investment costs.

Since about 1980 they have been widely applied in consumer electronics and power electronics.

A DLC is also ideally suited as a UPS to bridge short voltage failures. A new application could be the electric vehicle, where they could be used as a buffer system for the acceleration process and regenerative braking. [7]

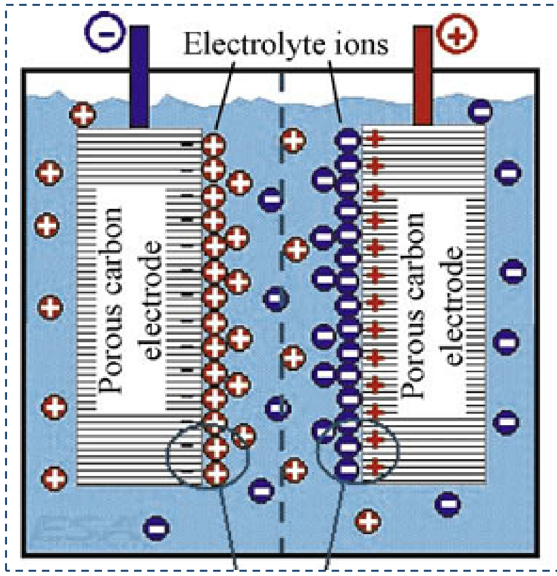



*Figure 0.10 Double layer capacitor*

## 3.7 Super Capacitor Energy Storage (SCES)

Super capacitors have the same principle as capacitors except that the insulating material is replaced by electrolyte ionic conductor in which ion movement is made along a conducting electrode with a very large specific surface providing higher energy density to the system. The design of the electrodes and the choice of electrolyte allow a very high charge density on the electrode surfaces, but limits the voltage to approximately 2.7 V per cell. Despite the low voltage the energy content is much higher than in conventional capacitors and can reach the scale of a few Wh for some of the largest super capacitors which are now commercially available. Super capacitors are connected to form larger modules with up to 1 kWh energy content and can be further joined together for larger energy storage units.

Super capacitors have very high power output and energy storage systems now under trial reach approximately 50–100 kW. In most applications, the energy stored will supply the load only for a few seconds to minutes. The number of charge and discharge cycles is for all practical purposes nearly unlimited but the energy throughput in fast cyclic operation is limited. Control circuit to balance the individual voltages of each super capacitor is necessary for safe and reliable operation if super capacitors are connected in series to achieve a high output voltage. The lifetime of super capacitors will probably be in the range of large conventional capacitors, e.g. 10 years. The in–out efficiency is very high, but the self-discharge rate is considerable compared with batteries. Finally, it can be noted that the most important drawback of super capacitors is their high cost estimated at 5 times that lead–acid battery cost.

In the last two decades, a new class of capacitors—super capacitors—have been developed and commercialized that operation a somewhat different principal; these are electrochemical double layer capacitors. They have significantly higher charge densities than ordinary capacitors. Their properties are between those of a conventional capacitor and a battery. These devices are finding uses in situations in which a larger capacitance is needed and fast response time is desirable, but the full storage capacity of battery is not needed. They have also been proposed as devices to be combined with batteries in some applications. The material properties of the super capacitors are very different from those of conventional capacitors and they cannot withstand high voltages, but can be placed in series like batteries to operate at modest volt-ages.

## 3.8 Superconducting Magnetic Energy Storage (SMES)

Superconductors have the apparently near magical property of having no resistance to direct current flow (no electrical losses) and, hence, the current in a closed loop of superconductor can persist indefinitely under ideal conditions. This property under-lies the concept of superconducting magnetic energy storage originally proposed as a competitor to pumped storage in the early 1970s. Very large superconducting magnets have been designed with the potential to store energy on the scale only achieved in practice by hydro pumped storage. While no large system has ever been built, the concept appears feasible and a very detailed design for a modest system capable of storing some 20 mWh was engineered for the U.S. Department of Defence as part of potential future weapon systems in the 1980s and early 1990s. At a substantially smaller scale, the technology has been commercialized and used in power quality applications at the level of megawatts and discharge applications of seconds. The economics of these systems has limited their market to rather special applications and today they are not being widely used.

Superconducting magnetic energy storage systems work according to an electrodynamic principle. The energy is stored in the magnetic field created by the flow of direct current in a superconducting coil, which is kept below its superconducting critical temperature. 100 years ago, at the discovery of superconductivity a temperature of about 4°K was needed. Much research and some luck has now produced superconducting materials with higher critical temperatures. Today materials are available which can function at around 100°K. The main component of this storage system is a coil made of superconducting material. Additional components include power conditioning equipment and a cryogenically cooled refrigeration system. The main advantage of SMES is the very quick response time: the requested power is available almost instantaneously. Moreover, the system is characterized by its high overall round-trip efficiency (85 % - 90 %) and the very high power output which can be provided for a short period of time. There are no moving parts in the main portion of SMES, but the overall reliability depends crucially on the refrigeration system. In principle, the energy can be stored indefinitely as long as the cooling system is operational, but longer storage times are limited by the energy demand of the refrigeration system. Large SMES systems with more than 10 MW power are mainly used in particle detectors for high-energy physics experiments and nuclear fusion. To date a few, rather small SMES products are commercially available; these are mainly used for power quality control in manufacturing plants such as microchip fabrication facilities

Typically, the conductor is made of niobium-titanium, and the coolant can be liquid helium at 4.2 K, or super fluid helium at 1.8 K. The SMES system normally consists of three major components, as shown in figure, a superconducting unit, a cryostat system (a cryogenic refrigerator and a vacuum-insulated vessel), and a power conversion system. The energy stored in the SMES coil can be calculated by $E=0.5LI^2$, where L is the inductance of the coil and I is the current passing through it. [8]

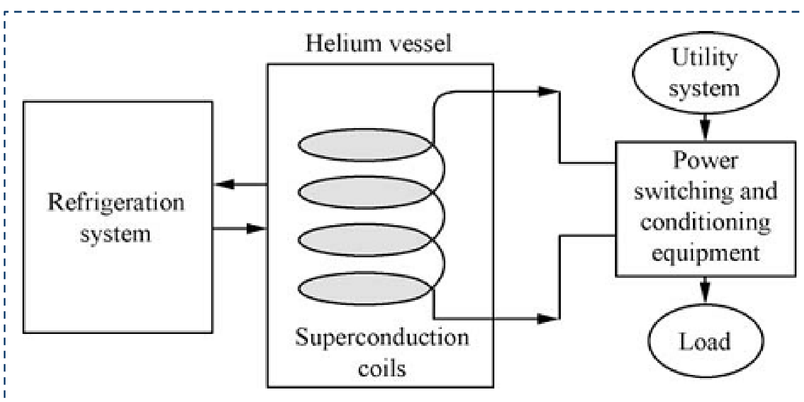



*Figure 0.11 SMES System*

## 3.9 Latent Heat Storage (LHS)

Thermal (energy) storage systems store available heat by different means in an insulated repository for later use in different industrial and residential applications, such as space heating or cooling, hot water production or electricity generation. Thermal storage systems are deployed to overcome the mismatch between demand and supply of thermal energy and thus they are important for the integration of renewable energy sources.

Latent heat storage is accomplished by using phase change materials (PCMs) as storage media. There are organic (paraffins) and inorganic PCMs (salt hydrates) available for such storage systems. Latent heat is the energy exchanged during a phase change such as the melting of ice. It is also called “hidden” heat, because there is no change of temperature during energy transfer. The best known latent heat – or cold – storage method is the ice cooler, which uses ice in an insulated box or room to keep food cool during hot days. Currently most PCMs use the solid-liquid phase change, such as molten salts as a thermal storage medium for concentrated solar power (CSP) plants. The advantage of latent heat storage is its capacity to store large amounts of energy in a small volume and with a minimal temperature change, which allows efficient heat transfer. [7]

Latent heat storage (LHS) is based on the heat release or heat absorption during phase change of a storage material from solid to liquid or liquid to gas or vice versa. The phase change process of the material is adapted to store the latent heat thermal energy. There is a visible advantage of PCMs (paraffin wax, salt hydrates, and fused salts) over sensible heat storage materials. LHS, compared to SHS, offers higher density of energy storage with near zero temperature changes. However, difficulties usually arise in real due to the low-density change, thermal conductivity, sub cooling of the phase change materials, stability of properties under extended cycling and sometimes phase segregation. Phase change materials are specifically used in latent heat energy storage systems, and thus PCM can also be called latent heat storage material. The thermal energy transfer of PCM occurs during the charging or discharging (melting or solidification) process at which the state or phase of the material changes from liquid to solid or from liquid to solid. At the start of the heating of the material, the PCM temperature rises as it absorbs the thermal energy. When the material reaches a specific temperature range; it will start to melt as the material begins to experience a phase transition from solid to liquid state. However, unlike sensible heat storage materials; during the phase transition process the PCM releases or absorbs heat at a constant or nearly constant temperature. Many authors have experimented with different types of PCMs, subdividing them into organic, inorganic and eutectic types. However, the majority of the phase change material does not possess the recommended properties for an ideal thermal energy medium and thus thermal enhancers are used to improve any disadvantages that the medium may have.

Chapter 4

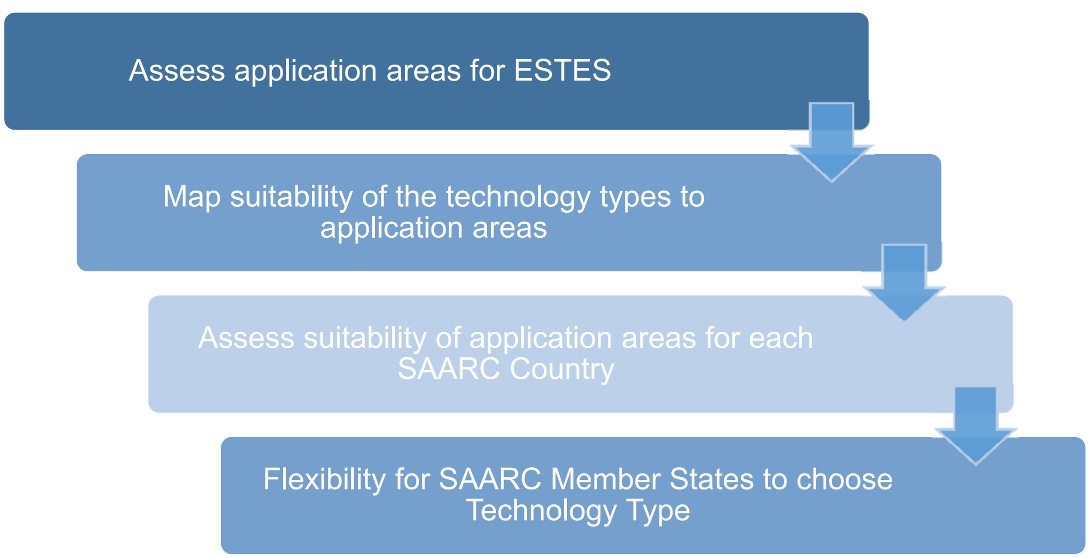
# ESTES IN THE SAARC REGION

# Chapter 4: ESTES in the SAARC region

## 4.1 Requirement/ Need of ESTES in the SAARC Region

An investigation was done into the Power Sector of the SAARC Region to assess the state of the power sectors in the context of searching for potential for Energy Storage Technologies. This included searching for underlying needs and enablers for storage such as increasing renewable potential, the state of the transmission and distribution sector and the underlying investment needs, the degree of electrification of a country and the need for micro-grids. The power sector assessment also looked at factors such as the institutional strength of the power sector, regulatory and tariff regimes as well as their impact on the financial health of the sector.

The study results show that as the SAARC countries attempt to meet their energy sector targets, energy storage technologies may offer unique opportunities in several application areas. The assessment methodology for potential is to look at application areas and how each technology would map onto these application areas e.g. what is the suitability of different energy storage technologies for an application such as ancillary services provision. Then the assessment is made for the potential for each application area for all the SAARC Member States. This application based approach has the benefit of allowing each SAARC Member State to have flexibility in the choice of technology as each application area may be served by different technology types. This approach is summarized below:



The first stage was to identify potential application areas which would be relevant to ESTES in the context of SAARC Member States. The application areas, broken down into sub-groups, have been identified as follows:

Table 4.1.1 Main application areas identified

| Application Group | Potential Applications |
|---|---|
| **Bulk Energy Services** | Energy Arbitrage by utilizing demand shift properties of storage |
| | Electric Supply Capacity |
| **Ancillary Services** | Frequency Regulation |
| | Reserve Services (Spinning, non-spinning and supplemental) |
| | Voltage Support |
| | Black Start Support |
| | Other potential support services |
| **Transmission Infrastructure** | Infrastructure investment deferral by peak-levelling allowing asset investment to be deferred |
| | Transmission Congestion Relief |
| **Distribution Infrastructure** | Distribution infrastructure investment deferral peak-levelling allowing asset investment to be deferred |
| | Providing voltage support at distribution end |
| **Customer-End Services** | Power Quality adjustment |
| | Improving reliability including SAIDI/SAIFI Metrics |
| | Time of use energy shifting |
| | Demand side management |

The next stage of the process has been to assess how different storage technologies map onto different applications. This is shown as follows:

| Technology | Primary Application | What we know currently | Challenges |
|---|---|---|---|
| CAES | • Energy management<br>• Backup and seasonal reserves<br>• Renewable integration | • Better ramp rates than gas turbine plants<br>• Established technology in operations since the 1970's | • Geographically limited<br>• Lower efficiency due to roundtrip conversion<br>• Slower response time than flywheels or batteries<br>• Environmental impact |
| Pumped Hydro | • Energy management<br>• Backup and seasonal reserves<br>• Regulation service also available through variable speed pumps | • Developed and mature technology<br>• Very high ramp rate<br>• Currently most cost effective form of storage | • Geographically limited<br>• Plant site<br>• Environmental impacts<br>• High overall project cost |
| Fly Wheels | • Load levelling<br>• Frequency regulation<br>• Peak shaving and off peak storage<br>• Transient stability | • Modular technology<br>• Proven growth potential to utility scale<br>• Long cycle life<br>• High peak power without overheating concerns<br>• Rapid response<br>• High round trip energy efficiency | • Rotor tensile strength limitations<br>• Limited energy storage time due to high frictional losses |
| Advanced Lead-Acid | • Load levelling and regulation<br>• Grid stabilization | • Mature battery technology<br>• Low cost<br>• High recycled content<br>• Good battery life | • Limited depth of discharge<br>• Low energy density<br>• Large footprint<br>• Electrode corrosion limits useful life |
| NaS | • Power quality<br>• Congestion relief<br>• Renewable source integration | • High energy density<br>• Long discharge cycles<br>• Fast response<br>• Long life<br>• Good scaling potential | • Operating temperature required between 250° and 300° C<br>• Liquid containment issues (corrosion and brittle glass seals) |
| Li-ion | • Power quality<br>• Frequency regulation | • High energy densities<br>• Good cycle life<br>• High charge/discharge efficiency | • High production cost scalability<br>• Extremely sensitive to over temperature, overcharge and internal pressure buildup<br>• Intolerance to deep discharges |
| Flow Batteries | • Ramping<br>• Peak shaving<br>• Time shifting<br>• Frequency regulation<br>• Power quality | • Ability to perform high number of discharge cycles<br>• Lower charge/discharge efficiencies<br>• Very long life | • Developing technology, not mature for commercial scale development<br>• Complicated design<br>• Lower energy density |
| SMES | • Power quality<br>• Frequency regulation | • Highest round trip efficiency from discharge | • Low energy density<br>• Material and manufacturing cost prohibitive |
| Electrochemical capacitors | • Power quality<br>• Frequency regulation | • Very long life<br>• High reversible and fast discharge | • Currently cost prohibitive |
| Thermochemical energy storage | • Load levelling and regulation<br>• Grid stabilization | • Extremely high energy densities | • Currently cost prohibitive |

*Figure 4.1.1 Source: (U.S. Department of Energy, 2013, pp.19–20)*

Next, the application areas and the suitability of technologies has been combined and the results of the assessment are shown in the figure below:

| Application | Description | CAES | Pumped Hydro | Fly wheels | Lead-Acid | NaS | Li-ion | Flow Batteries |
|---|---|---|---|---|---|---|---|---|
| **Off-to-on peak intermittent shifting and firming** | Charge at the sites of off peak renewable and/ or intermittent energy sources; discharge energy into the grid during on peak periods | ◐ | ◐ | ○ | ● | ● | ● | ● |
| **On-peak intermittent energy smoothing and shaping** | Charge/discharge seconds to minutes to smooth intermittent generation and/or charge/ discharge minutes to hours to shape energy profile | ○ | ◐ | ◐ | ● | ● | ● | ● |
| **Ancillary service provision** | Provide ancillary service capability in day ahead markets and respond to ISO signalling in real time | ◐ | ◐ | ◐ | ◐ | ◐ | ◐ | ◐ |
| **Black start provision** | Units sites fully charged, discharging when black start capability is required | ◐ | ◐ | ○ | ● | ● | ● | ● |
| **Transmission infrastructure** | Use an energy storage device to defer upgrades in transmission | ○ | ○ | ○ | ● | ● | ● | ● |
| **Distribution infrastructure** | Use an energy storage device to defer upgrades in distribution | ○ | ○ | ○ | ● | ● | ● | ● |
| **Transportable distribution level outage mitigation** | Use a transportable storage unit to provide supplemental power to end users during outages due to short term distribution overload situations | ○ | ○ | ○ | ◐ | ● | ● | ● |
| **Peak shifting downstream of distribution system** | Charge device during off peak downstream of the distribution system (below secondary transformer); discharge during 2-4 hour daily peak | ○ | ○ | ○ | ● | ● | ● | ● |
| **Intermittent distributed generation integration** | Charge/discharge device to balance local energy use with generation. Sites between the distributed and generation and distribution grid to defer otherwise necessary distribution infrastructure upgrades | ○ | ○ | ○ | ● | ◐ | ◐ | ◐ |
| **End-user time-of-use rate optimization** | Charge device when retail TOU prices are low and discharge when prices are high | ◐ | ◐ | ○ | ◐ | ◐ | ◐ | ◐ |
| **Uninterruptible power supply** | End user deploys energy storage to improve power quality and/or provide backup power during outages | ○ | ○ | ◐ | ● | ● | ● | ● |
| **Micro grid** | Energy storage is deployed in conjunction with local generation | ○ | ○ | ○ | ● | ● | ● | ● |

| | |
|---|---|
| **formation** | to separate from the grid, creating an islanded micro-grid |
| **Definite suitability for application** ● | |
| **Possible use for application** ◐ | |
| **Unsuitable for application** ○ | |

*Figure 4.1.2 Source: (U.S. Department of Energy, 2013, p.29)*

After the assessment for the need for the various application areas, a summary of the potential was generated. Finally, the team used the sector assessment to generate radar maps for assess the gaps along the following metrics with a relative score ranging from 1 to 5 (5 being highest, on parity with advanced economies and 1 being the lowest):

1. Political Will
2. Policy Framework
3. Favourable Deployment Scenario
4. Institutional Arrangement
5. Infrastructure
6. Human Resource and Expertise
7. Market Conditions

## 4.2 Assessment of ESTES Potential and Gap Assessment for SAARC Member States

## 4.2.1 Afghanistan

### 4.2.1.1 Afghanistan - Sector Assessment

Afghanistan has one of the lowest per capital electricity usage in the work: 100 kilowatt hours (kWh) per person per year. The grid connectivity in the country has also been reported to be very sparse with just 30% of the country connected to the grid. Within the network there is significant supressed demand at about 2500 MW. This is significant compared to the 750 MW peak demand of the grid reported in 2014. The energy balance in Afghanistan is skewed in favour of energy import (in the form of fuel etc.). Post the Afghan-war the demand in cities has been increasing rapidly.

The installed capacity in the system stood at a little over 500 MW in 2014. The generation mix is shown in the Figure 4.1 below:

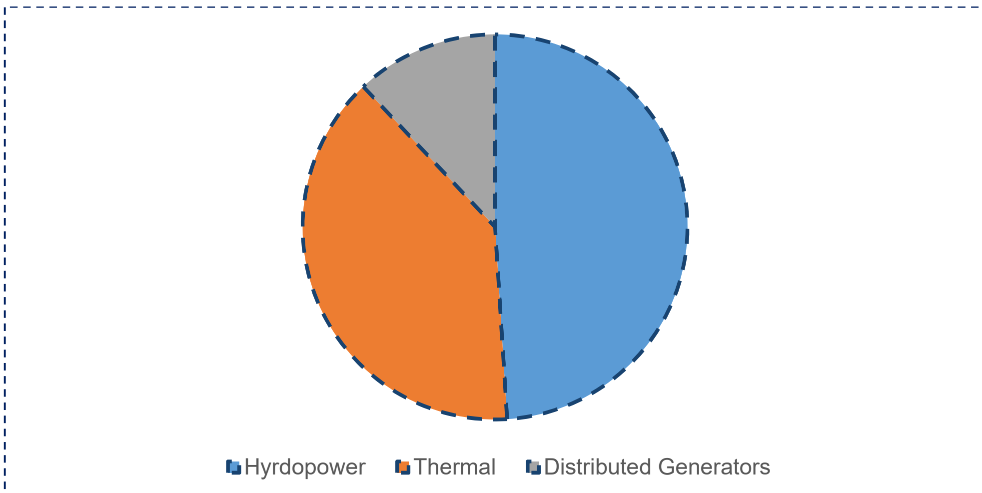



*Figure 4.1 Afghanistan generation mix*

There is a rising concern of the energy import bill which has by a factor of 14 over the past 8 years. Future development of hydropower would be dependent on being able to establish water usage treaties with neighbours with whom Afghanistan shares the river resource. It would be pertinent to mention that most of the installed thermal capacity in Afghan network is for emergency use and not for base load as is understood a normal practice in the world. This is due to high fuel costs

Access to electricity remains an issue within Afghanistan. The access is particularly problematic in rural areas where less than 10% of the population has access to electricity while more than 70% of the population is based there. This is also an economic issue as the GDP of the country mainly originates from rural areas (Asian Development Bank, 2015a).

From a renewable energy perspective, Afghanistan has very significant potential. These resources are estimated at:

- More than 20,000 MW of Hydropower potential.
- More than 65,000 MW of wind potential
- More than 200,000 MW of solar potential

Although metrics such as grid reliability have been improving, the frequent load shedding within the country means that increased reliance has to be based on backup generators. Afghanistan is envisaging the development of its renewable resources along with a mix of conventional fuel power plants to help with energy security and reduce the load shedding problem.

On the side of the electricity grid, the key issue for Afghanistan is its islanded grid which is composed of several grid networks that have not been connected and synchronised. This has created an inherent inflexibility in the means of operation for the grids in these areas. The problems in connecting the network would include aligning the voltage levels and frequency of these networks. As the network is not connected, this also creates higher reserve requirements, failing which the system reliability has suffered. The combination of poor grid connectivity, lower reliability and inadequate generation of the grid in Afghanistan is felt particularly in the rural areas; although the larger cities like Kabul, Kandahar etc. have up 75% connectivity, in the rural areas this drops to as low as 10%. To alleviate this situation, the Afghan government is looking into collaborating with developmental institutions and partners to extend the distribution network and connect the islanded grids. However, the focus of the distribution expansion is likely to be at the load centres of Afghanistan.

T&D losses in the region are significant and estimated to be around 47% by the ministry of Water and Energy in Afghanistan. The cost of the losses beyond what could be benchmarked as reasonable is in excess of US$70 million a year and this issue has been assessed to be significant for the financial sustainability of the Power Sector of Afghanistan.

The sector’s financial sustainability is also impacted significantly by the tariff regime where the average total cost of the electricity service is estimated to be between 13 cents – 22 cents per kWh as opposed to the 8 cents – 12 cents per kWh that is being charged in the tariff. The financial sustainability and the tariff mismatch are also impacted by the risk of new investment in the country driving up the investment cost due the security concerns in the region.

In order to develop the power sector in Afghanistan and ESTES technologies, a combination of public and private investment would be needed. Key constraints in the sector have been highlighted to be:

- Transmission and distribution system constraints
- The economic and financial state of the escort which faces issues of sustainability as the tariffs are not appropriate given the cost of services provided by the sector
- Insufficiently legal and development regulatory mechanisms for the sector
- Capacity building of public sector institutions to ensure accountability and enhance collaboration mechanism
- Human resource development

There has been some improvement in certain elements of the shortcomings including sector corporatization and the development of the recent Electricity Services Act in 2015 which is a step in improvement the regulatory framework of the sector. Power sector master planning in Afghanistan is also taking off with the National Energy Supply Programme (NSEP) being approved which envisages investments up to 2030.The Power Sector Master Plan for Afghanistan, prepared in 2013 by Fichtner funded by ADB shows that Afghanistan also has considerable renewable potential from solar and wind power plants. Parts of the focus of NSEP include renewable energy generation which provides for possible synergies with battery based storage and extending the distribution network in which storage can play a role through investment deferral. To date the application of energy storage in Afghanistan has been through battery systems coupled with renewable energy systems and Afghanistan boasts one of the largest off-grid systems which has a capacity of 1MW and has been deployed to power nearly 2,500 homes in the BMA province (SMA Solar Technology, 2014).

The power utility in Afghanistan (DABS) is also aiming to improve along institutional and commercial lines with the help of developmental agencies through the following initiatives:

- Improving the O&M practices throughout the sector value chain
- Providing protection to revenues
- Improving procurement and sector governance mechanisms
- Improved business planning measures

The potential for ESTES in Afghanistan is enhanced by the factor that approximately US$ 5 billion has been envisaged as a combination of grants and private sector investment for the Afghan energy sector in the forthcoming years. This presents an opportunity for appropriate policy to be made at this stage allowing for storage investment to be made.

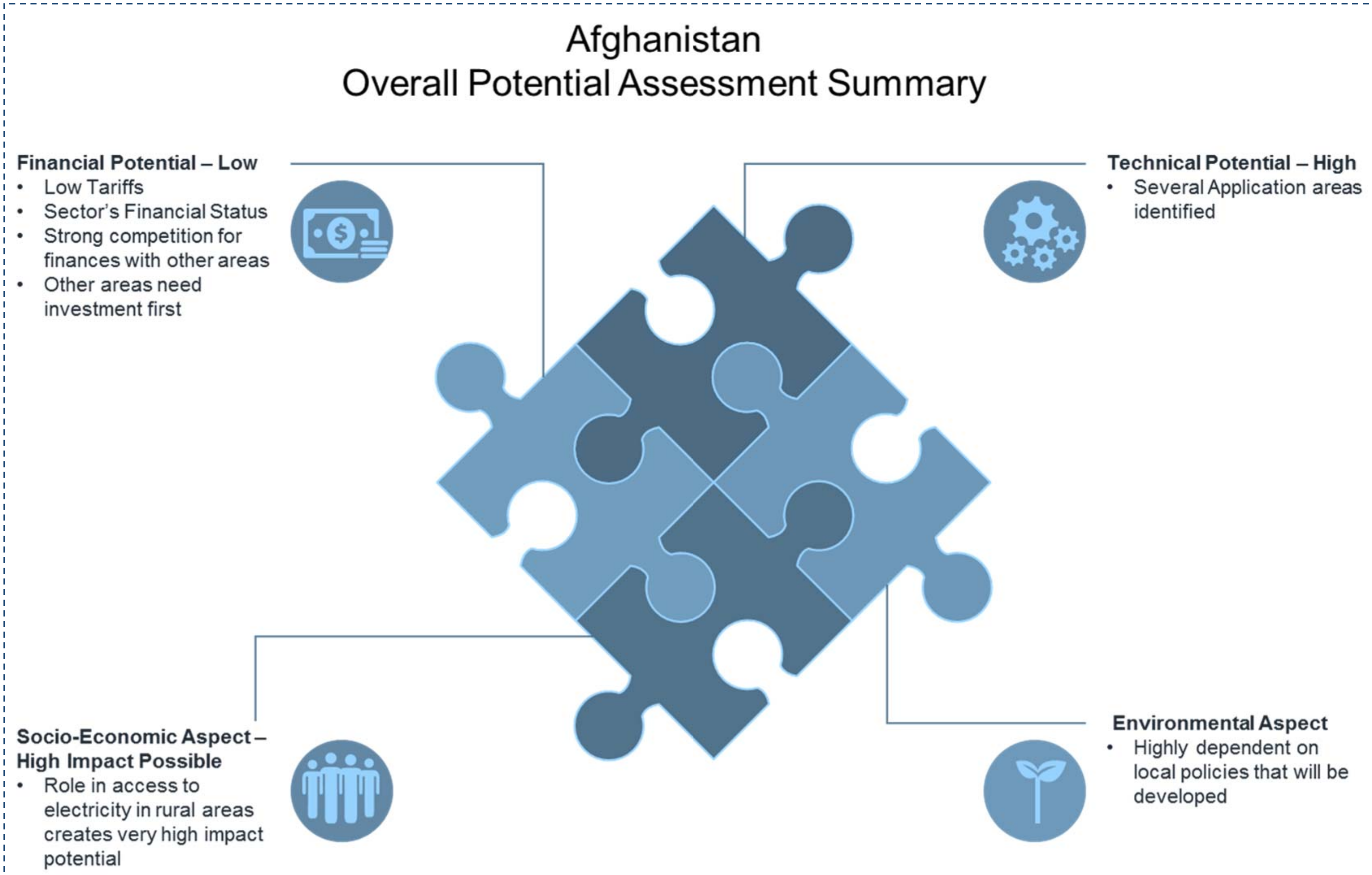
### 4.2.1.2 Afghanistan - ESTES Potential Evaluation

The sector assessment done for Afghanistan has been utilized to generate a potential evaluation for ESTES in Afghanistan which is shown below:

Table 4.1 Afghanistan evaluation

| Application | Potential | Explanatory Factors |
|---|---|---|
| **Off-to-on peak intermittent shifting and firming** | Medium | As renewable energy is still growing, this is not identified to be a high potential area |
| **On-peak intermittent Energy smoothing and Shaping** | Medium | Islanded networks mean that storage can give load-following support during that would have otherwise been provided by other generation in the system |
| **Ancillary service provision** | High | Requirement for frequency regulation in the islanded networks of Afghanistan is likely to be higher than for completely synchronised networks . ESTES benefits may also include potential voltage regulation and voltage stability provided by these technologies in the islanded networks |
| **Black start provision** | Low | Afghanistan is already operating several islanded networks – this suggests that there is sufficient black start capability in the overall power sector |
| **Transmission Infrastructure** | High | The islanded network nature of Afghanistan means that significant investment would be needed to build infrastructure – any application for deferring investment could be potentially high impact |
| **Distribution Infrastructure** | High | The same assessment for transmission infrastructure in Afghanistan applies to distribution infrastructure – the potential is higher because the capacities could be more distributed and the cost is easier to share with the consumer |
| **Transportable Distribution level outage mitigation** | Low | The sector needs other investments before this category is considered |
| **Peak load shifting downstream of distribution system** | High | By shifting load downstream, infrastructure can be more effectively utilized to provide higher effective capacities |
| **Intermittent distributed Generation integration** | High | Distributed generation has significant potential in Afghanistan especially given the renewable resources of Afghanistan leading to high application with storage systems |

| | | |
|---|---|---|
| **End-user time of-<br><br>Use (ToU) rate optimization** | Low | Already low energy tariffs mean low incentive for ToU optimization |
| **Uninterruptible power supply (UPS)** | High | Frequent outages mean that local population requires UPS support |
| **Micro grid formation** | High | As it may take significant time for the electrification of rural areas within Afghanistan, micro-grids can lead to acceleration of rural electrification. This can be coupled with the micro-hydro and small scale solar potential in Afghanistan. |



Afghanistan
Overall Potential Assessment Summary
Financial Potential – Low
• Low Tariffs
• Sector's Financial Status
• Strong competition for finances with other areas
• Other areas need investment first
Technical Potential – High
• Several Application areas identified
Socio-Economic Aspect – High Impact Possible
• Role in access to electricity in rural areas creates very high impact potential
Environmental Aspect
• Highly dependent on local policies that will be developed

### 4.2.1.3 Afghanistan – Gap Assessment

Based on the sector assessment for Afghanistan, the gaps for ESTES deployment were assessed and the results are shared in the table below. This is followed up a figure which maps the discussed underlying factors onto a gap assessment summary chart.

Table 4.2 Afghanistan gap assessment

| Issue Area | Summary of Explanatory Factors and Trends |
|---|---|
| **Political Will** | • Although the power sector is a priority for policy makers, specific support for ESTES has not been exhibited (↓) |
| **Policy Framework** | • Weak sector regulation historically (↓)<br>• Recent improvements to regulatory environment have taken place (↑) |
| **Institutional Arrangement** | • Weak institutional capability (↓)<br>• Institution building in progress through support of international development organizations (↑) |
| **Infrastructure** | • Significant war-periods have meant that infrastructure for supply chain development for ESTES has remained severely under-developed especially in rural areas where ESTES based micro-grids etc. have significant potential (↓) |
| **Human Resource and Expertise** | • Limited expertise available which is local (↓)<br>• ADB has identified lack of expert human resource as an overall sector issue (↓)<br>• ESTES international expertise difficult to bring to the country due to security situation (↓) |
| **Market Conditions** | • Non-liberalized market with fewer incentives available for private sector profitability through energy arbitrage and other revenue making (↓)<br>• Low tariffs and overall sector financial sustainability low (↓)<br>• Large non-grid connected areas and significant need for investment deferral means that there could be significant potential demand (↑) |
| **Favourable Development Scenario** | • As the sector's financials, regulation, capacity and renewable penetration increases so will the outlook for ESTES, however given that the rebuilding effort in Afghanistan will take significant time and the security situation remains uncertain, the score for the future development scenario also remains lower than determined by market factors alone |

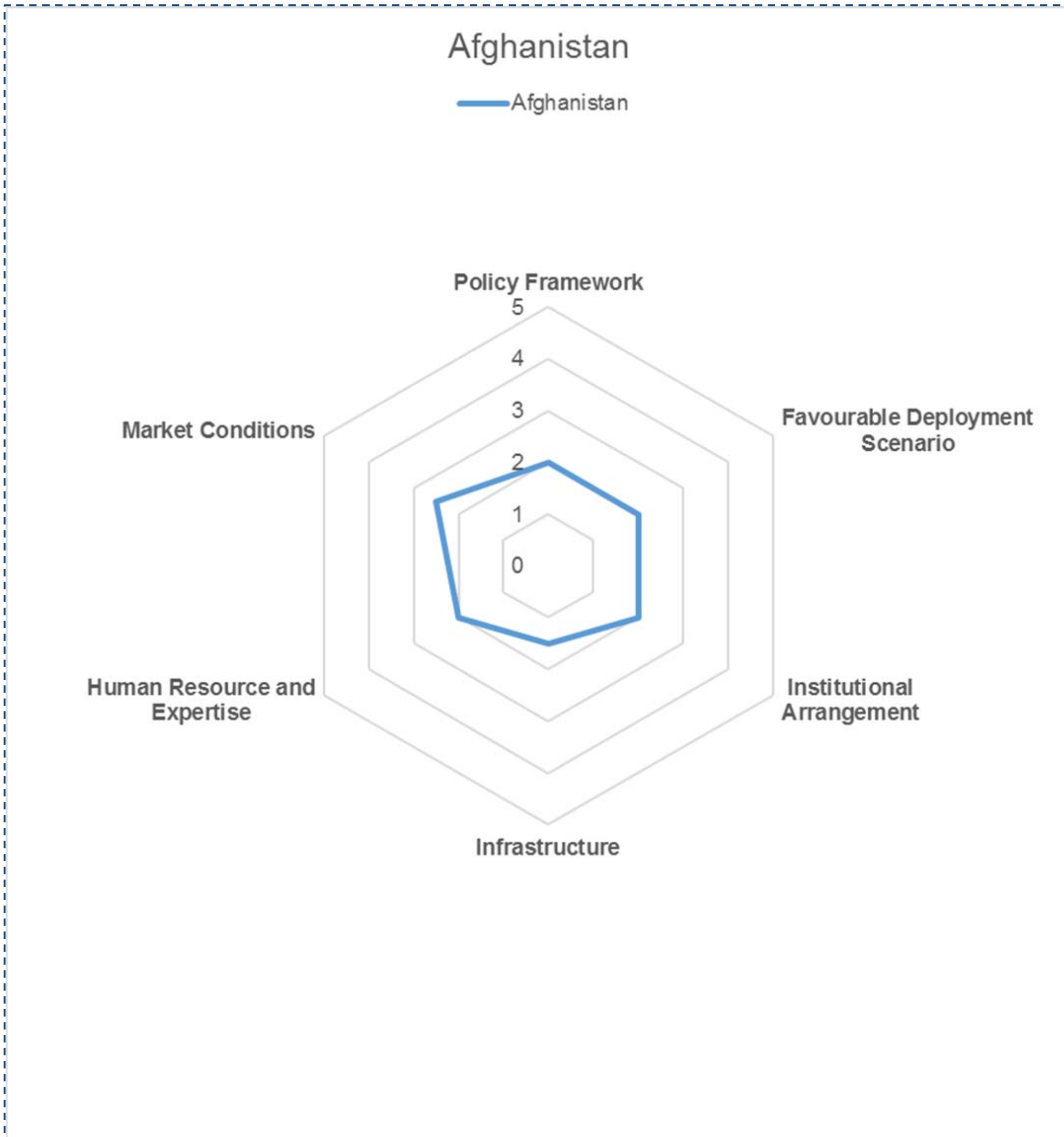



*Figure 4.2 Afghanistan Assessment Key: 1 (lowest) to 5 (highest)*

### 4.2.2 Bangladesh

#### 4.2.2.1 Bangladesh – Sector Assessment

The economy in Bangladesh has been growing at very significant rates with the GDP growth estimated to be over 6% for 2015 and 2016. The success of the power sector in increasing installed capacity is one of the underlying reasons of this growth. However, this rapid economic growth has resulted in significant increase in the electricity demand of the country. Although, as of 2014 the installed capacity of the country stood at above 11,000 MW compared to a peak demand of around 7,700 MW, the country has faced chronic power outages due to the actual deliver capability of the generation system being considerably lower due to the condition of the generation equipment being classified as relatively poor (Asian Development Bank, 2015b). The energy mix of the country is as follows:

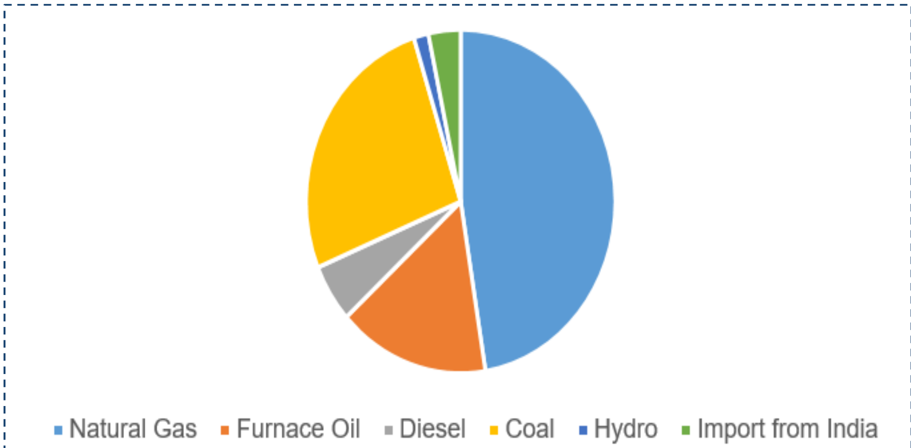



*Figure 4.3 Bangladesh energy mix (Asian Development Bank, 2015b)*

The country suffers from limited electrification of the country with the only 70% of the country being electrified as of 2015. Increasing access to electricity is one of the major policy aims of the country with significant requirement in transmission and distribution infrastructure required to enable it. According to the Seventh Five Year Plan for Bangladesh, the future power sector requirements have been envisioned as:

| Financial Year | Public Sector (MW) | Private Sector (MW) | Total (MW) |
|---|---|---|---|
| **2016** | 334 | 1271 | 937 |
| **2017** | 738 | 3337 | 2599 |
| **2018** | 867 | 1943 | 1076 |
| **2019** | 1716 | 3036 | 1320 |
| **2020** | 1247 | 2997 | 1750 |
| **Total** | 4902 | 12584 | 7682 |

Tariff regime in the country, given the high penetration of imported fuels in the energy generation mix, has not progressed to the point where entire cost recoveries are being done. Although in recent years, evidence was found that the tariff related regulation in the country was improving. However, increase in tariff remains a politically sensitive subject.

The overall governance of the power sector is headed in the direction of corporatization with several of the public power sector entities of the country have been listed on the country's stock exchanges. However, ownership of the government in the sector remains high and the process of corporatization is not complete.

Although current renewable energy deployment within the country was low, plans exist to increase this capacity to 10% by 2020. Given the significant renewable energy potential and application within Bangladesh, the potential for energy storage to create synergies with this deployment was investigated. We started with the renewable energy potential within Bangladesh which is shown at a glance within Bangladesh in the figure below:

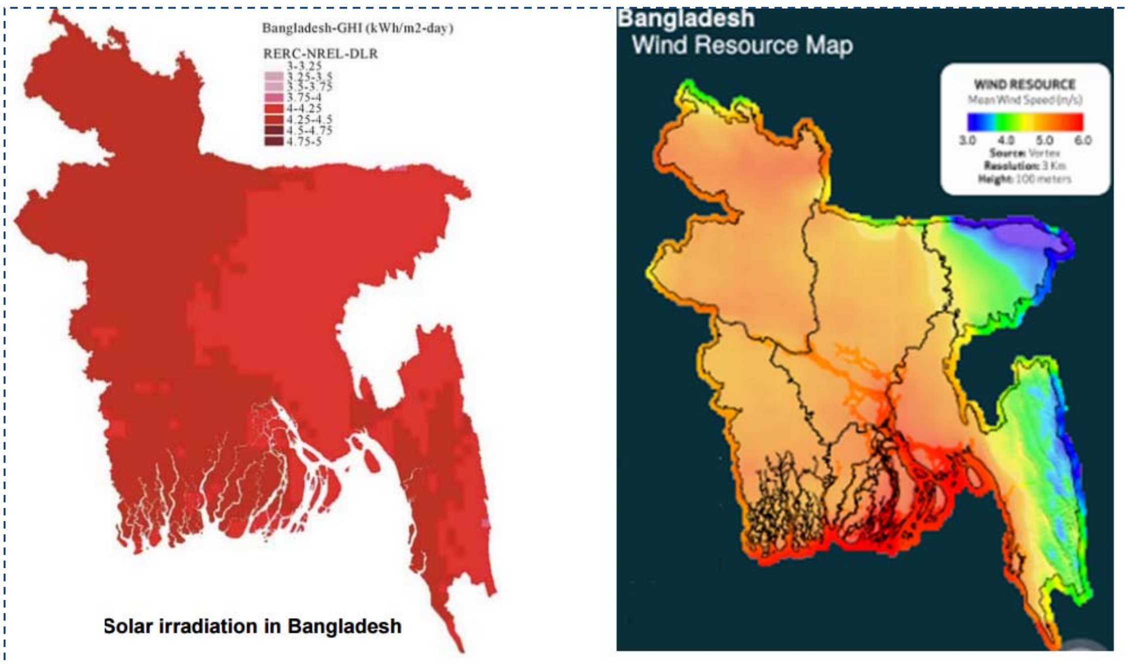



*Figure 4.4 Bangladesh Renewable Energy Potential (Rechsteiner and Basu, 2015)*

This shows that solar resource is generally abundant throughout Bangladesh. Wind resource is mostly concentrated in parts of the coastal regions. Before the potential application for energy storage to participate in applications such as peak-shaving and any potential synergies with the renewable generation is concerned, the correlation between solar and wind energy was considered. This is shown in the figure below:

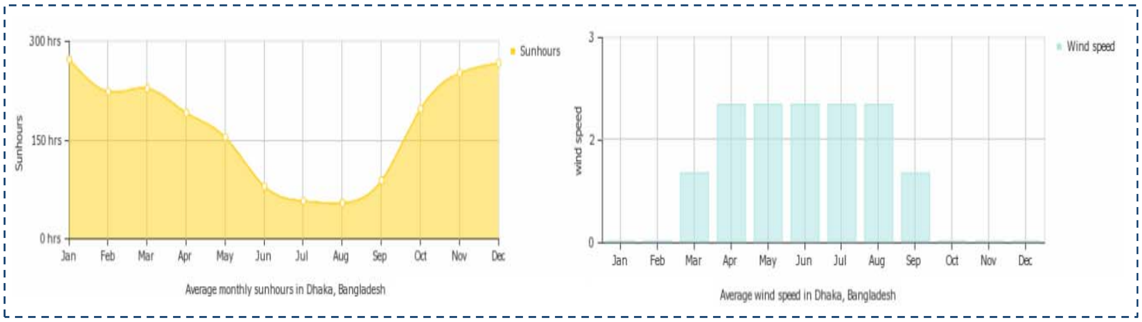



*Figure 4.5 Solar and wind energy correlation (Rechsteiner and Basu, 2015)*

The lower solar output during the monsoon seasons (June - September) is complemented well by the higher wind potential. However, we also look at the daily load curves to understand the situation further:

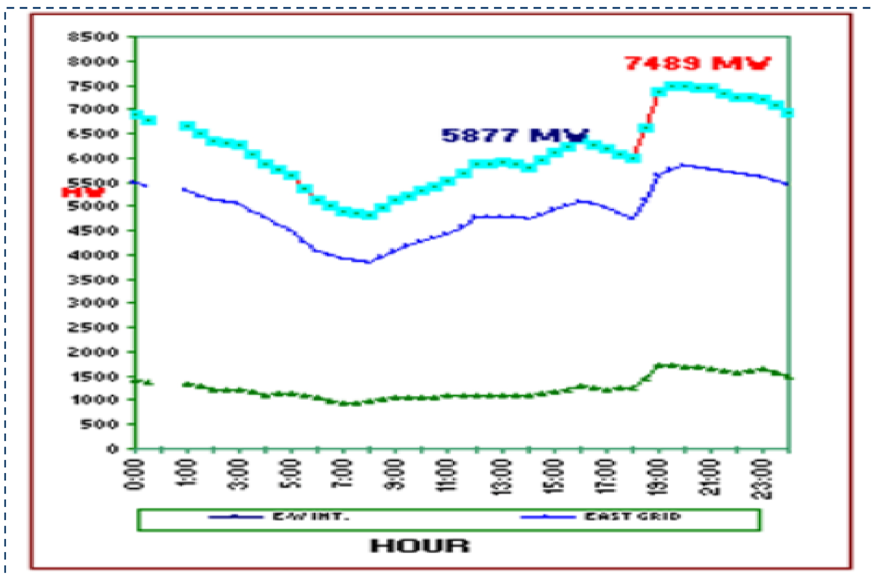



*Figure 4.6 Daily load curve (Rechsteiner and Basu, 2015)*

This shows that although seasonally there is an advantage from coupling solar and wind resources, there is still potential for energy storage to play a role especially in conjunction with solar as the solar peak output does not coincide with the peak load which occurs in the evening/night.

Apart from Grid-scale solar, Bangladesh has wisely been incentivising small-household solar systems. Their historical deployment is shown as follows:

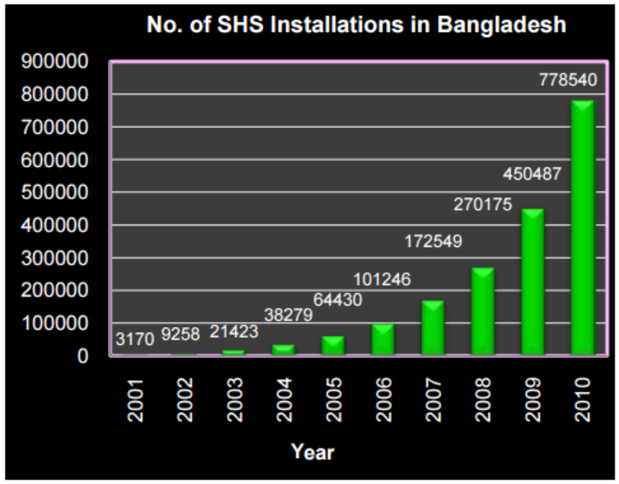



*Figure 4.7 Number of SHS installations in Bangladesh (Biswas et al., 2011)*

The energy storage in this scenario has taken the form of battery storage coupled with domestic solar solutions. The batteries are either tubular plate or flat plate ones, with the tubular plate batteries being more durable and having higher demand. The battery industry in Bangladesh is mature with tubular battery being manufactured locally. The main maufucaters of batteries in Bangladesh are shown below:

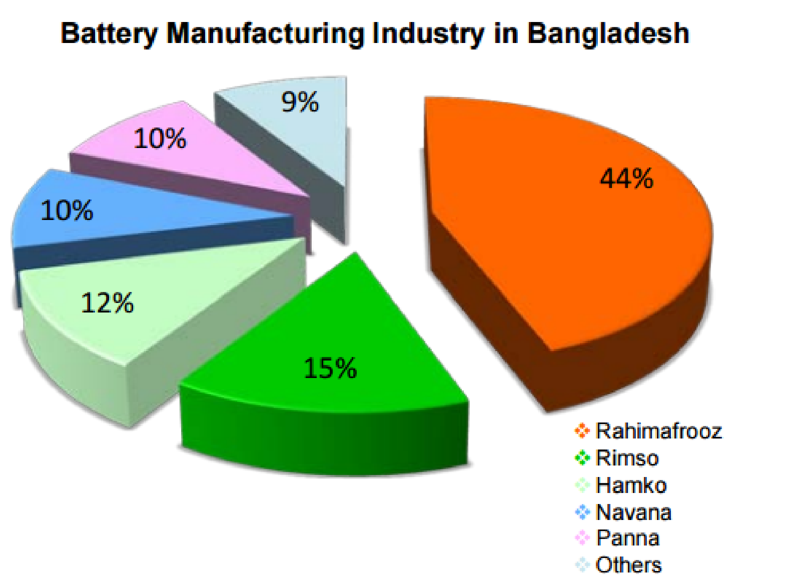



*Figure 4.8 Battery manufacturing industry in Bangladesh (Biswas et al., 2011)*

This gives the understanding that local expertise in battery production is likely to be available. Bangladesh is also the source of an interestsing case study for energy storage where a sustainable value chain around energy storage has been created. The estimated installed capacity in Bangladesh in the form of battery storage has been estimated to be 200

MW of deep-cycle lead-acid type. A policy has been implemented wherein it is the battery providers that are responsible for the end-of-life recycling of the batteries. This has subsequently resulted in a very significant incentive on batter manufacturees to create highter quality sotage batteries and develop local supply chains thus resulting in higher sustainablility of storage. (IRENA, 2015).

From a transmission network perspective, although currently the network infrastructure where electricity access exists is broadly sufficient but it is rapidly reaching the point where lines are operating at their thermal limits and others would become significantly overloaded. Like several other SAARC Member States, N-1 provision is also missing in parts of the network (Asian Development Bank, 2014a). T&D losses in Bangladesh have been on an overall long-term downward trajectory as shown in the figure that follows:

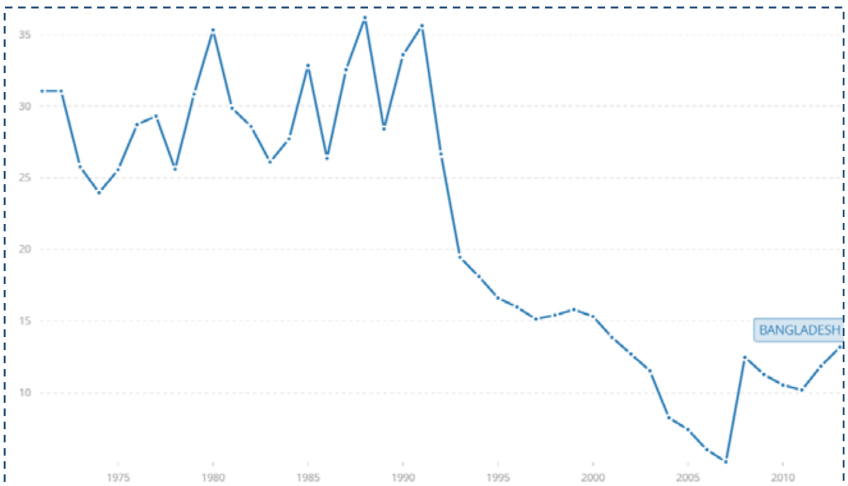



*Figure 4.9 T&D losses (The World Bank)*

Key underlying issues in the sector are as follows:

- Insufficient physical infrastructure in the form of inadequate generation capability as well as lack of connectivity to about 30% of the population
- Limited institutional capability in areas such as
    - Developing and operating power exchanges
    - Slow regulatory reform
    - System capacity planning
- Limited corporate governance of utilities

### 4.2.2.2 Bangladesh - ESTES Potential Evaluation

The sector assessment done for Bangladesh has been utilized to generate a potential evaluation for ESTES in Bangladesh which is shown below:

Table 4.3 Bangladesh evaluation

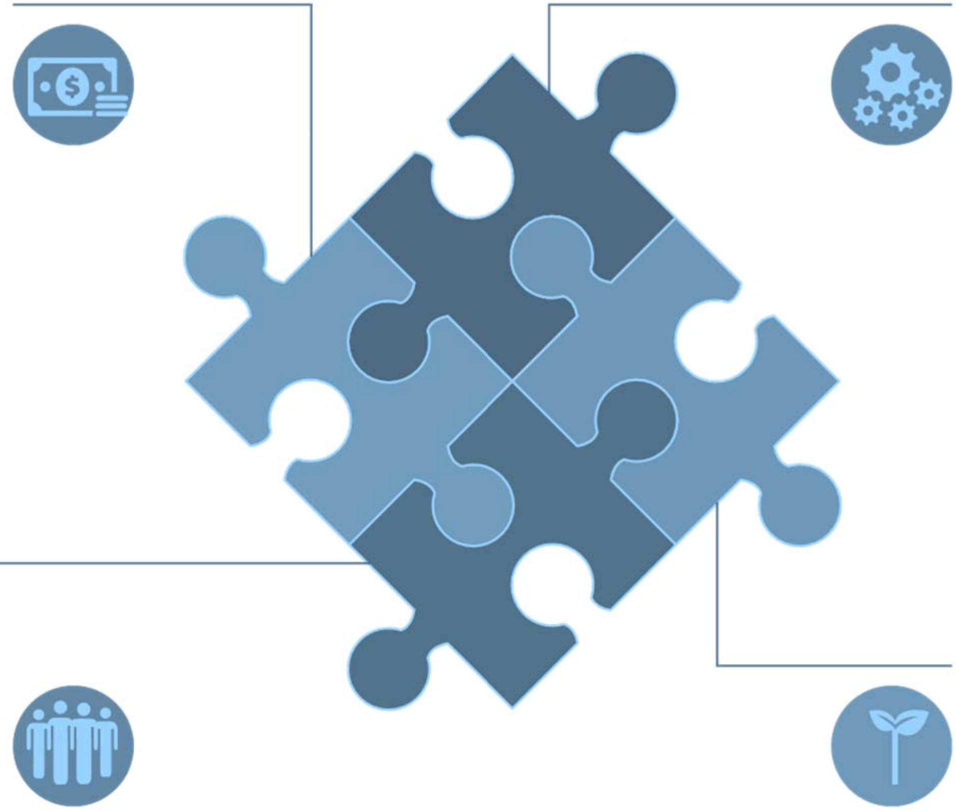
| Application | Potential | Explanatory Factors |
|---|---|---|
| **Off-to-on peak intermittent shifting and firming** | Medium | The low reliability of the generation sector in the country means that the during peak scenarios storage can be used to increase reliability |
| **On-peak intermittent Energy smoothing and Shaping** | Low | Very low renewable penetration for this to be relevant at this stage |
| **Ancillary service provision** | Low | Frequency regulation can be provided by the high amount of thermal power plants in the system which have very fast response rate especially for the gas fired plants |
| **Black start provision** | Low | Evidence suggest that there is sufficient black start capability in the overall power sector |
| **Transmission Infrastructure** | Medium | The sector assessment showed that significant future investment may be required in the Transmission infrastructure of the country increasing the Investment deferral value of ESTES technologies |
| **Distribution Infrastructure** | Medium | The same assessment for transmission infrastructure in Bangladesh applies to distribution infrastructure – the potential is higher because the capacities could be more distributed and the cost is easier to share with the consumer |
| **Transportable Distribution level outage mitigation** | Low | The sector needs other investments before this category is considered |
| **Peak load shifting downstream of distribution system** | High | By shifting load downstream, infrastructure can be more effectively utilized to provide higher effective capacities |
| **Intermittent distributed Generation integration** | High | Distributed generation based storage has significant potential in Bangladesh as evidenced by deployment of domestic level solar systems |
| **End-user time of-Use (ToU) rate** | Low | Already low energy tariffs mean low incentive for ToU optimization. The difference between the peak and off-peak |

| | | |
|---|---|---|
| **optimization** | | tariffs is very low |
| **Uninterruptible power supply (UPS)** | High | Chronic outages mean that local population requires UPS support |
| **Micro grid formation** | High | With 30% of the country remaining to be electrified, micro-grids can lead to acceleration of electricity to areas in conjunction with solar power deployment |

## Bangladesh
## Overall Potential Assessment Summary

**Financial Potential – Medium**
- Low Tariffs
- Distributed renewable generation deployed and market exists with upto 200 MW of storage

**Technical Potential – High**
- Several Application areas identified



**Socio-Economic Aspect – Medium Possible**
- Further development of local storage industry to provide jobs
- Micro-grid with storage can accelerate electrification of areas without electricity access

**Environmental Aspect**
- Policies developed favor sustainable disposal of batteries through making producer responsible for disposal

### 4.2.2.3 Bangladesh – Gap Assessment

Based on the sector assessment for Bangladesh, the gaps for ESTES deployment were assessed and the results are shared in the table below. This is followed up a figure which maps the discussed underlying factors onto a gap assessment summary chart.

Table 4.4 Bangladesh gap assessment

| Issue Area | Summary of Explanatory Factors and Trends |
|---|---|
| **Political Will** | • Political will in the country is likely to be linked to keeping tariffs affordable which would mean insufficient cost recovery (↓) |
| **Policy Framework** | • Evidence found that correct policy making direction being taken with regards to storage as found in the battery storage disposal formulation (↑) |
| **Institutional Arrangement** | • Weak institutional capability including slow regulatory reform (↓) |
| **Infrastructure** | • Local supply chain for storage especially in the form of battery storage exists (↑) |
| **Human Resource and Expertise** | • Local industry has expertise available which is also local (↑)<br>• Presence of academic and research institutions (↑) |
| **Market Conditions** | • Non-liberalized market with fewer incentives available for private sector profitability through energy arbitrage and other revenue making (↓)<br>• Low tariffs and overall sector financial sustainability low (↓)<br>• Large non-grid connected areas and significant need for investment deferral means that there could be significant potential demand (↑)<br>• Incentivized house-hold solar schemes (↑) |
| **Favourable Development Scenario** | • As the sector's financials, regulation, capacity and renewable penetration increases so will the outlook for ESTES (↑) |

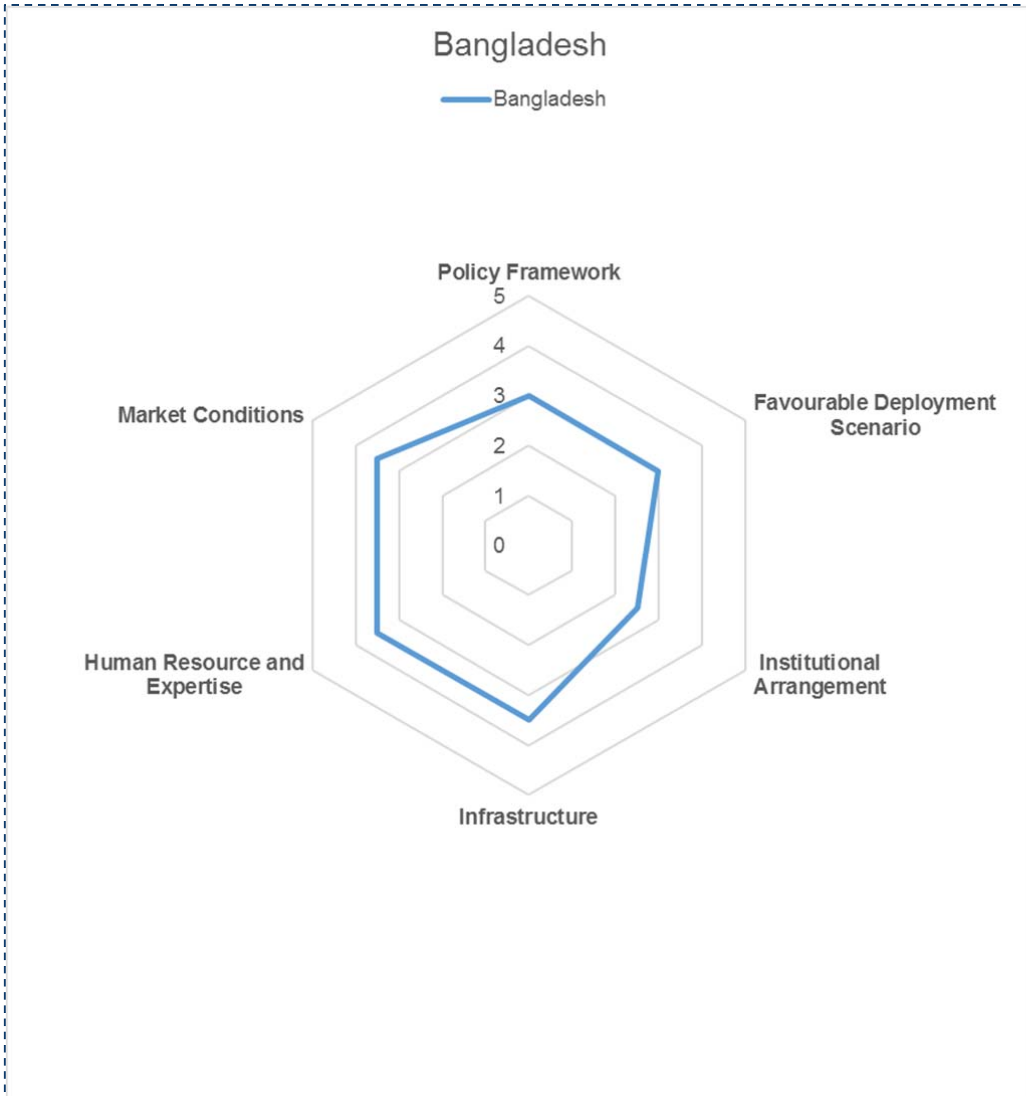



*Figure 4.10 Bangladesh Assessment Key: 1 (lowest) to 5 (highest)*

### 4.2.3 Bhutan

#### 4.2.3.1 Bhutan – Sector Assessment

The energy sector situation in Bhutan has been improving over the past decade with the strengthening of the institutional arrangements in the power sector. Bhutan is the only country in South-Asia in which the generation capacity is nearly in surplus.

Energy plays a unique role in Bhutan's economy in the context that the contribution of the energy sector has been quite significant. It has accounted for:

- Up to 40% of government revenue
- 45% of export earnings generated by Bhutan through export of electricity to India
- 25% of the GDP

The energy balance scenario of Bhutan is shown in the figure below:

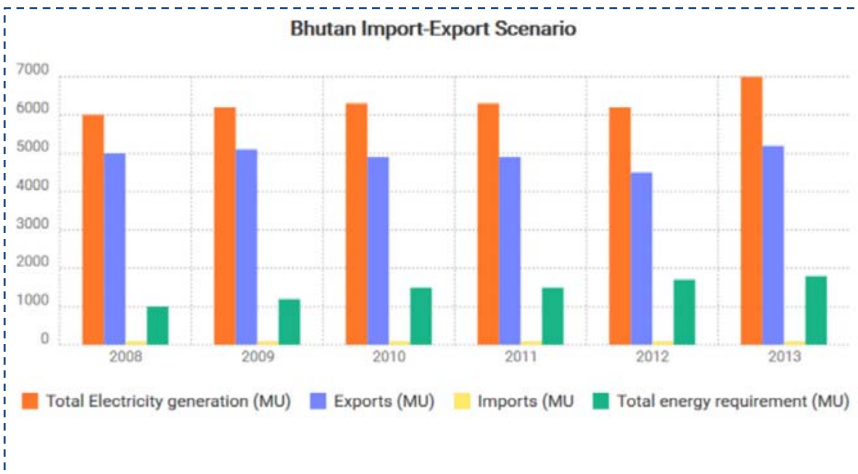



*Figure 4.11 Bhutan Import-Export Scenario (SARI)*

Hydropower exports have been playing a significant role in the economic growth of the country; the GDP growth rate between 2003 and 2012 was a very significant 14.5% annually on average. With increased economic growth, the income level of the local population has also increased. This has consequently resulted in improved living conditions and therefore increased electricity demand in the country.

Understanding the actual constraints and real challenges of the energy sector in Bhutan requires looking at the difference of the load profiles during different periods of the year. This is shown in the figure below:

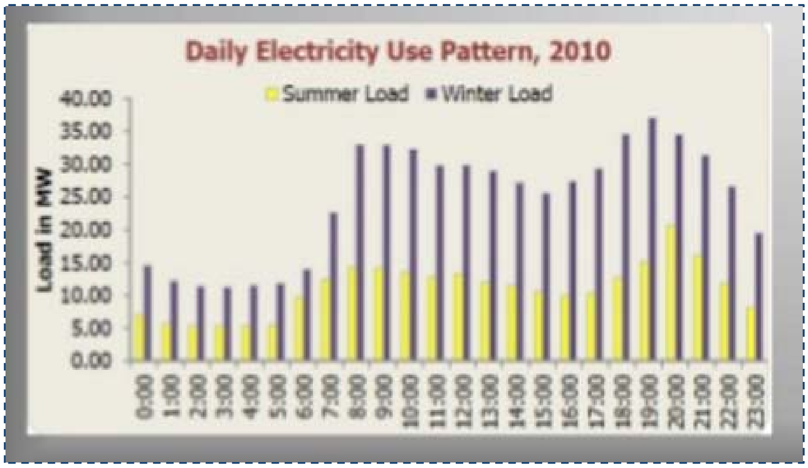



*Figure 4.12 Daily Electricity Use Pattern Source: goo.gl/xroX83 (slide 30)*

The Power Generation sector in Bhutan relies almost exclusively on hydropower. The Hydro power resources are run of the river type resources without having storage capability. The power station output varies significantly between seasons and during winter when the rivers dry up and the power output drops significantly. This creates huge mismatch between the indigenous generation capability of Bhutan the local demand. Currently the measures used to compensate for this drop in electricity output include:

- Curtailing power to industries in the winter
- Importing electricity from India in the winter

However, as India grapples with its own electricity shortages, this may become a problem in the future as Bhutan may not be able to import electricity for its needs (Asian Development Bank, 2014b).

Bhutan's Power Sector has been undergoing institutional change along several fronts. Previously, the power sector was managed by the government through civil service rules and regulations. A shift away from this bureaucratic structure happened in 2002 with the formation of the Bhutan Power Company. This institutional reform along with the corporatization of the sector has allowed the Bhutanese Power Sector to deliver results in areas such as electrification etc. that would not have been difficult to achieve otherwise.

The institutional reform and overall corporatization of the has also been coupled with the tariff reform of the sector. Increased emphasis has been placed on achieving cost recovery benchmarks in the country as well as ensuring that there is an adequate return on investments made in the power sector to ensure a more financially sustainable development of the power sector. This has taken the form of understanding the actual cost of electricity supply to the various consumer categories within the country as well as implementing a tariff regime that allows for appropriate cost recoveries.

From a financing perspective, the financial position of the energy sector in Bhutan is relatively healthy. The energy companies operating in Bhutan including the Bhutan Power Corporation (BPC), which provides domestic power supply, and Druk Green Power Company (DGPC), responsible for the hydropower projects, have been profitable. It is important to note that the sector has achieved adequate self-finance and debt servicing capabilities. This is a very positive note for financing storage based solutions in the country. The financial performance is summarized as follows:

| Item | 2005 | 2006 | 2007 | 2008 | 2009 | 2014 | 2017 | 2020 |
|---|---|---|---|---|---|---|---|---|
| **Export revenues** | 3,606 | 3,953 | 8,922 | 11,776 | 10,857 | 12,750 | 34,398 | 71,706 |
| **Domestic revenues** | 225 | 218 | 423 | 457 | 778 | 1,582 | 1,391 | 932 |
| **Operation and maintenance cost** | 423 | 444 | 1,422 | 1,422 | 1,422 | 1,611 | 2,433 | 6,423 |
| **Debt service** | 715 | 685 | 1,091 | 4,543 | 4,449 | 3,820 | 7,594 | 18,532 |
| **Wheeling charges** | 231 | 253 | 566 | 740 | 676 | 684 | 1,231 | 2,152 |
| **Subsidy to domestic sector cash surplus** | 2,461 | 2,788 | 6,265 | 5,527 | 5,088 | 8,217 | 24,532 | 45,532 |
| **Source Independent Evaluation Department staff estimates** | | | | | | | | |

*Figure 4.13 Financial Performance of Export-Oriented Power Sector Source: goo.gl/xroX83 (slide 36)*

Bhutan currently has an ambitious electrification program aiming to achieve hundred percent electrification of the country by 2020. The majority of the electrification programme has been undertaken through grid extensions. The cost of this program has been economically efficient, however as the programme is extended to more far flung and remote rural areas the cost of grid extensions is expected to rise. This creates the opportunity for off-grid solutions involving battery storage and electricity storage measures to play a significant role in the energy sector of Bhutan (Asian Development Bank, 2010). However, it is recommended that a cost-benefit analysis study be undertaken to assess the threshold values for which this would become economical compared to grid extension.

Bhutan's extensive hydropower potential has been mapped to be 30,000 MW of which nearly 80% is deemed to be feasible from a techno-economic perspective. The T&D losses are reported to be around 9.25% (Ministry of Economic Affairs, 2015). The major hydropower developments planned in Bhutan are as follows:

- Punatsangchhu-I (1200MW)
- Punatsangchhu-II (1020MW)
- Mangdechhu (720MW)
- Tangsebji (118MW)
- Kholongchhu (600MW)

Bhutan's major hydro-power plants have been planned with the cooperation of India; the cooperation envisions deployment of 10,000 MW of hydropower generation in the country. This suggests that hydro-power based storage solutions would have the potential of storing additional power for domestic use and even export during off-peak seasons. However, before the energy from these plants can be evacuated and exported to India as well as transported within the country for domestic use, extensive investment would be needed in the transmission infrastructure of the country. An integrated approach towards developing these investment and overall transmission planning may benefit from including the potential that energy storage applications may have in investment deferral by lowering network reinforcement requirements. As well as expansion planning, the increase in hydropower resources would also require BPC to improve operational control measures so that system reliability is also ensured.

The government recognizes that the overall supply situation in Bhutan is skewed heavily towards hydropower and that long-term energy security requires thinking along the lines of fuel diversification. These views were reflected in the 2013 Alternative Renewable Energy Policy developed by the Government for Bhutan. The key objectives of the policy include:

- Diversifying the energy resource mix leading to increased long term energy security
- Reduction of fossil fuel imports
- Reduction of greenhouse gas emissions
- stimulating social and economic development – this is envisioned to be done via a combination of attracting power sector participation and governmental interventions

The renewable resource within the country is mapped below; the numbers for wind resource are more firm with the solar energy resources still being investigated.

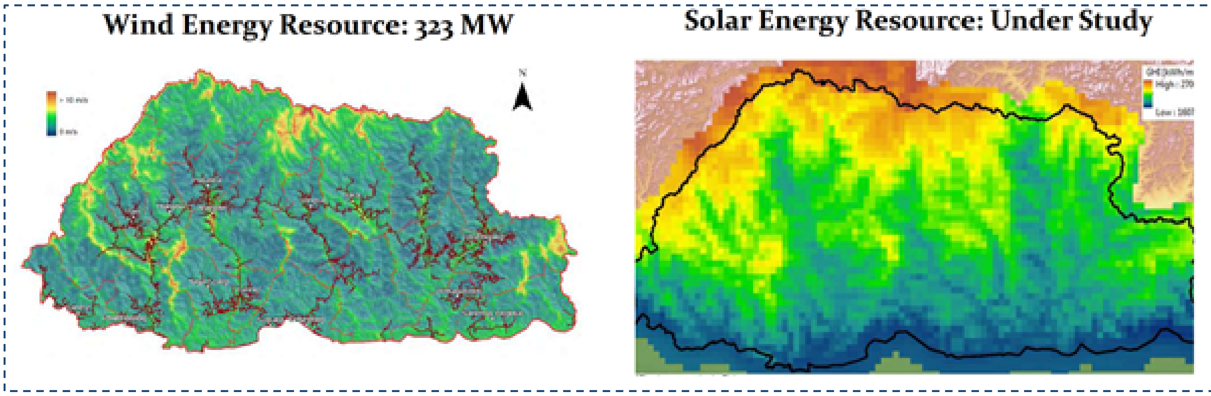



*Figure 4.14 Bhutan - Wind and solar energy (Ministry of Economic Affairs, 2015)*

The government is planning to diversify the fuel mix using wind, solar, biomass as well as micro hydropower based power systems.

With the increased participation of the renewable energy sector, certain energy storage applications including battery storage also again increase scope within the region. The daily fluctuation of wind power is a natural factor that can allow wind power plants to have synergy with energy storage.

### 4.2.3.2 Bhutan - ESTES Potential Evaluation

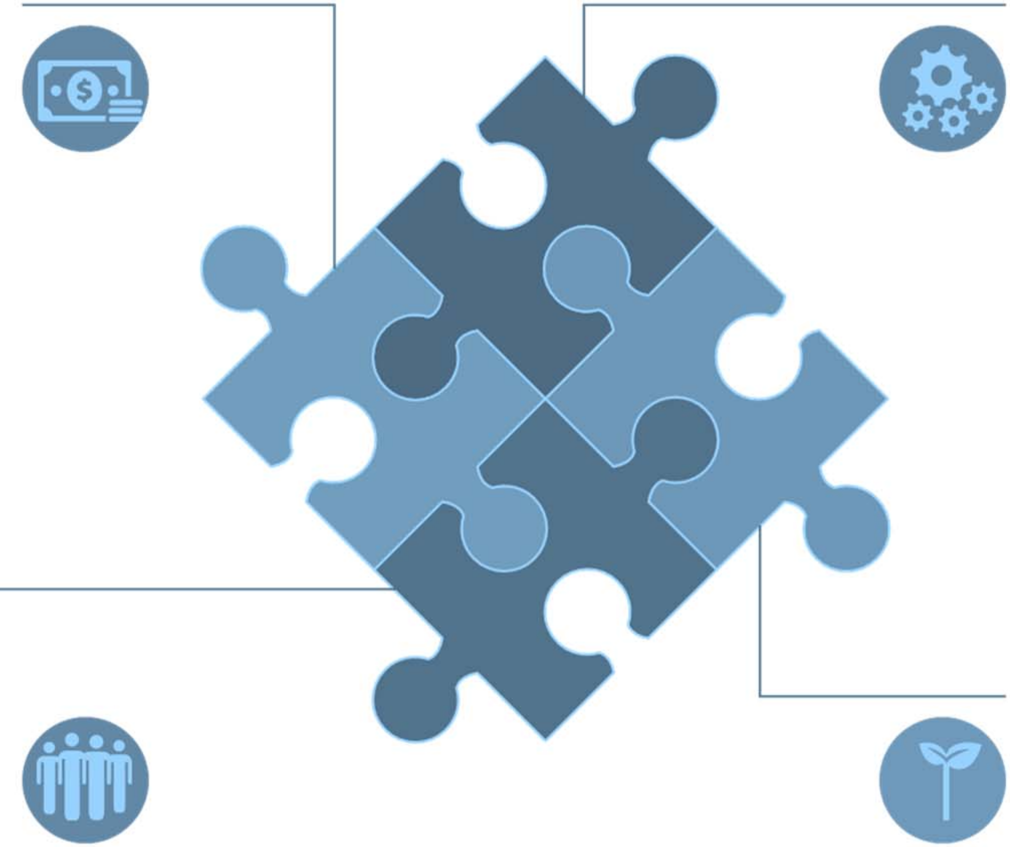
The sector assessment done for Afghanistan has been utilized to generate a potential evaluation for ESTES in Afghanistan which is shown below:

Table 4.5 Bhutan evaluation

| Application | Potential | Explanatory Factors |
|---|---|---|
| **Off-to-on peak intermittent**<br>**shifting and firming** | High | The ability to shift storage patterns combined with potential renewable deployment will prove helpful as it has the ability to increase the export potential for Bhutan – however the final ability would depend on the degree of co-relation between the consumption patterns of India and Bhutan |
| **On-peak intermittent**<br>**Energy smoothing and**<br>**Shaping** | Medium | The low size of the network in winter when hydro power is limited and reliance would be on other resources especially renewables, storage would help smooth the intermittency of the generation |
| **Ancillary service provision** | High | Requirement for frequency regulation in the very small network of Bhutan would likely be high given lower spinning reserves and inertia in the system<br>This also means that ancillary services such as reserve |

| | | |
|---|---|---|
| | | etc. are likely to be valued highly from a system security perspective as the system has lower capacity to deal with shocks |
| **Black start provision** | Low | Evidence suggests that there is sufficient black start capability in the overall power sector |
| **Transmission Infrastructure** | Medium | Considerable need has been identified for transmission investment – part of this may be offset by storage which allows for peak-shaving |
| **Distribution Infrastructure** | Medium | The same assessment for transmission infrastructure in Bhutan applies to distribution infrastructure |
| **Transportable Distribution level outage mitigation** | Low | The sector needs other investments before this category is considered |
| **Peak load shifting downstream of distribution system** | Medium | Can lead to investment deferral |
| **Intermittent distributed Generation integration** | Medium | Distributed generation has potential in Bhutan especially given the renewable resources of Bhutan leading to application with storage systems |
| **End-user time of-Use (ToU) rate optimization** | Low | Already low energy tariffs mean low incentive for ToU optimization |
| **Uninterruptible power supply (UPS)** | Medium | UPS support is likely to be needed in winter when hydro resources |
| **Micro grid formation** | Medium | As it may take significant time for the electrification of rural areas within Bhutan, micro-grids can lead to off-grid electrification – however the potential is limited by the relatively high electrification rate achieved by Bhutan |

## Bhutan
## Overall Potential Assessment Summary



**Financial Potential – High**

- Sector's Financial Status strong – profit making power sector enterprises
- Potential for export of power to India to generate additional revenues

**Technical Potential – Medium**

- Several possible application areas identified
- T&D loss reduction additional application area
- Overall low volume potential for deployment

**Socio-Economic Aspect – Medium Impact Possible**

- Increase in export potential to lead to general prosperity
- Reduction in winter outages to improve quality of life

**Environmental Aspect**

- Highly dependent on local policies that will be developed

### 4.2.3.3 Bhutan – Gap Assessment

Based on the sector assessment for Bhutan, the gaps for ESTES deployment were assessed and the results are shared in the table below. This is followed up a figure which maps the discussed underlying factors onto a gap assessment summary chart.

Table 4.6 Bhutan gap assessment

| Issue Area | Summary of Explanatory Factors and Trends |
|---|---|
| **Political Will** | • Bhutan displays a strong focus on improving the state of the electricity sector(↑) |
| **Policy Framework** | • Recent improvements to regulatory environment have taken place such as tariff development for cost recoveries (↑)<br>• Overall the policies of the power sector have been identified as inadequate (↓) |
| **Institutional Arrangement** | • Institutional capability has been improving through corporatization of the sector and delivery of results has been successful (↑<br>• The government has limited experience of project formulation |
| **Infrastructure** | • Infrastructure levels required for supply chain development of ESTES locally e.g. manufacturing etc. are not present to a high degree in Bhutan (↓) |
| **Human Resource and Expertise** | • Limited academic or professional expertise available which is local (↓)<br>• ADB has identified lack of expert human resource as an overall sector issue (↓) |
| **Market Conditions** | • Non-liberalized market with fewer incentives available for private sector profitability through energy arbitrage and other revenue making (↓)<br>• Potential for export exists (↑)<br>• Profit making power sector (↑)<br>• However, lack of commercial business practices still exists (↓) |
| **Favourable Development Scenario** | • As the sector's financials, regulation, capacity and renewable penetration increases so will the outlook for ESTES, however given that the volume of ESTES deployment is dependent on the size of the power sector of Bhutan, which is relatively small, the score for the future development scenario also remains lower than determined by market factors alone |

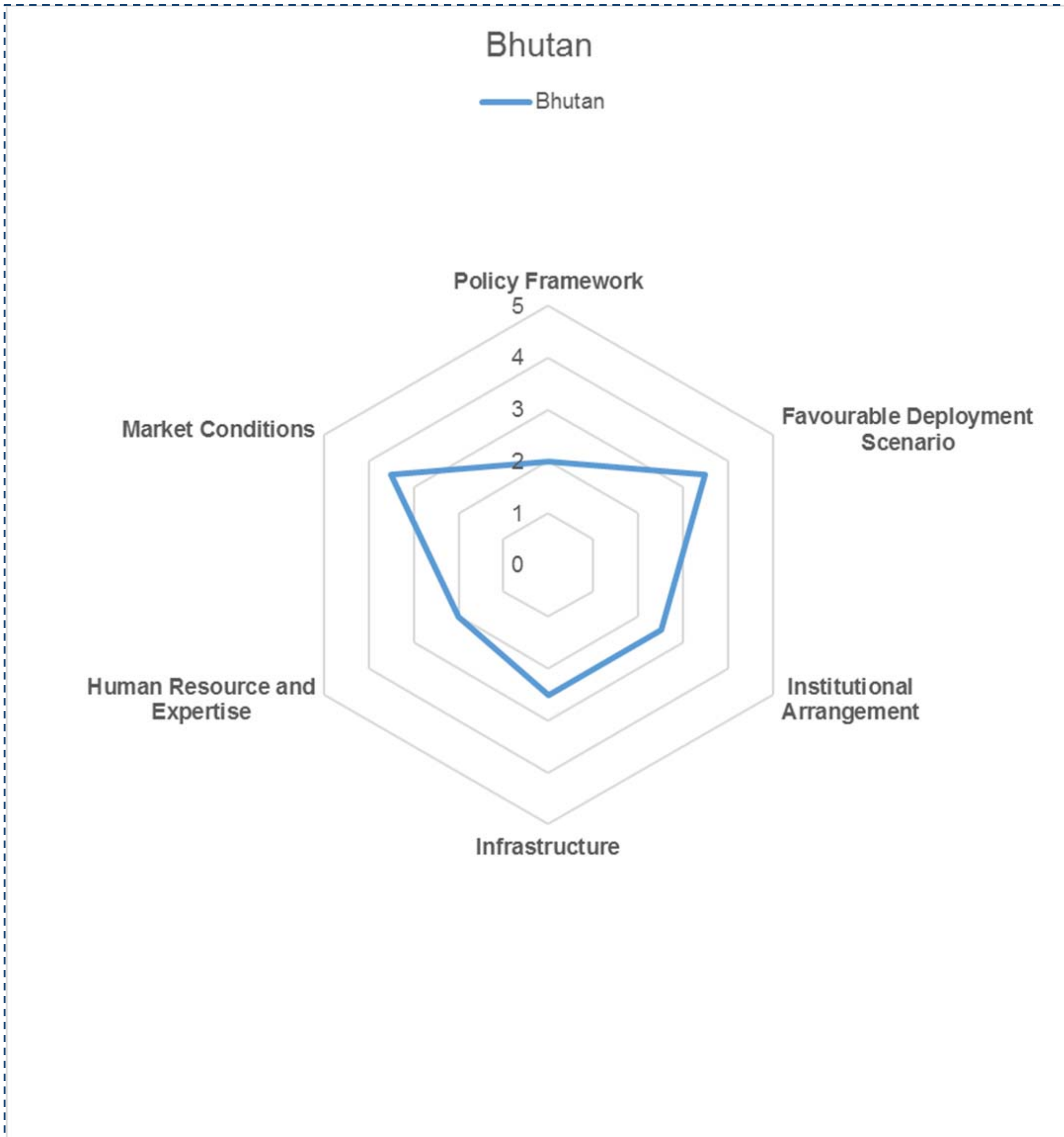



*Figure 4.15 Bhutan Assessment Key: 1 (lowest) to 5 (highest)*

### 4.2.4. Maldives

## 4.2.4.1. Maldives – Sector Assessment

Maldives is a small island nation located in the Indian Ocean. With reference to Sri-Lanka, it is located in the southwest. It consists of some 26 major atolls and 1,190 tiny islands lying. Only 33 of these Islands have an area greater than 1 km$^2$. The country has more territorial sea than land. The population is highly concentrated on relatively few islands. Distances between atolls and inhabited islands are great and transport costs are significant.

The economy is mostly service oriented. The scope for agriculture and manufacturing is limited within Maldives. The primary industries are:

- Tourism (70% of GDP)
- Fishing and Fish Processing (10% of GDP)

The country has shown strong Economic Performance over the past two decades with the growth rate on average boing 7% (SARI/EI, no date). The details of the energy consumption in Maldives are given in the figure below

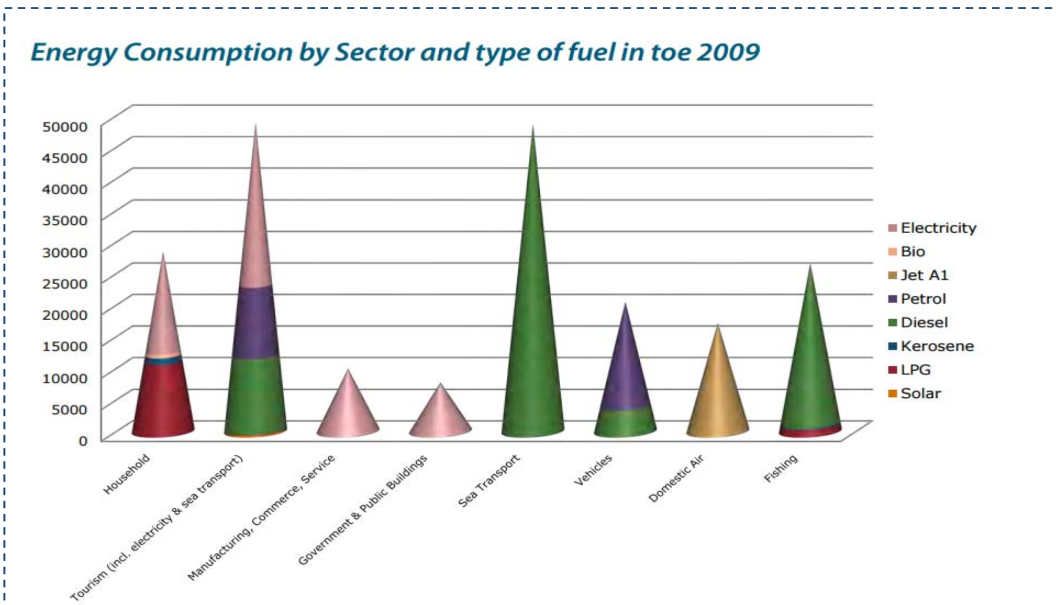



*Figure 4.16 Energy Consumption by sector and type of fuel in toe 2009 (Maldives Ministry of Housing and Environment, 2010)*

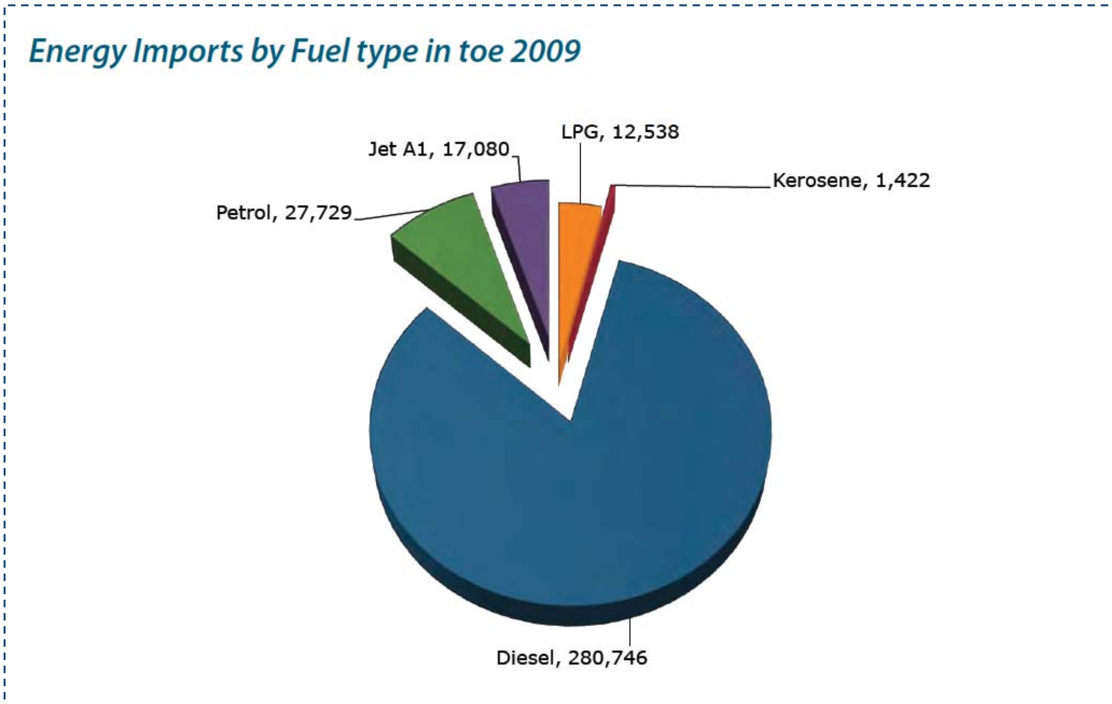



*Figure 4.17 Energy imports by fuel type in toe 2009 (Maldives Ministry of Housing and Environment, 2010)*

The energy needs and Motives are met primarily though import of fossil fuels. Given its unique to graphical situation Maldives does not have access to conventional energy e.g. fossil fuels and hydropower etc. This situation makes energy security a priority for Maldives. It also puts the country at a greater risk and exposure to the market prices in the world energy market.

The unique situation in Maldives makes it a potential area for storage application as it can make a significant impact allowing Maldives to take advantage of the natural resources of renewables and reduce its overall energy import bills.

To assess the potential application areas of Energy Storage within Maldives, the main energy policy aims of the Maldives Government were reviewed. These are as follows:

1. Provide all citizens with access to affordable and reliable supply of electricity
2. Achieve carbon neutrality in the sector by 2020
3. Promote energy conservation and energy efficiency
4. Increase national energy security
5. Promote renewable energy technologies
6. Strengthen the management of the energy sector
7. Adopt appropriate pricing policy for the energy sector
8. Ensure consumer protection
9. Enhance the quality of energy services

The main issues in the energy sector in Maldives which serve as barriers to achieving the energy policy goals of the country include:

- The dependence on fossil fuels as it has no local production sources for Petroleum, gas and oil. Because of the geographical topology hydropower is not possible and diesel required for fuel in the power generators in Maldives is imported. This exposes the country's international market prices as petroleum products now account for over 31% of the imports of the country.
- The legal and regulatory framework within Maldives is still evolving. The government has identified key areas of Focus which include:
    - Widening access of all citizens to clean, affordable and reliable energy
    - Increasing the energy security within the Country
    - Increasing renewable energy production within the country

- The policy aims for the energy policy within the Maldives which are formed by the Ministry of Environment and Energy to achieve some of the aforementioned objectives include:
    - The creation of regional utilities
    - Setting up and developing regulators to regulate the energy sector

  These measures require focused action and multiple facets of the energy sector including technical issues, legal and licensing aspects, regulatory developing and financial frameworks for taking the energy sector forward. Currently, the existing institutions within the country seem to have limited capacity to implement the measures within the energy policy.
- Access to adequate financing remains a problem within the energy sector in Maldives.
- Increasing energy prices on has meant that the Government has had to subsidise the electricity prices for the Citizens. This has subsequently placed substantial financial Burden on the government.
- In terms of Manpower, the electricity system in Maldives has faced issues due to unavailability of appropriately skilled Manpower for the maintenance, operation and management of energy systems
- An assessment done to evaluate the barriers for increasing the penetration of renewable energy in low income countries several other financial barriers were identified for the renewable energy sector. These factors would also be relevant for increasing the penetration of energy storage technologies in Maldives. These include:
    - the absence of a framework; this would include appropriate frameworks and agencies for development, implementation, and monitoring;
    - Insufficient development of standardized instruments which includes tariff schemes
    - Investment risk perceptions reducing available investment

To increase the energy security of Maldives, fuel diversification is being pursued as a priority policy. Due to the nature of the islanded network within Maldives, the fuel imported for electricity generation for the islands in Maldives is stored in the main region of Male' it's neighbouring islands. The transportation costs of fuel to the 190 of the islands of the Maldives, this results in a significant disparity in the cost of electricity and subsequently other consumer goods in the region. This creates potential for energy storage applications to reduce the subsequent cost of energy. This also has potential synergies with the renewable energy potential for the country which has significant solar potential and pilot projects based on distributed solar deployment have started to emerge.

Although the sector has limited sector-level planning, consolidation has happened in recent years two utility companies have been formed which has potential to improve planning. The government is also reported to be developing a medium-term plan for the power sector which includes technology evaluation.

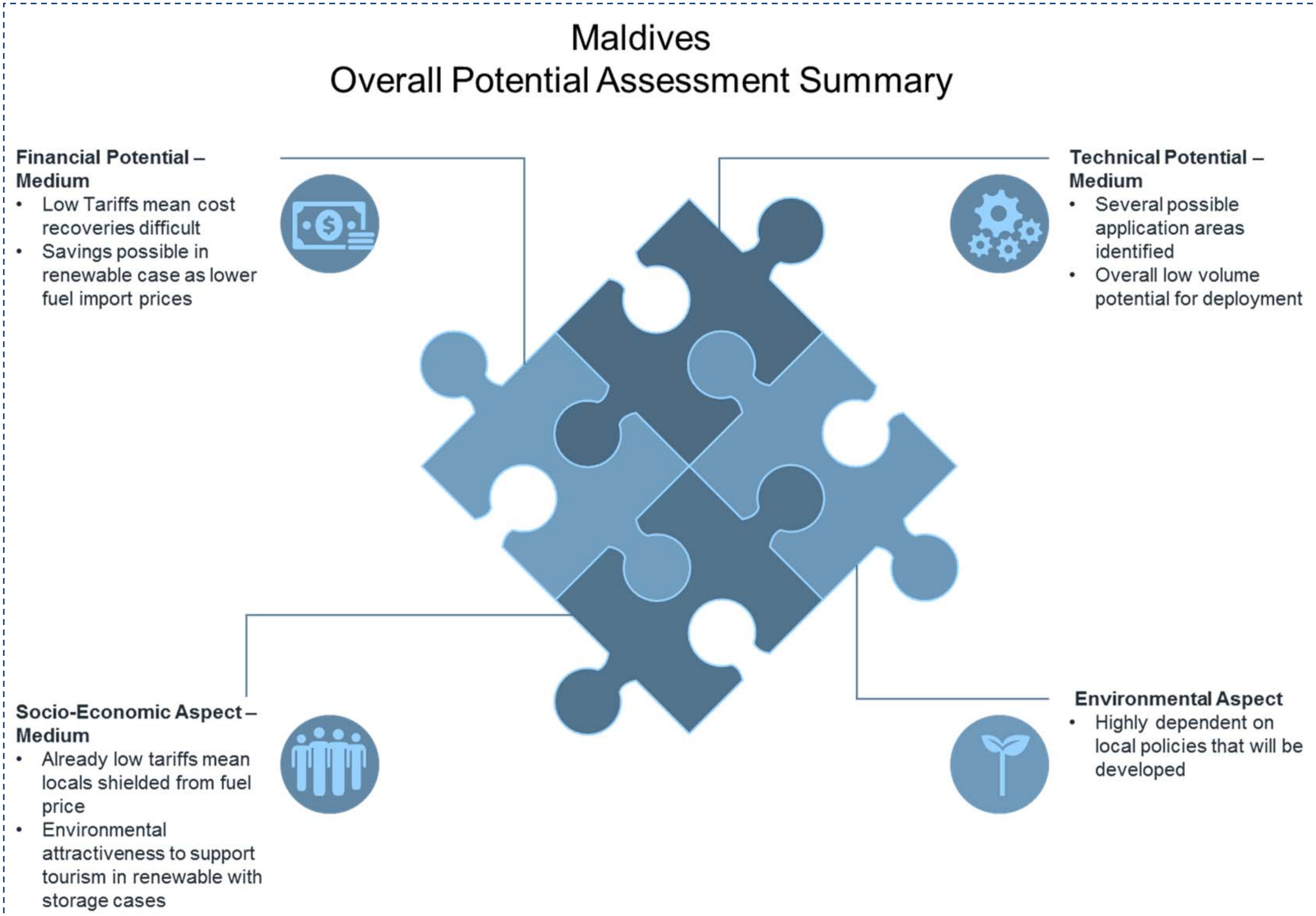
### 4.2.4.2 Maldives - ESTES Potential Evaluation

The sector assessment done for Maldives has been utilized to generate a potential evaluation for ESTES in Maldives which is shown below:

Table 4.7 Maldives evaluation

| Application | Potential | Explanatory Factors |
|---|---|---|
| **Off-to-on peak intermittent shifting and firming** | High | The ability to shift storage patterns combined with potential renewable deployment will prove helpful as it has the ability to lower the fuel usage of Maldives which heavily impacts the economy |
| **On-peak intermittent Energy smoothing and Shaping** | Medium | In the future as renewables resources grow, storage would help smooth the intermittency of the generation |
| **Ancillary service provision** | High | Requirement for frequency regulation in the very small island networks of Maldives would likely be high given lower spinning reserves and inertia in the system<br>This also means that ancillary services such as reserve etc. are likely to be valued highly from a system security perspective as the system has lower capacity to deal with shocks |
| **Black start provision** | Low | Sufficient black start capability expected in the islanded networks in the form of the diesel generation deployed |
| **Transmission Infrastructure** | Medium | Considerable need has been identified for transmission investment – part of this may be offset by storage which allows for peak-shaving |
| **Distribution** | Medium | The same assessment for transmission |

| | | |
|---|---|---|
| **Infrastructure** | | infrastructure in Maldives applies to distribution infrastructure |
| **Transportable Distribution level outage mitigation** | Low | The sector needs other investments before this category is considered |
| **Peak load shifting downstream of distribution system** | Medium | Potential for investment deferral exists in the small islanded networks by shifting load downstream |
| **Intermittent distributed Generation integration** | Medium | Storage with distributed generation has significant potential for Maldives given its explicit policy aims of low carbon development and renewable energy deployment |
| **End-user time of-Use (ToU) rate optimization** | Low | Already low energy tariffs mean low incentive for ToU optimization |
| **Uninterruptible power supply (UPS)** | Medium | UPS support although needed is not projected to be extremely significant as the generation mix yields more towards utilizing generators |
| **Micro grid formation** | High | The islanded nature of the Maldives grid yields particular applications for storage deployment in the grid of Maldives |


Maldives
Overall Potential Assessment Summary
Financial Potential – Medium
• Low Tariffs mean cost recoveries difficult
• Savings possible in renewable case as lower fuel import prices
Technical Potential – Medium
• Several possible application areas identified
• Overall low volume potential for deployment
Socio-Economic Aspect – Medium
• Already low tariffs mean locals shielded from fuel price
• Environmental attractiveness to support tourism in renewable with storage cases
Environmental Aspect
• Highly dependent on local policies that will be developed

### 4.2.4.3 Maldives – Gap Assessment

Based on the sector assessment for Maldives, the gaps for ESTES deployment were assessed and the results are shared in the table below. This is followed up with a figure which maps the discussed underlying factors onto a gap assessment summary chart.

Table 4.8 Maldives gap assessment

| Issue Area | Summary of Explanatory Factors and Trends |
|---|---|
| **Political Will** | • Maldives displays a focus on improving the power sector with reforms (↑) |
| **Policy Framework** | • Clearly defined but very high-level policy (↑)<br>• Policy development underway includes evaluating new technologies (↑) |
| **Institutional Arrangement** | • Institutional capability requires significant improvement with limited evidence of sector level planning (↓)<br>• Utility capacity has been identified to be limited to deploy project based on new technologies (↓)<br>• Commercial contracts capacity underdeveloped (↓)<br>• Limited independence of the regulator (↓) |
| **Infrastructure** | • Infrastructure levels required for supply chain development of ESTES locally e.g. manufacturing etc. are not present to a high degree in Maldives – significant import would be required (↓) |
| **Human Resource and Expertise** | • Lack of expert human resource as an overall sector issue (↓) |
| **Market Conditions** | • Non-liberalized market with fewer incentives available for private sector profitability through energy arbitrage and other revenue making (↓)<br>• Potential for lowering fuel import (↑)<br>• Lack of commercial arrangement and instruments (↓)<br>• High risk perception of investors (↓) |
| **Favourable Development Scenario** | • Given that the volume of ESTES deployment is dependent on the size of the power sector of Maldives, which is relatively small, the score for the future development scenario also remains lower than determined by market factors alone |

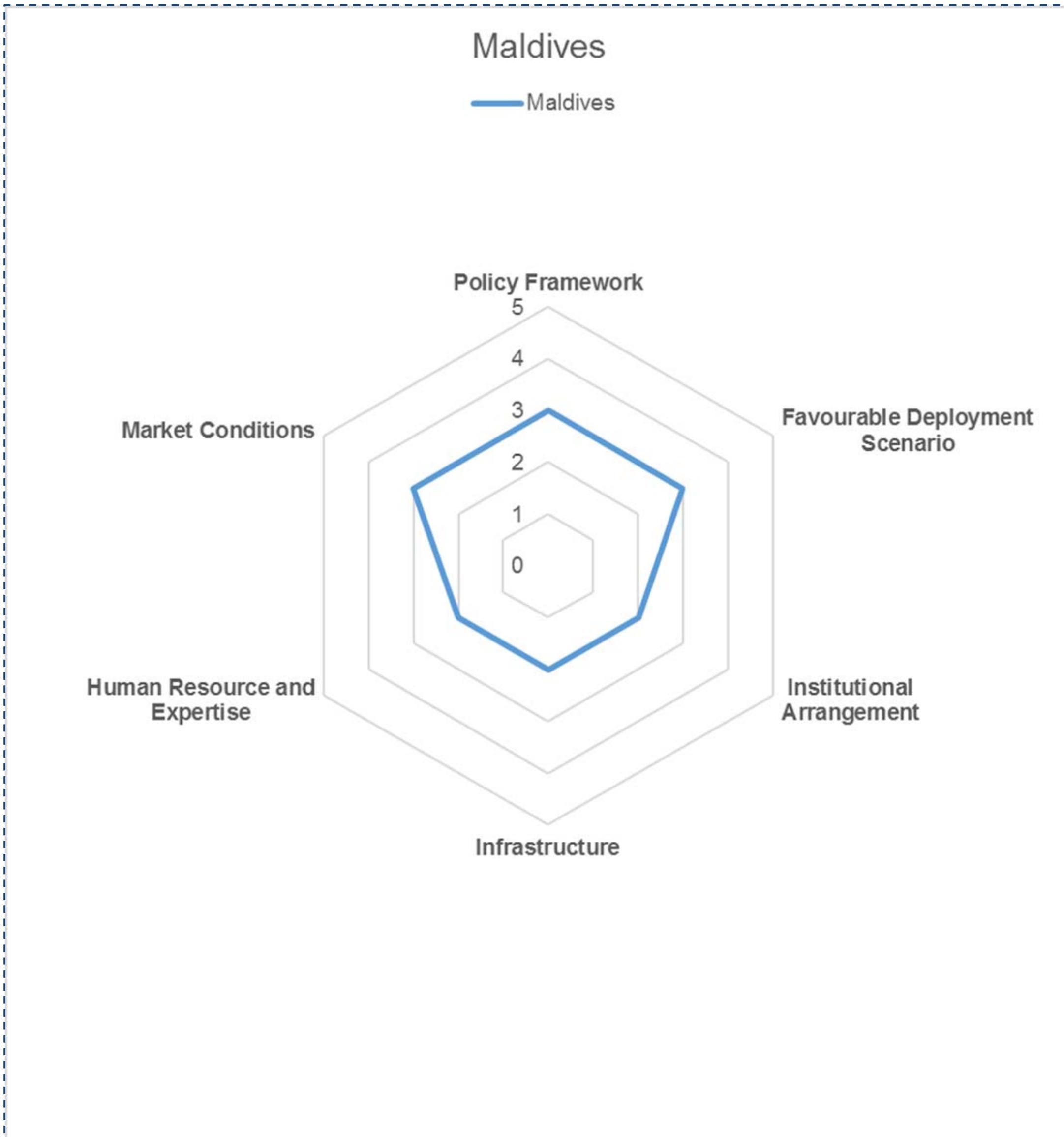



*Figure 4.18 Maldives Assessment Key: 1 (lowest) to 5 (highest)*

### 4.2.5. Nepal

## 4.2.5.1. Nepal – Sector Assessment

The Nepal Electricity System is a relatively smaller system with a peak generation capacity of around 800 MW. Hydroelectric power forms the main cornerstone of the electricity system in Nepal and also forms one of the foundations of the poverty reduction and economic growth strategy of Nepal. However, advances in this sector have been slow to materialize. The power sector is generally negatively affected by lack of investment in generation, transmission and distribution. Project development work has also been affected by the pace of development of the legal and regulatory frameworks within the country. Consequently, Nepal is also a country within and this has had negative implications for the economic growth of the country. (Asian Development Bank, 2013)

The 2014-15 demand figures put the peak load of Nepal's at 1291.1 MW which is significantly higher than the 2015 installed capacity figure even before factoring in load growth. To reduce the country's power shortfall, previous plan in Nepal have envisioned addition of 281 MW in new generation and initiating projects totally 1,743 MW. However, reasons for not being able meet targets have included:

- Inadequate infrastructure, including a lack of roads and transmission capacity
- Failing to restructure the electricity tariffs within the country;
- Local implementation issues

The projected demand for 2020 (dry peak) is indicated around 2200 MW. There is some activity in terms of addition of new generation but it does may not catch up with the growing demand Nepal may be required to import increasing amount of power from neighbouring countries.

In addition to the installed capacity issue, the power deficit problem is exacerbated due to the seasonal nature of the hydroelectric power in the country. During the winter season when the river flows dry up, the power output of the predominantly hydroelectric power system of Nepal falls leaving to seasonal load-shedding of as much as 12 hours in winter. Storage has been playing a role in the hydroelectric sector in the context that close to 14% of the installed capacity in the power sector is 'dam-storage' which essentially allows for storage that can be used in later seasons when water dries up. However, compared to the overall demand of the country and the skew of the sector towards hydropower, this number is quite low. Thermal installed capacity is also quite low in the country with approximately 50 MW of thermal plants in operation and at the moment the diversification through other renewables is also low. However, Nepal does have interconnectors that allow the import of power from India with the import figure reaching around 27% of the annual consumption in 2015-16

Micro-hydels are significant in the Nepal system as shown in the figure that follows. The total deployment stood at 54 MW as of 2015-16.

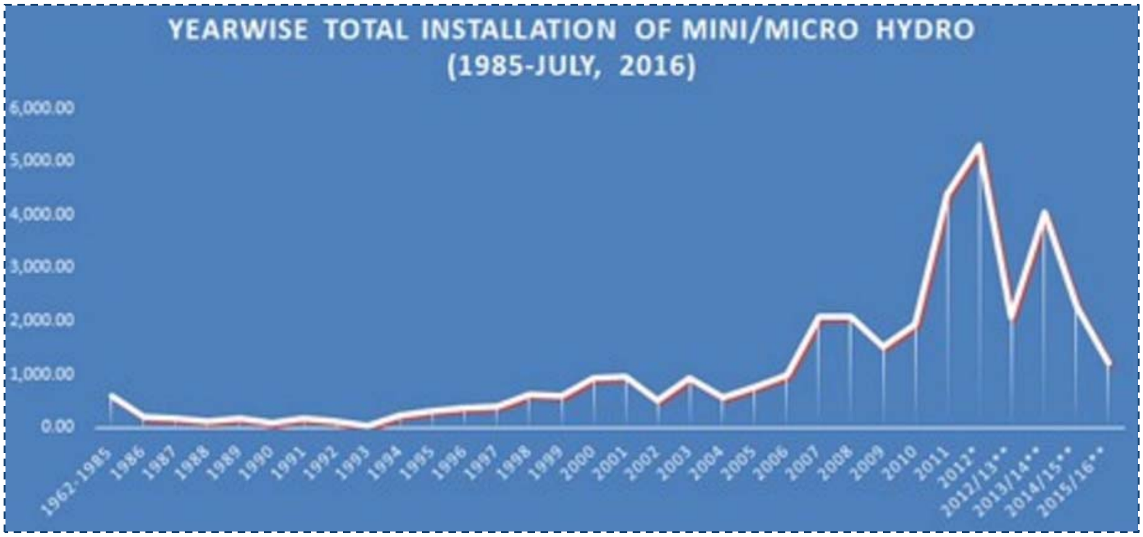



*Figure 4.19 Installation of mini hydro in Nepal*

The study team also found evidence that Nepal is planning a long-term scale-up of its distributed solar deployment with over 100,000 systems planned for long-term deployment.

Apart from the generation sector, the transmission sector is also facing issues with power evacuation proving to be a bottleneck which the actual network expansions lagging considerable behind planned developments. Transmission bottlenecks have also led to dis-incentivising Independent Power Producers. The cross-border interconnection with India is also limited with 2010 numbers suggesting that the interconnection link was limited to 150 MW. However, there have been plans to increase this connectivity to a higher capacity link on 400 kV; the execution of this link has however faced delays. According to the Nepal Energy Authority, the lack of transmission capacity in the country led to over 25 system collapses in 2010.

Going down to the distribution level, domestic consumers who make up about 95% of the customer base, account for about 42% of the energy sale whereas industrial consumers who are only 2.3% of the base, account for about 48% of the sales. Key metrics of the sector as of 2014 are showed that consumption access to electricity remained at a low 62% for the country (Sameer Ratna Shakya, 2015).

The overall T&D losses in Nepal have historically been quite high as shown in the figure that follows:

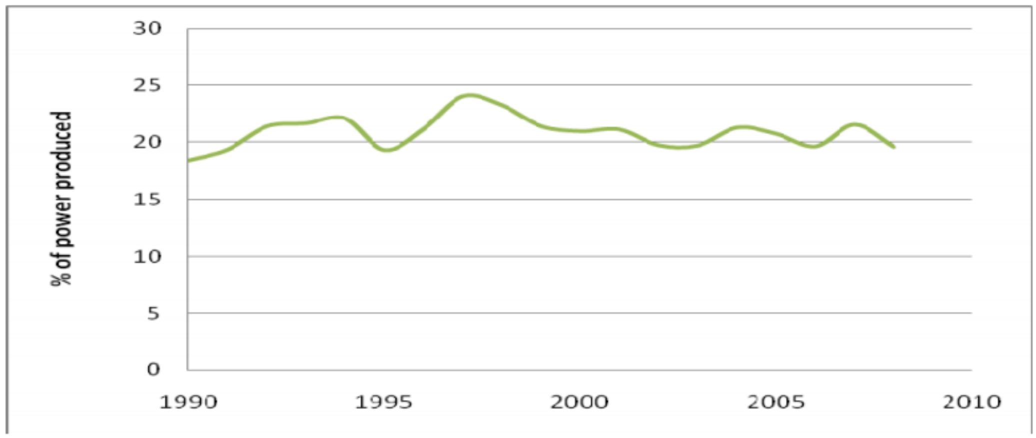



Figure 4.20 Electricity distribution losses (Nepal and Jamasb, 2011)

The losses have been a mixutre of technical as well as non-technical losses. The techinical losses are caused by an aging grid with overall low system reliability and lack of timely grid expansions. However, in recent years, the losses have been declining due to measures such as:

- Monitoring of distribution networks,
- Establishment of loss reduction committees,
- Legal measures taken in support of loss-reduction

It is important to note that previously the prices in the power sector in Nepal had remained supressed due to political interventions to keep energy affordable. This has also resulted in lower financial resources being available to the sector for investing in energy storage.

The Ministry of Energy in Nepal has started a restructuring program for NEA to improve its financial health. The measures taken in this regard include:

- Increasing NEA's share capital
- Writing off accumulated losses
- Other Financial Measures
- Allowing for an increase in the tariff

Together it is expected that these initiatives would improve the financial health of the NEA allowing it to make future investments in the energy sector. These initiatives along with the NEA's objective of attractive private sector investment improve the prospects for energy storage application in Nepal. On the issue of reform, the unbundling of the Nepal Energy

Authority has also been progressing with the national transmission grid company being established in the 2014-15 timeframe.

However key issues in the sector with regards to attracting private investment which would also be relevant to the energy storage sector remain as follows:

- Inconsistent policies,
- Lack of comprehensive planning including development of long-term transmission expansion plans – however regional expertise may allow this to be rectified
- Financial limitations,
- NEA's credit and offtake risks,
- Difficulty in land acquisition (more relevant for pumped storage)
- Right-of-way issues (more relevant for pumped storage)

Source (Sameer Ratna Shakya, 2015)

Source: (Nepal and Jamasb, 2011):

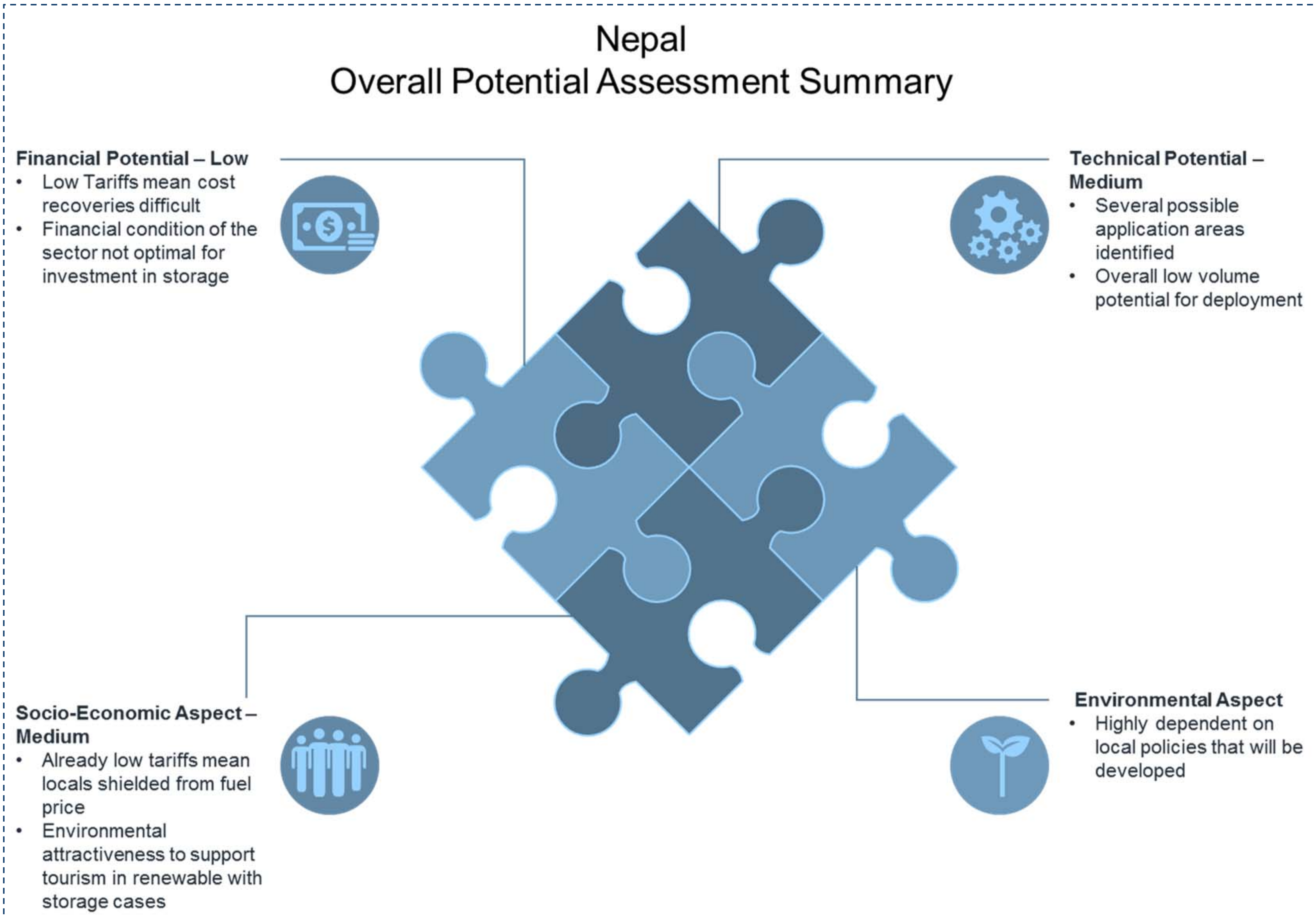
### 4.2.5.2 Nepal - ESTES Potential Evaluation

The sector assessment done for Nepal has been utilized to generate a potential evaluation for ESTES in Nepal which is shown below:

Table 4.9 Nepal evaluation

| Application | Potential | Explanatory Factors |
|---|---|---|
| **Off-to-on peak intermittent shifting and firming** | Medium | The ability to shift storage patterns combined with increased generation deployment will prove helpful as it provides the ability to utilize generation using off-peak times to increase supply during peak times – Potential achievable is limited by the low hydro production in winter |
| **On-peak intermittent Energy smoothing and Shaping** | Medium | In the future as renewables resources grow, storage would help smooth the intermittency of the generation |
| **Ancillary service provision** | High | Requirement for frequency regulation in the smaller network of Nepal would likely be high given lower spinning reserves and inertia in the system |
| **Black start provision** | Low | Sufficient black start capability expected in the networks |
| **Transmission Infrastructure** | High | Considerable need has been identified for transmission investment – part of this may be offset by storage which allows for peak-shaving |
| **Distribution Infrastructure** | Medium | The same assessment for transmission infrastructure in Nepal applies to distribution infrastructure |
| **Transportable Distribution level outage mitigation** | Low | The sector needs other investments before this category is considered |
| **Peak load shifting downstream of distribution system** | High | By shifting peak loads downstream, the delivery capability of the system can be enhanced which can lower bottlenecks of the system |

| | | |
|---|---|---|
| **Intermittent distributed Generation integration** | Medium | Storage with distributed generation has significant potential for Nepal given its renewable potential |
| **End-user time of-Use (ToU) rate optimization** | Low | Already low energy tariffs mean low incentive for ToU optimization |
| **Uninterruptible power supply (UPS)** | Medium | UPS support needed to lower impact of electricity cuts |
| **Micro grid formation** | High | With presence of certain electrified areas, micro-grids with renewable generation can accelerate reliable supply of power |


Nepal
Overall Potential Assessment Summary
Financial Potential – Low
• Low Tariffs mean cost recoveries difficult
• Financial condition of the sector not optimal for investment in storage
Technical Potential – Medium
• Several possible application areas identified
• Overall low volume potential for deployment
Socio-Economic Aspect – Medium
• Already low tariffs mean locals shielded from fuel price
• Environmental attractiveness to support tourism in renewable with storage cases
Environmental Aspect
• Highly dependent on local policies that will be developed

### 4.2.5.3 Nepal – Gap Assessment

Based on the sector assessment for Nepal, the gaps for ESTES deployment were assessed and the results are shared in the table below. This is followed up a figure which maps the discussed underlying factors onto a gap assessment summary chart.

Table 4.10 Nepal gap assessment

| Issue Area | Summary of Explanatory Factors and Trends |
|---|---|
| **Political Will** | • Evidence found suggested focus on political with regards to tariff levels (↓) |
| **Policy Framework** | • Power Sector Policies are currently developing and have been inconsistent historically (↓) |
| **Institutional Arrangement** | • Institutional capability requires significant improvement with limited evidence of sector level planning (↓)<br>• Some recent improvement in terms of developing institutions and legal measures for tacking issues such as electricity loss (↑) |
| **Infrastructure** | • Infrastructure levels required for supply chain development of ESTES locally e.g. manufacturing etc. are not present to a high degree in Maldives – significant import would be required (↓) |
| **Human Resource and Expertise** | • Lack of expert human resource as an overall sector issue (↓) |
| **Market Conditions** | • Non-liberalized market with fewer incentives available for private sector profitability through energy arbitrage and other revenue making (↓)<br>• Lack of commercial arrangement and instruments (↓)<br>• High risk perception of investors due to financial situation of the sector (↓) |
| **Favourable Development Scenario** | • Given political will rises, organizations such as the IFC, World Bank and the ADB can provide significant assistance in development of the sector which will have spill overs for storage technology deployment |

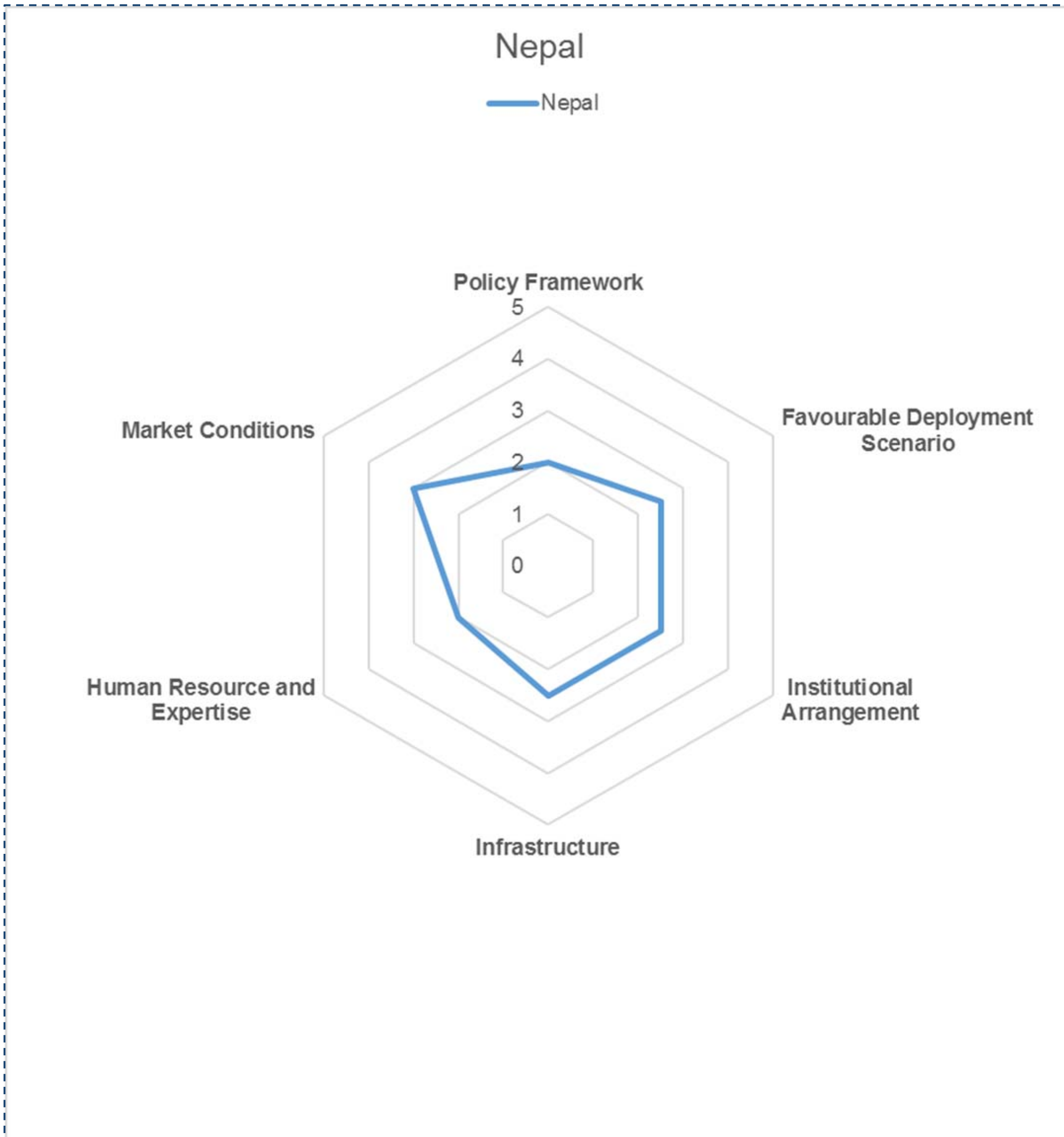



*Figure 4.21 Nepal Assessment Key: 1 (lowest) to 5 (highest)*

### 4.2.6 Pakistan

## 4.2.6.1 Pakistan – Sector Assessment

Pakistan has the second largest electricity demand in the SAARC region which was about 23.5 GW in 2015 against an installed capacity of around 25 GW. However, the country faces frequent power outages with the actual demand that is met being lower than the 23.5 GW figure.

The power sector of Pakistan underwent a restructuring in 1998 where WAPDA, a vertically bundled utility was unbundled into Generating Companies (GENCOS), a Transmission Network Operator called the National Transmission and Despatch Company (NTDC) and 10 distribution companies (DISCOs) covering the different geographical regions of the country. The structure of the sector has been summarized below.

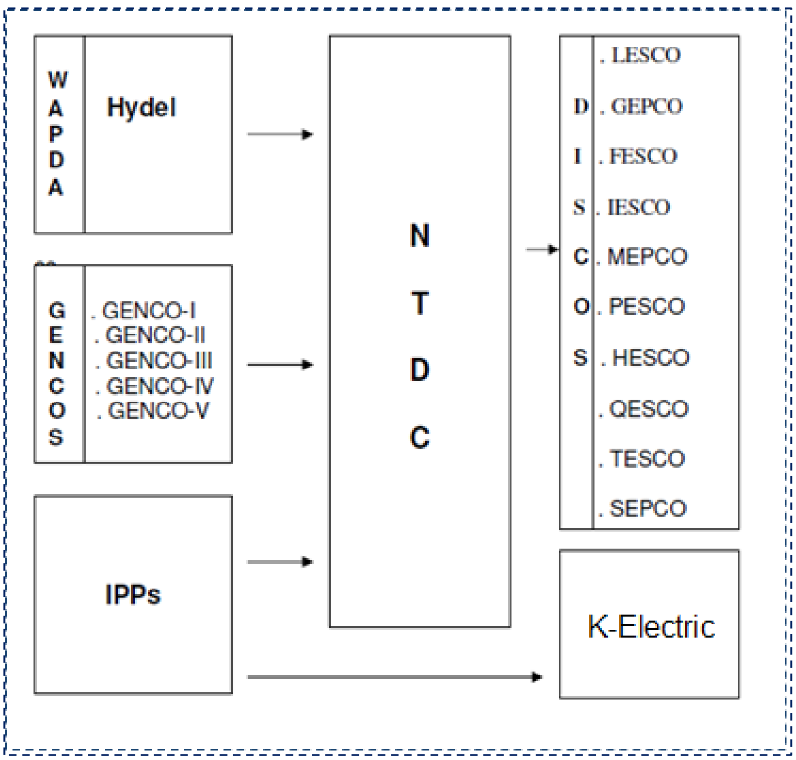



*Figure 4.22 Pakistan - Sector structure summary*

The generation mix of the country which was originally predominantly hydro has been shifting across the years to a point where it become dominated by thermal plants which are a mix of GENCOs and independent power producers (IPPs). In recent years, a number of alternative renewable energy plants based on wind and solar have also been added to the system. The generation mix of the country as of June 2015 is shown in the figure that follows:

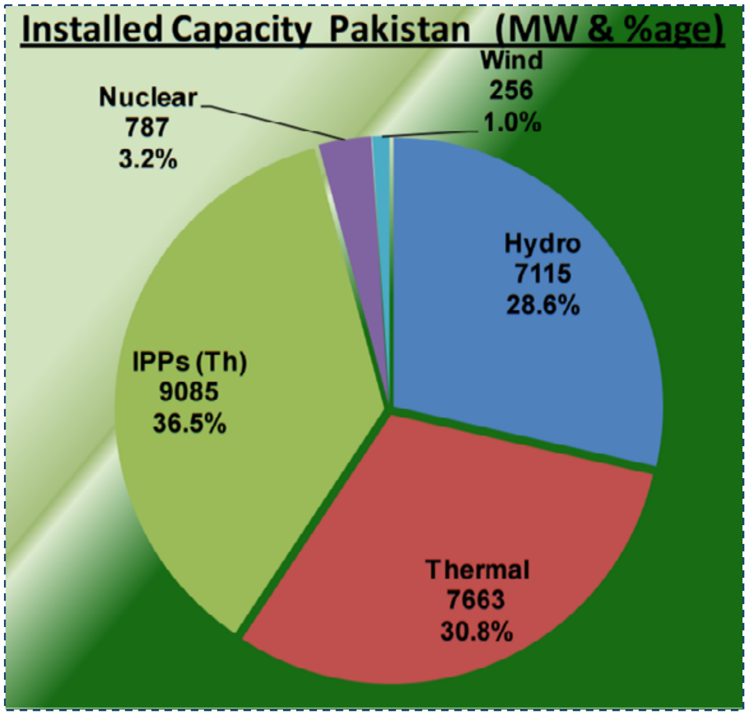



*Figure 4.23 Installed Capacity Pakistan (NTDC, 2015)*

The change in the power system of Pakistan has not only been in the energy mix but also in the composition of the consumption economic groups which has seen a rapid increase in the proportion of electricity that is consumed by the domestic sector as shown in the figure below:

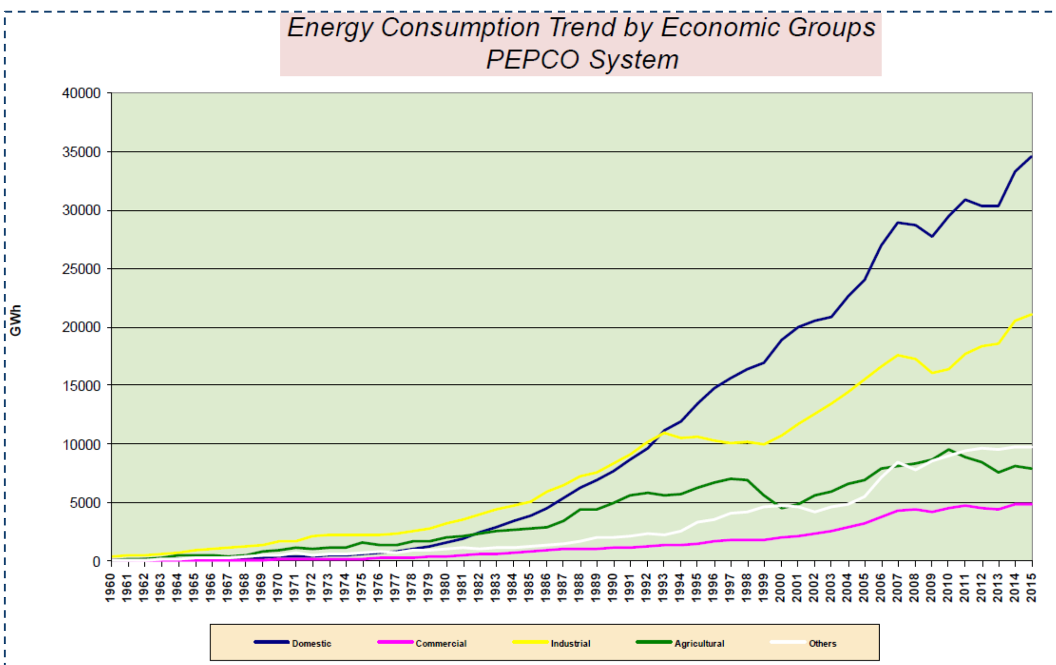



*Figure 4.24 Energy consumption trend by economic groups (NTDC, 2015)*

In recent years, Pakistan's power sector has been affected significantly by power shortages which have had severe economic impact including reducing the GDP growth by at least 2% per year. This has also lead to a decrease in the growth of the industrial and manufacturing sector. The power shortages in the country have led the domestic sector to increasingly rely on battery based UPS systems, and in more affluent cases back-up generators, to reduce the impact of the load-shedding on a domestic level. Apart of the planned load-shedding, it is also noted that in the recent past there have been cases of Pakistan of country-wide power outages caused by large scale generation tipping. This could potentially have been caused due to insufficient flexibility in the system due to lack of reserves that could have led to insufficient frequency support if generating units had tripped and load-shedding had not been fast enough.

Although power tariffs in Pakistan have increase over 150% in the 5 years before 2013, the money generated by these tariffs has been unable to keep up with the increased cost of the fuel import bill in those years. The power sector also had subsidies for the consumers that equalled about 1.8% of the GDP in 2013. The subsidies reduced the ability of the government to spend on other areas which included social welfare (Asian Development Bank, 2014d).

The sector's distribution losses stood at about 23% in 2012 which is estimated to be a combination of both technical and non-technical losses. The recoveries were below 90% levels. World Bank data puts the electrification rate in Pakistan to be significantly high at 93.6% as of 2012. It is understood that which these losses and recoveries represent a country level analysis, within the country, at a more granular DISCO level, the numbers may be better in some DISCOs and significantly worse in others.

The case of the rising fuel prices and the subsidies combined with the power losses in the sector along with under-recovery were some of the factors that resulted in Pakistan piling up a very significant circular debt. The issue has also been affected by the delay in tariff determination and application of the tariff as well as delays in making payment of the subsidies. The circular debt issue then subsequently in the following:

- Substantial payment arrears
- Lack of funds for maintenance and improvement of equipment
- Reduction in the working capital available to power sector entities
- Increase credit risk of the sector

Over the previous few years, the fuel prices have been coming down and the level of the tariff differential subsidy is also reducing and came down to 1.15% of the GDP in 2014 (Asian Development Bank, 2015c). However, the underlying issues have remained.

The overall regulatory regime in the country has also been improving over the years. Potentially positive steps have included the formation of a Central Power Purchasing Agency (CPPA) by carving it out of the domain of NTDC. The CPPA is also tasked with the development of competitive market within the country. Furthermore, there have been reports of plans for privatization of certain DISCOs and GENCOs. However, it is noted that these privatizations have yet to materialize.

Significant power sector issues are listed out as follows:

- Need for increased transparency within the sector
- Generation mix skew
- Insufficient independence of public sector power companies, DISCOs, GENCOs and the regulator
- Overall cost recovery regime in the sector impacting the financial health of the sector
- High losses which could mean underlying theft issues in certain areas
- Lack of consistent policies in the sector over time

Renewable energy in Pakistan has been taking off since the late 2000s with the deployment of several wind power plants and the establishment of Alternative Energy Development Board (AEDB) in 2003. The Grid Code was also amended to add two Addendum each for integration of Wind and Solar power into the grid in 2010 and 2012 respectively. Ministry of Energy and respective Power Development Boards have been established in the province of Punjab and Sindh who are promoting renewable energy by issuing LOIs to serious developers of RE Projects. Estimates show significant wind potential in the southern coastal wind corridor in Pakistan where deployment of plants such as Fauji Fertilizer has been done. Latest figures are 6 power plants already online i.e. FFC (50 MW), Zorlu (56 MW), TGF (50 MW), Sapphire (50 MW), FWEL-1 and FWEL-2 (2x50 MW). Nearly 6 more WPPs are under commissioning stage and would be online in next 3 to 4 months. Pakistan similarly has a strong solar profile in several regions of the country. The solar deployment at large scale has been through grid-connected projects rather than distributed generation. 4x100 MW Solar PPs are already in operation at Quaid-e-Azam Solar Park, Cholistan. Another 600 MW is in pipeline to be installed at the same location. The potential of wind and solar is shown in the figure below:

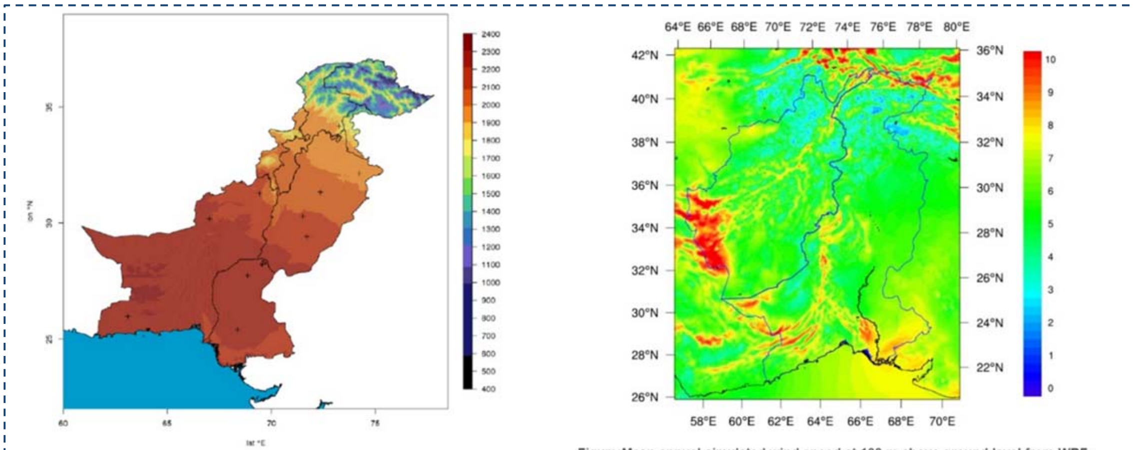


Figure: Multi-year mean (2000-2012) of annual Global Horizontal Irradiance (GHI) for Pakistan in kWh/m²

Figure:Mean annual simulated wind speed at 100 m above ground level from WRF 2001 to 2010 inclusive. The colour scale indicates wind speed in m/sec.

*Figure 4.25 Wind and solar potential (AEDB)*

Currently, the amount of wind and solar that can be added to the grid is restricted to a conservative percentage of the overall grid output. Within Pakistan, hybrid models by adding solar panels in wind farms in Jhimpir and Gharo areas are being explored. Some of the sponsors of wind farms have already started to work on this model and NEPRA is considering how to handle the tariff issues in this hybrid model. A detailed study for NTDC have been conducted by an international consultant GOPA under USAID funding to determine the safe proportion of RE that Pakistan's Grid can absorb considering:

- Technical aspects in terms of grid stability
- Operational aspects in terms of dispatch and control
- Economic factors as to how the higher tariffs of RE would affect the overall basket price at consumer end

The Grid Code addendum on Wind and Solar power penetration are being updated considering penalties on RE plants if the deviation goes beyond a certain percentage of the forecasted output of the plant.

Pakistan also has considerable hydro-power potential with nearly 60 GW of potential of which several large hydro-power plants are being planned in the north of the country. It is however noted that historically, hydropower development in the country has lagged behind stated plans.

On the technology and engineering side of the sector, Pakistan has a number to well established academic institutes that have the capacity to work on adapting any potential energy storage technologies to local conditions. Furthermore, in terms of the engineering work-force, the country is likely to have significant trained personnel in the power sector to work on conventional applications. Collaboration with international entities can help the country to fill the existing gaps to enable work on innovative technology deployment.

### 4.2.6.2 Pakistan - ESTES Potential Evaluation

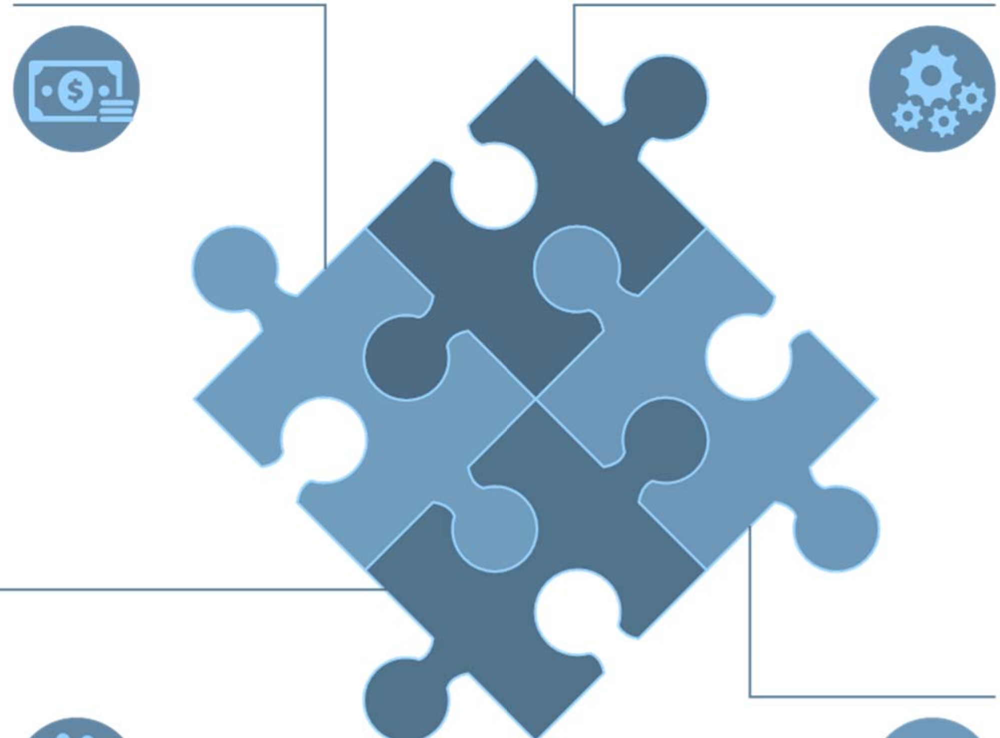
The sector assessment done for Pakistan has been utilized to generate a potential evaluation for ESTES in Pakistan which is shown below:

Table 4.11 Pakistan evaluation

| Application | Potential | Explanatory Factors |
|---|---|---|
| **Off-to-on peak intermittent shifting and firming** | Medium | The ability to shift storage patterns combined with potential renewable deployment will prove helpful as lack of reserves in the system means storage can be utilized to store excess energy from solar power plants at day or wind during night and re-supply to the grid during peak times. This is limited by the quantity of renewables that will eventually be deployed |
| **On-peak intermittent Energy smoothing and Shaping** | Medium | The ability to shift storage patterns combined with potential renewable deployment will prove helpful as lack of reserves in the system means storage can assist in lowering the impact of renewable intermittency |
| **Ancillary service provision** | High | In case of insufficient reserves in the system, storage based systems can provide temporary frequency support during a large-unit trip giving enough time for load-shedding to be done and add to system security. This can provide protection from system wide blackouts for which media evidence was found |
| **Black start provision** | Low | Sufficient black start capability expected in the network with generation being distributed across the different regions of the country |
| **Transmission Infrastructure** | Medium | Considerable need has been identified for transmission investment – part of this may be offset by storage which allows for peak-shaving |
| **Distribution** | High | The study team assessment suggests that the |

| | | |
|---|---|---|
| **Infrastructure** | | distribution infrastructure in Pakistan is significantly overloaded – utilizing storage to shift load between peak and off-peak times can increase utilization |
| **Transportable Distribution level outage mitigation** | Low | The sector needs other investments before this category is considered |
| **Peak load shifting downstream of distribution system** | High | System capacity can be enhanced if peak loads can be shifted downstream and saved off using storage during peak times |
| **Intermittent distributed Generation integration** | Low | Storage with distributed generation has shown slow pick-up in Pakistan although recent Grid Code developments seem supportive |
| **End-user time of-Use (ToU) rate optimization** | Low | Already low energy tariffs mean low incentive for ToU optimization |
| **Uninterruptible power supply (UPS)** | High | High level of power outages suggests that UPS support is needed by most households in the country |
| **Micro grid formation** | Low | Relatively high level of electrification in the country suggests the micro-girds would only be necessary in the few distant areas without electricity |

# Pakistan
## Overall Potential Assessment Summary



**Financial Potential – Medium**
- Low Tariffs mean cost recoveries difficult
- Lack of route-to-market for ancillary services
- Investor risk perception improving

**Technical Potential – Very High**
- Several possible application areas identified
- Capability exists to deploy storage

**Socio-Economic Aspect – Medium**
- Development of local storage industry possible
- Synergies possible with other sectors
- UPS based storage significantly improves lives

**Environmental Aspect**
- Highly dependent on local policies that will be developed
- Although environmental assessments are done, the team was unable to verify to their adherence

### 4.2.6.3 Pakistan – Gap Assessment

Based on the sector assessment for Pakistan, the gaps for ESTES deployment were assessed and the results are shared in the table below. This is followed up a figure which maps the discussed underlying factors onto a gap assessment summary chart.

Table 4.12 Pakistan gap assessment

| Issue Area | Summary of Explanatory Factors and Trends |
|---|---|
| **Political Will** | • Rectification of power sector problems have been identified as crucial politically – hence high level of political will is expected to be present (↑) |
| **Policy Framework** | • Historical evidence of frequent policy changes linked to government changes lead in sector wide uncertainty (↓) |
| **Institutional Arrangement** | • Although Transmission Utility capacity and capability is well developed in some areas, capacity is much more reduced at a distribution company level<br>• Commercial contracts capacity underdeveloped (↓)<br>• Increasing independence of the regulator needed (↓)<br>• Formation of new CPPA agency step in strengthening institutions (↑) |
| **Infrastructure** | • Infrastructure levels required for supply chain development of ESTES. can be developed with relative ease in Pakistan (↑) |
| **Human Resource and Expertise** | • Although in some areas sector level specialists are missing but on the whole, the country has good human resource potential with quality academic institutions and research capabilities compared to peers (↑) |
| **Market Conditions** | • Non-liberalized market with fewer incentives available for private sector profitability through energy arbitrage and other revenue making (↓)<br>• Lack of commercial arrangement and instruments (↓)<br>• High risk perception of investors (↓)<br>• Very high need for some areas such as UPS deployment (↑) |
| **Favourable Development Scenario** | • Depends on the level of institutional and policy reform that can be achieved by the sector however, the country has good potential for storage deployment. The current needs however are likely to be focused on enhancing generation capability |

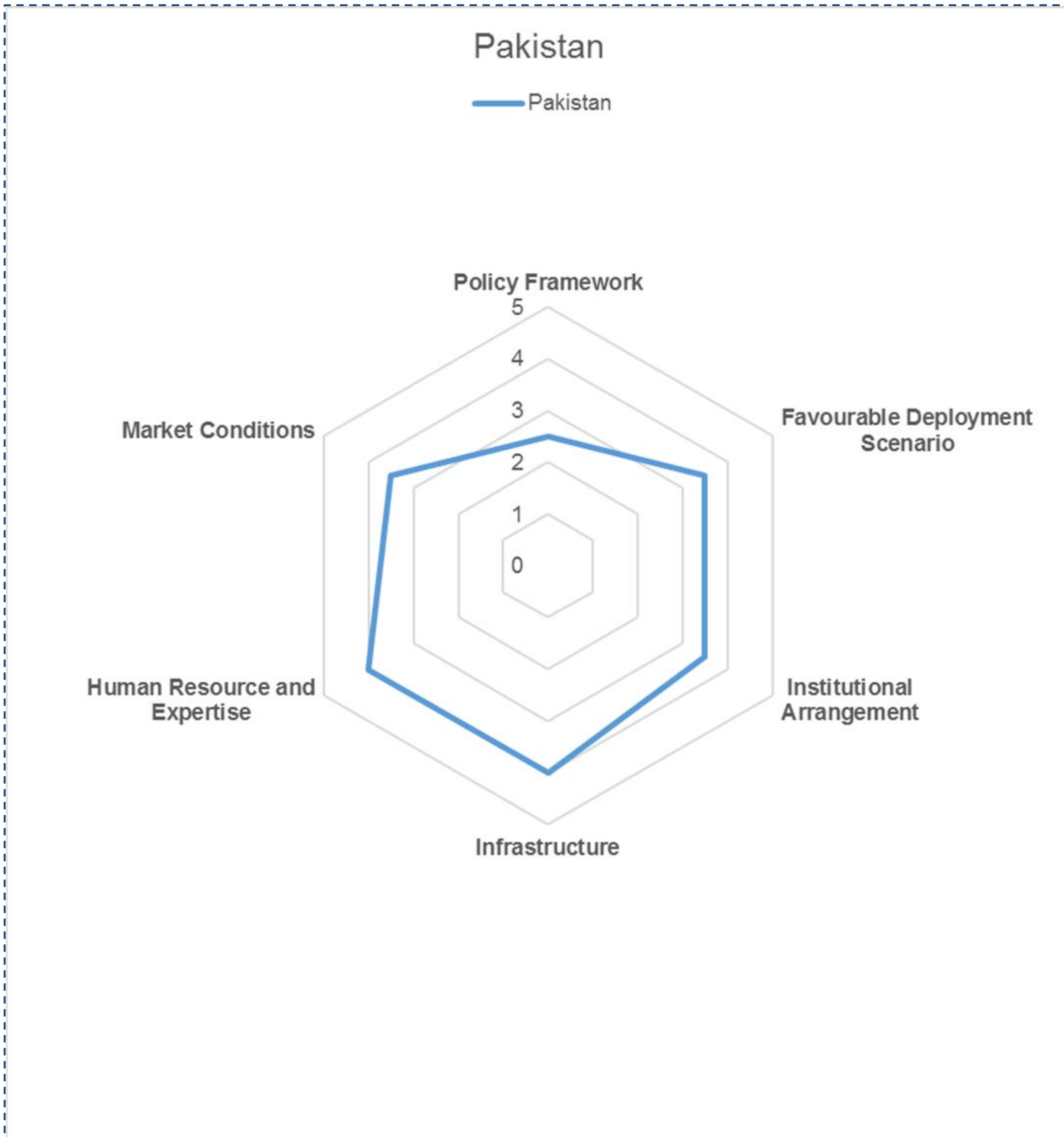



*Figure 4.26 Pakistan Assessment Key: 1 (lowest) to 5 (highest)*

### 4.2.7 Sri Lanka

### 4.2.7.1 Sri Lanka – Sector Assessment

With the growth of the economy in Sri Lanka, electricity consumption has been increasing at a rate of 4.3% during the 2000-2014 period. Sri Lanka is one of the countries in the SAARC Region in which the supply of electricity exceeds the demand and the country has been successful in meeting domestic electricity need. Over the past decade, the growth in installed capacity has been greater than the growth in the demand. The electrification of the country has also been to a greater extent than most of the other South Asian peers and as of 2014, stood at a very significant 98%. The evolution of the installed capacity compared to the demand of the network is shown in the figure below:

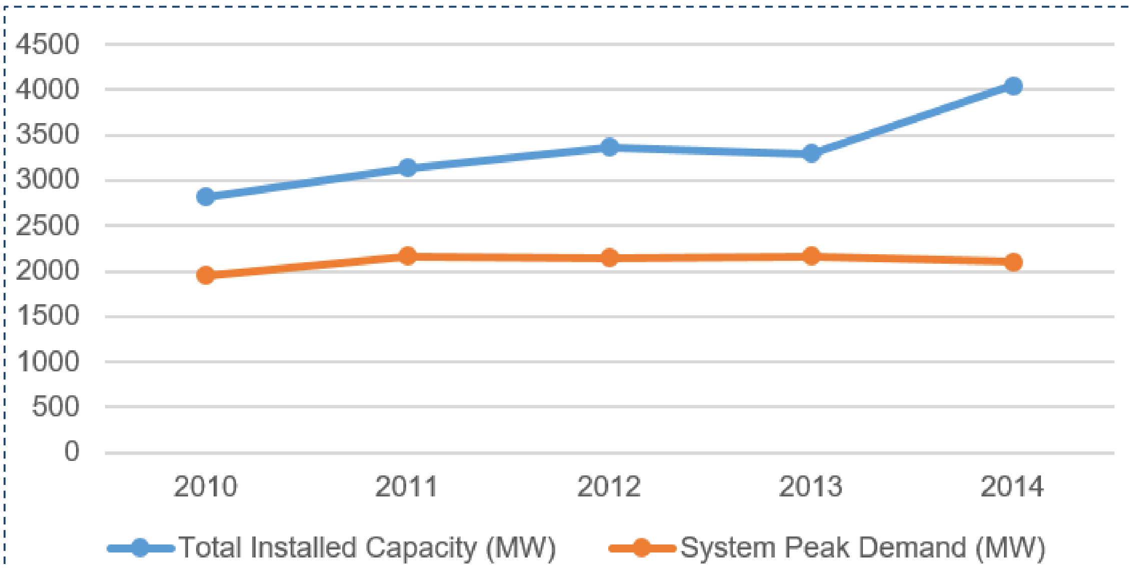



*Figure 4.27 Installed capacity and demand evolution Sri Lanka (Sri Lanka Sustainable Energy Authority, 2015)*

The energy mix of the country has changed over the years; in the early 2000s the share of thermal power was on an increasing trend with smaller oil-based plants being added based on private investment which was quicker than the slower base-load plants (Asian Development Bank, 2015d). However, in recent years, renewable generation has increased and base load plants in the form of coal has been added. As of 2015, the energy mix for the electricity sector was as follows:

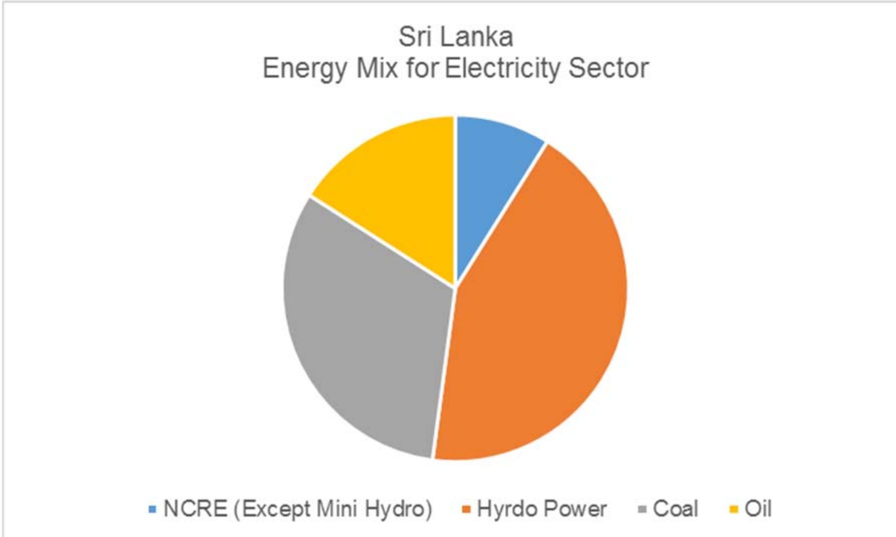


*Figure 4.28 Sri Lanka Energy Mix.(CEB, 2014)*

Despite the decrease in generation costs due to additional of base-load coal power and retiring of expensive oil-fired power plants over the last 3 years, tariffs is Sri Lanka, like several other SAARC Member States, do not properly reflect the true cost of the electricity service that is provided. The figure bellows shows how the level of difference between the costs and the tariffs has been rising which has potential impacts on the power sector financial stability.

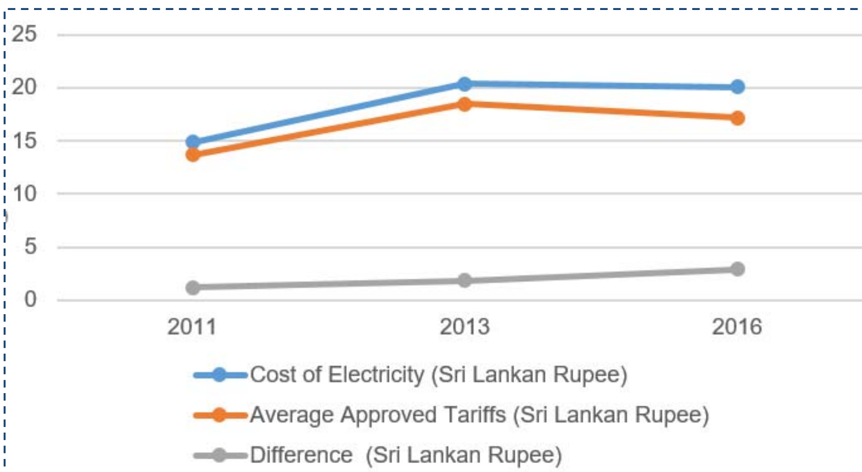


*Figure 4.29 Analysis of tariffs (Asian Development Bank, 2015d)*

Due to the insufficient cost recovery mechanisms through the tariffs, the power sector entities in the country have limited ability to generate new investments in generation, transmission and distribution elements of the power sector. In both the low-voltage and medium-voltage networks of the country, continued underinvestment has resulted in

The need for demand side management is very significant in Sri Lanka with nearly 40% difference between the peak and off-peak demands of the country, which provide a potential for electricity storage to bridge this gap and level off the peak.

The level of transmission and distribution losses of the country has also been on a general downward trajectory and is lower compared to some of the peer countries in the SAARC Region. The development of the T&D loss profile over time is shared in the figure the follows:

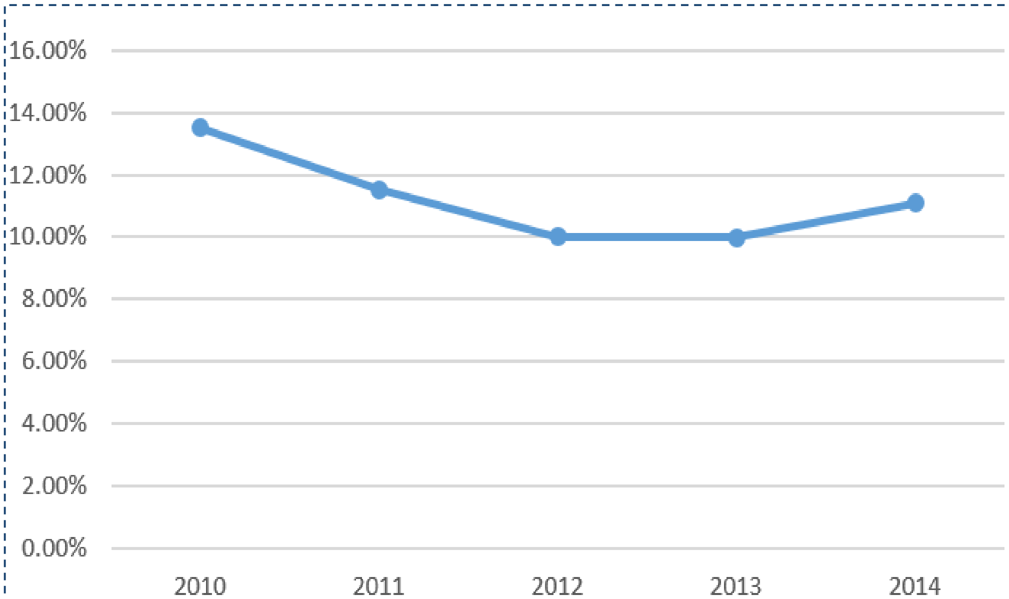



*Figure 4.30 T&D Loss (Sri Lanka Sustainable Energy Authority, 2015)*

The major underlying issues in the power sector of Sri Lanka are found to be as follows:

- Cost of generation being higher than the recovery though tariffs
- Decreased reliability of supply
- Increasing debt of the Ceylon Electricity board which increases credit risk for private sector investments and has reduced infrastructure investment capability

Progress on regulatory measures that would cover areas such as commercial and technical quality, continued development of grid codes and performance standards for the power sector has been slow. Although tariff reform in the country has progressed through fuel adjustment charging being done, these efforts need to be sustained to improve the economic regulation of the sector.

On the policy and institutional development side, the government formed the Sustainable Energy Authority in 2007 tasked with planning and policy for the energy sector and the entity has been playing a significant role in providing institutional frameworks for the development of the sector especially with regards to renewable energy.

Corporate reform of the Public Utilities Commission of Sri Lanka has also been slow and targets have been missed in recent years; however, the path of the reform appears to be heading in the correct direction.

Sri Lanka is also one of the few SAARC countries that has exhibited an active interest in storage. Very recently in August 2016, Sri Lanka hosted what was marketed as its first major international solar energy, storage & grid technology exhibition and conference. From a policy perspective, Sri Lanka is planning to have up to 20% penetration of renewable energy by 2020 and has a very ambitious long term plan to increase this to a 100%. The figure below shows the renewable potential within the country.

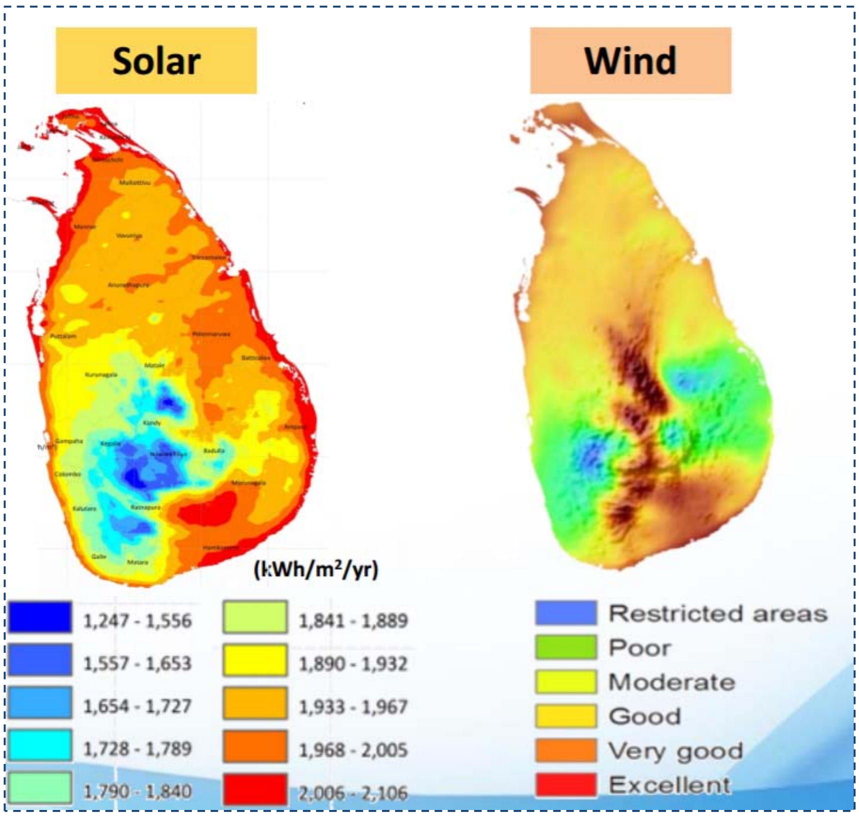



*Figure 4.31 Wind and solar potential (Jayasekera, 2015)*

### 4.2.7.2 Sri Lanka - ESTES Potential Evaluation

The sector assessment done for Sri Lanka has been utilized to generate a potential evaluation for ESTES in Sri Lanka which is shown below:

Table 4.13 Sri Lanka evaluation

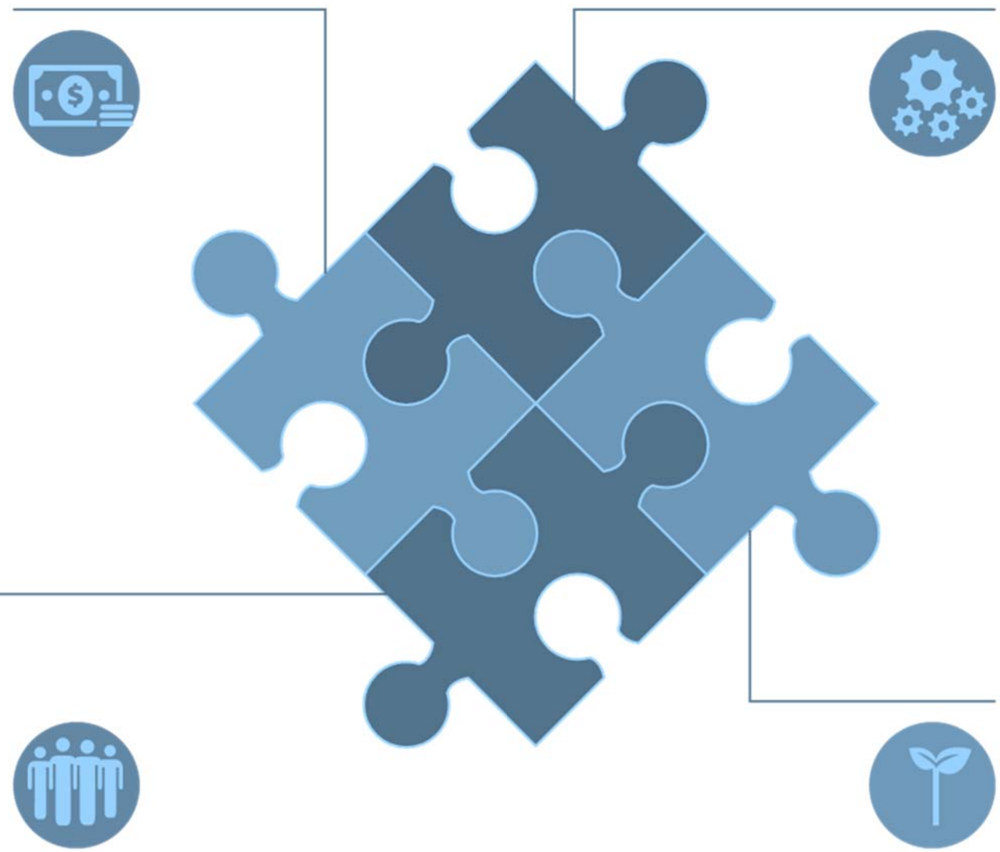
| Application | Potential | Explanatory Factors |
|---|---|---|
| **Off-to-on peak intermittent shifting and firming** | High | 40% difference between peak and off peak consumption patterns makes this a high potential application as there is sufficient generation available during off-peak times to be able to charge storage |
| **On-peak intermittent Energy smoothing and Shaping** | Low | Sufficient generation in the system available for this to be graded low |
| **Ancillary service provision** | Medium | Currently low penetration of renewables with good generation reserve. In the future as renewables grow, this may grow as well |
| **Black start provision** | Low | Sufficient black start capability expected in the network |
| **Transmission Infrastructure** | High | Transmission infrastructure has been identified to be stressed due high peak-to-off-peak load differences coupled with historic underinvestment in infrastructure. Using storage can defer infrastructure requirements |
| **Distribution Infrastructure** | High | The same assessment for transmission infrastructure in Sri Lanka applies to distribution infrastructure |
| **Transportable Distribution level outage mitigation** | Low | The sector needs other investments before this category is considered |
| **Peak load shifting downstream of distribution system** | High | 40% difference between peak and off peak consumption patterns makes this a high potential application |
| **Intermittent distributed Generation integration** | Medium | Storage with distributed generation has significant potential for Sri Lanka given its explicit policy aims of high renewable energy |

| | | |
|---|---|---|
| | | deployment in the future |
| **End-user time of-Use (ToU) rate optimization** | High | Recent ToU approved tariffs mean high cost of electricity during peak times which is 4 times as expensive as during peak times. This creates financial incentive for storage |
| **Uninterruptible power supply (UPS)** | Low | Sufficient generation in system - however low grid reliability means that sometimes UPS are needed |
| **Micro grid formation** | Low | Very high degree of electrification (98%) in Sri Lanka means that there is limited rationale to deploy micro-grids |

# Sri Lanka
# Overall Potential Assessment Summary

**Financial Potential – Medium**
- Low Tariffs mean cost recoveries difficult
- ToU regime makes consumer level storage very attractive

**Technical Potential – Very High**
- Several possible application areas identified
- Excess generation means that storage has very high potential



**Socio-Economic Aspect – Medium**
- Already low tariffs mean locals shielded from fuel price
- Environmental attractiveness to support tourism in renewable with storage cases

**Environmental Aspect**
- Highly dependent on local policies that will be developed

### 4.2.7.3 Sri Lanka – Gap Assessment

Based on the sector assessment, the gaps for ESTES deployment were assessed and the results are shared in the table below. This is followed up a figure which maps the discussed underlying factors onto a gap assessment summary chart.

Table 4.14 Sri Lanka gap assessment

| Issue Area | Summary of Explanatory Factors and Trends |
|---|---|
| **Political Will** | • Although political will is hard to assess but the overall direction of the power sector in Sri Lanka shows that there is political will to rectify the sector situation (↑) |
| **Policy Framework** | • Clearly defined but very high-level policy (↑)<br>• Overall the policies of the power sector have been identified as adequately forward looking (↑) |
| **Institutional Arrangement** | • Institutional capability require improvement especially on technical and commercial frameworks (↓) |
| **Infrastructure** | • Infrastructure levels required for supply chain development of ESTES locally e.g. manufacturing etc. are not present to a high degree in Sri Lanka – significant import would be required (↓) |
| **Human Resource and Expertise** | • The human resource within the sector and expertise can be regarded as relatively better compared to several other South Asian peers (↑) |
| **Market Conditions** | • Non-liberalized market with fewer incentives available for private sector profitability through energy arbitrage and other revenue making (↓)<br>• ToU regime makes it possible to<br>• Potential for lowering fuel import (↑)<br>• Lack of commercial arrangement and instruments (↓)<br>• High risk perception of investors (↓) |
| **Future Development Scenario** | • Given that the volume of ESTES deployment can be positively co-related with renewable energy deployment due to |

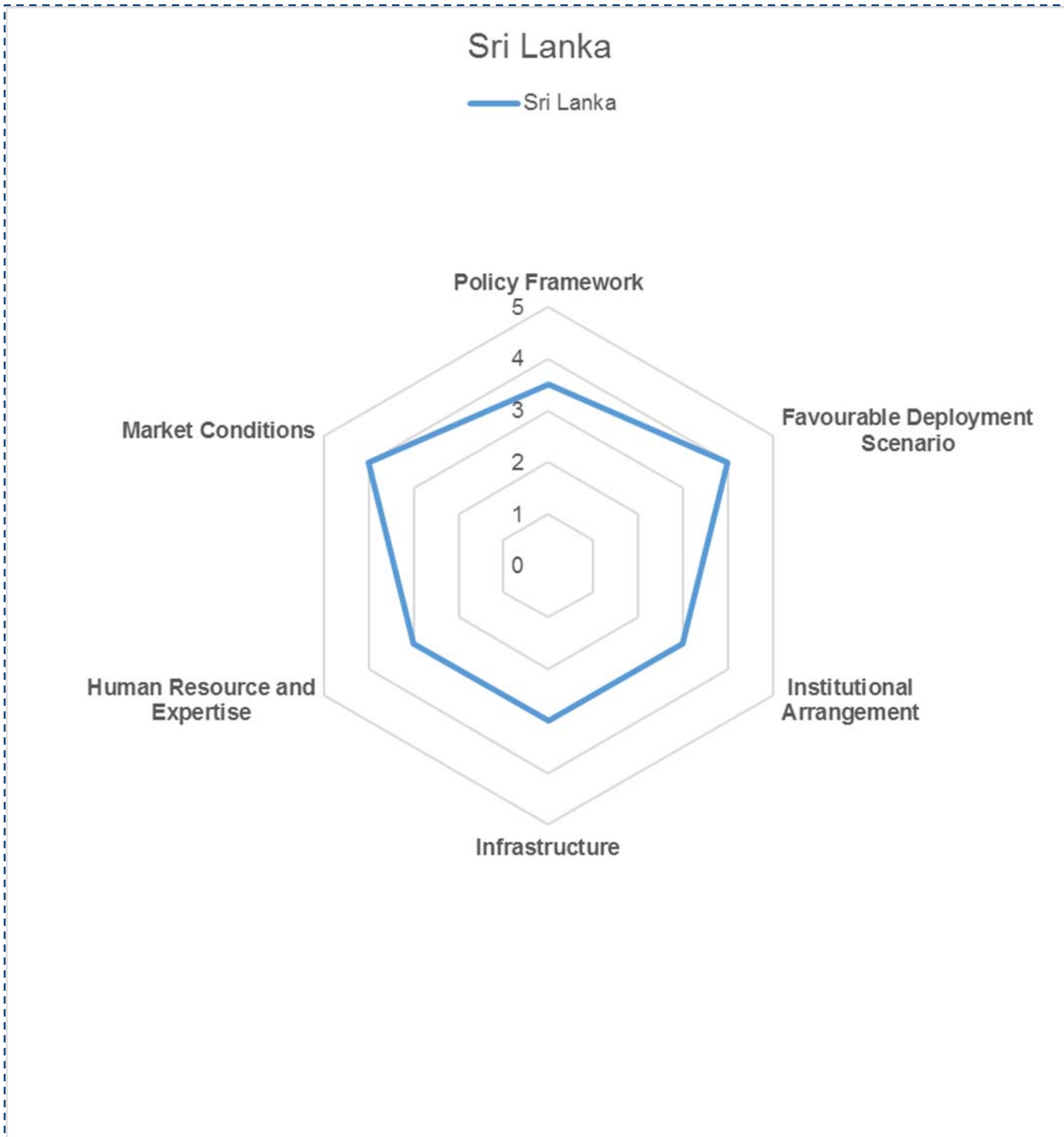



*Figure 4.32 Sri Lanka Assessment Key: 1 (lowest) to 5 (highest)*

## 4.3 Other Considerations of Gaps in the SAARC Region

### 4.3.1 Cost Based Barriers – Cost vs. Benefit Valuation

One of the biggest barriers in the adoption of Energy Storage Systems in the SAARC Region will be the cost factor of these systems and the overall attractiveness of these systems from a cost-benefit analysis. Internationally, the costs of the storage components of these systems has been decreasing however, ultimately, the value that these systems can offer will be dependent on factors such as

- the value that individual countries place on the flexibility of their power systems
- the degree of interconnection between the power systems
- the amount of renewable penetration in the system
- The number of services that storage systems can participate on and the extent to which this participation and the offerings for storage based services are stackable.

### 4.3.2 Issues of How the Power System is Viewed – Acceptance

Storage technologies are new technologies which come with their own requirements in terms of what would be required by system operators. i.e. the Transmission System Operators (TSOs) and the Distribution Network Operators (DSOs). In most cases, the power sector in the SAARC Region is non-competitive and formed of State Owned Enterprises (SOEs). In the absence of competitive mechanisms which would allow energy storage to find ways into the power sector of the SAARC Region, the impact of how system operators and utilities view energy storage technologies becomes pivotal in their acceptance in the region.

The challenges of integrating new storage based technologies in the system, other than pumped hydro, which is a much more mature technology, forms an inherent conflict with some of the aims of the system operators who are required to operate the grid safety and within tightly defined parameters. The integration of storage presents an uncertainly in terms of how these technologies would be used in practice and their performance. Taking a step back, before even deployment is considered, from a utility planning perspective, there are limited applications and processes in place in the region for planners to consider how to integrate storage into grids (U.S. Department of Energy, 2013).

### 4.3.3 Dynamic vs Static Efficiency Evaluation

Unlocking the potential for several of the true long-term and sustainable energy storage technologies requires that adequate funding mechanisms be set up for them. As storage from technologies such as batteries progresses into participating in the market, it becomes a competitor to incumbent technologies in the power sector. These incumbents may appear to be lucrative from a static efficiency (economic efficiency) perspective whereas storage could have more dynamic efficiency (again economic efficiency) potential. However, the upfront investment in incumbents may make them appear to be much more attractive than storage technologies (Power Engineering International, no date).

The issues discussed above when viewed in the light of the situation that upon introduction, storage technologies would be more expensive, would require considerable upfront investment. Making storage a contender requires that dedicate mechanisms are available for facilitating and incentivising this investment in storage.

### 4.3.4 Innovation Funding Mechanisms

Given that storage technologies are an emerging technology, energy innovation will play a significant role in their development and deployment in the future. Funding for innovation may come from a variety of sources, both public and private depending on the risk and readiness profile of the technology. There is also a question of whether technology-push or market-pull measures will be required i.e. will the market incentivise innovation based on an unmet need for technology or will public intervention be needed to incentivise innovation.

With reference to the SAARC Region, for a majority of the SAARC Member States, storage technologies have not matured to the stage where there is significant market pull and therefore technology push interventions will be needed in the sector.

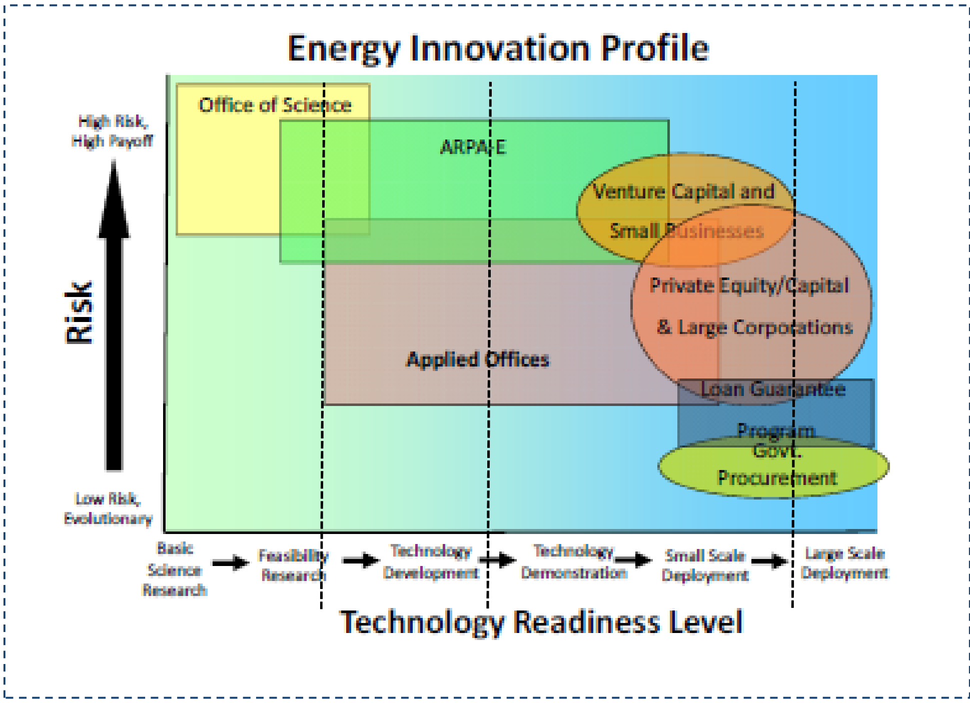
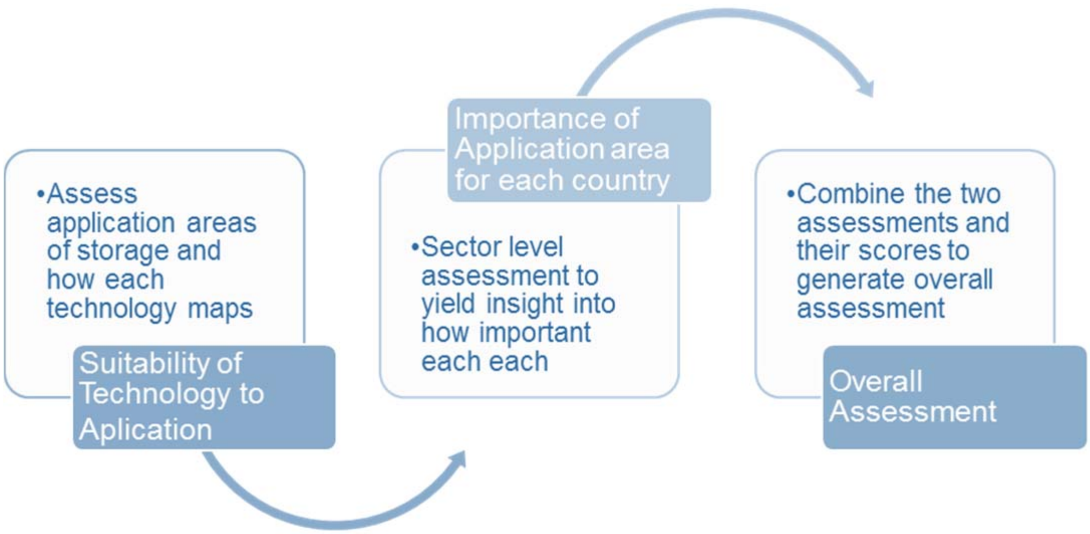



*Figure 4.33 Energy Innovation Profile (U.S. Department of Energy, 2013, p.31)*

Given the nascent level of the sector in the overall region, development of an innovation strategy remains a gap for ESTES deployment.

### 4.3.5 Technology-wise Potential Matrix

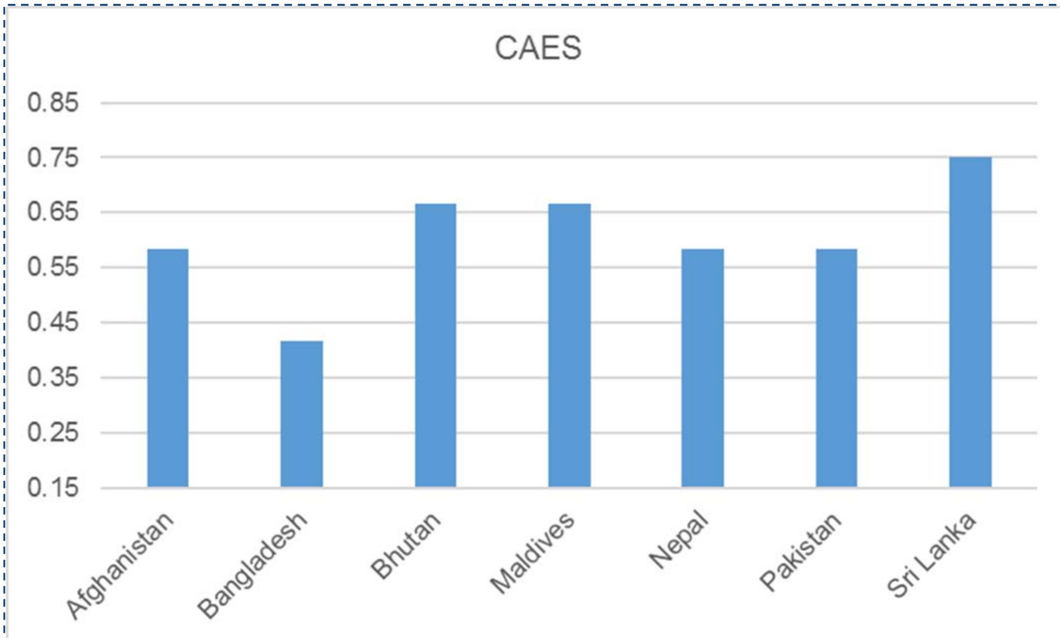
This methodology envisions assigning scores to assess both the suitability of the technology to the importance area as follows:

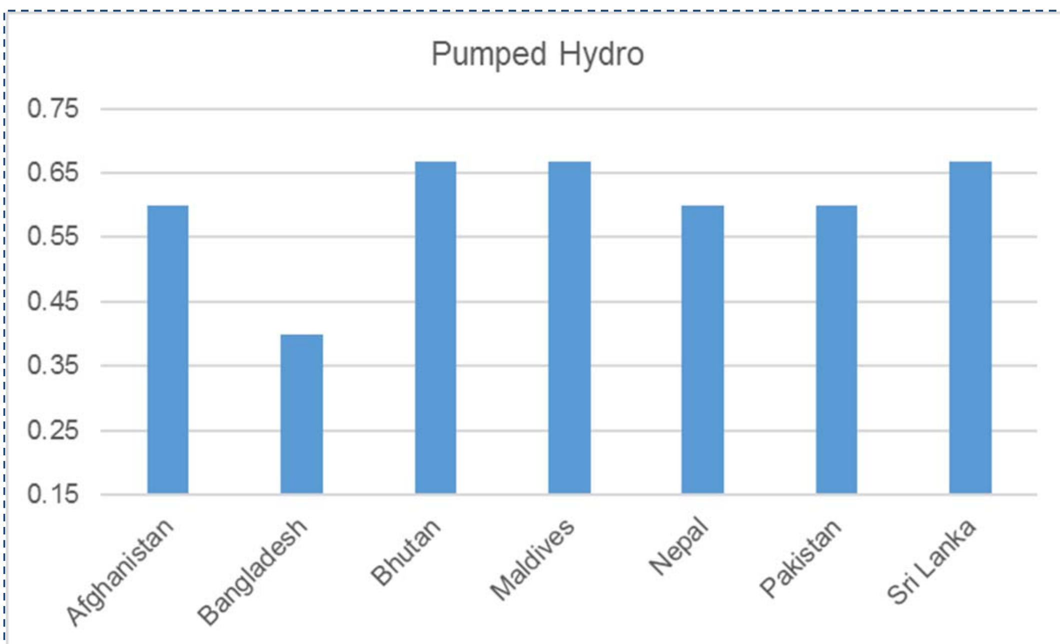


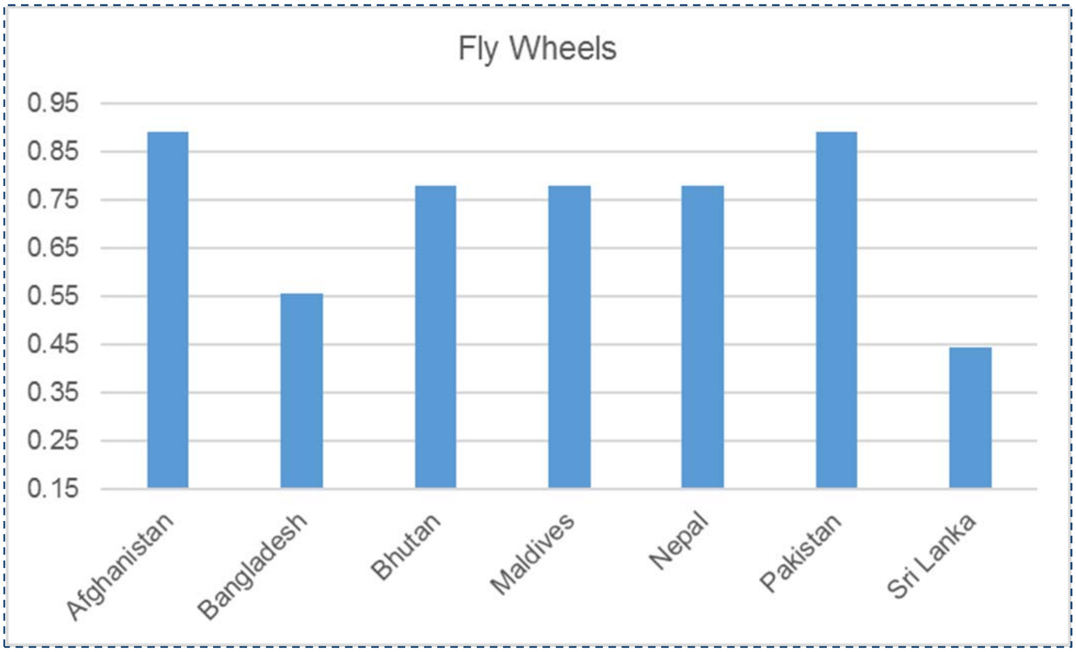

| Application Potential | Score | Technology Suitability | Score |
|---|---|---|---|
| High | 3 | High | 2 |
| Medium | 2 | Partial | 1 |
| Low | 1 | Un-suitable | 0 |

Based on these two scores, a total score is evaluated by multiplying the two score-factors together and then adding them for each technology. For example, if a country has high potential for the application area 'Micro-Grid formation', this will be assigned a score of '3' and a technology type e.g. lead-acid batteries which has a high suitability for the area i.e. a score '3' will mean that a total of '6' i.e. 3x2 will be added to score of that technology for the region. But if a technology such as which has partial suitability for the 'Micro-grid' application and hence a score of '1' is considered, it will add '3' to the score. This will then be done for each application area for each technology and the score will be summed for each technology individually. The technology's total achieved score will be compared to the total score achievable by the technology and this will allow separation into the potential of each technology type for each country in the SAARC Region. This methodology was utilized to develop the graphs that follow assessing the technology potentials.

The relative importance of each technology was assessed across countries on a scale ranging from 0 (zero relevance) to 1 (highest possible relevance).




Fly Wheels
0.95
0.85
0.75
0.65
0.55
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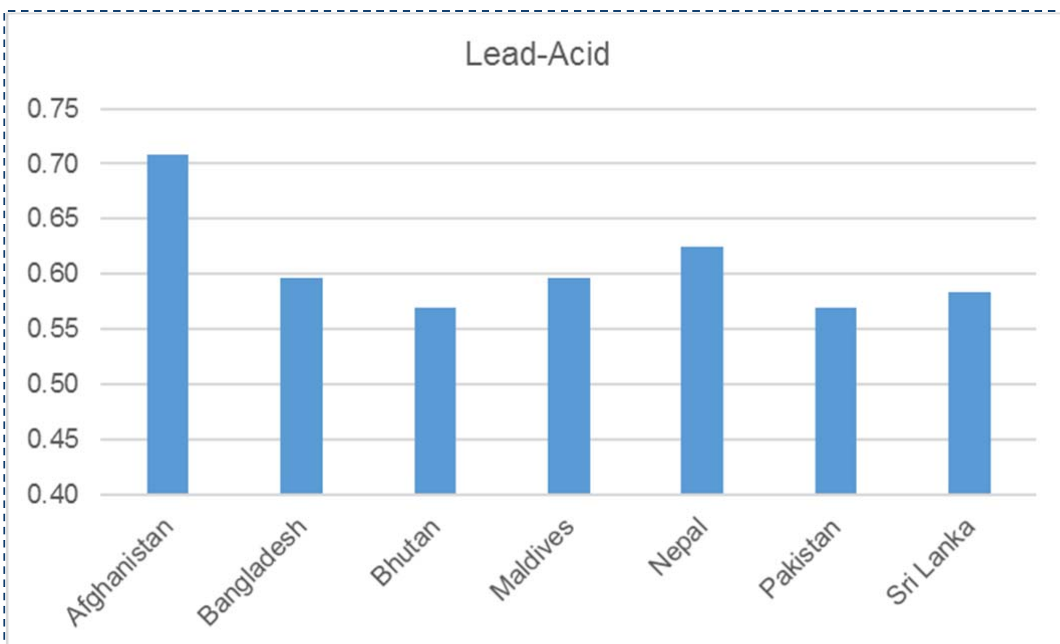
0.35
0.25
0.15
Afghanistan
Bangladesh
Bhutan
Maldives
Nepal
Pakistan
Sri Lanka


Lead-Acid
0.75
0.70
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Maldives
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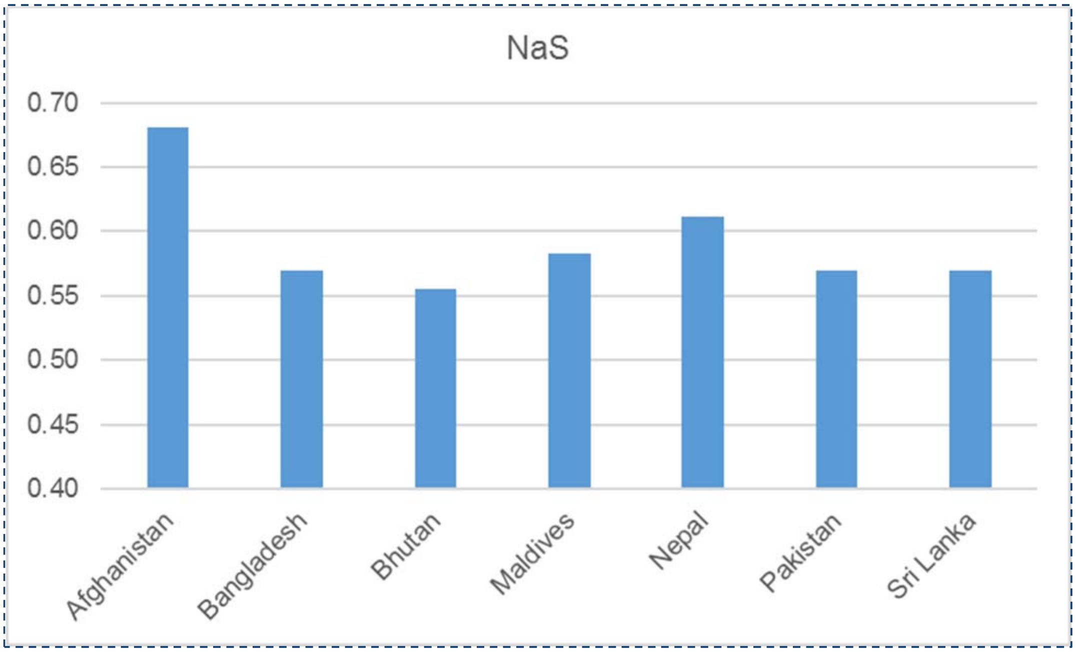
Pakistan
Sri Lanka


NaS
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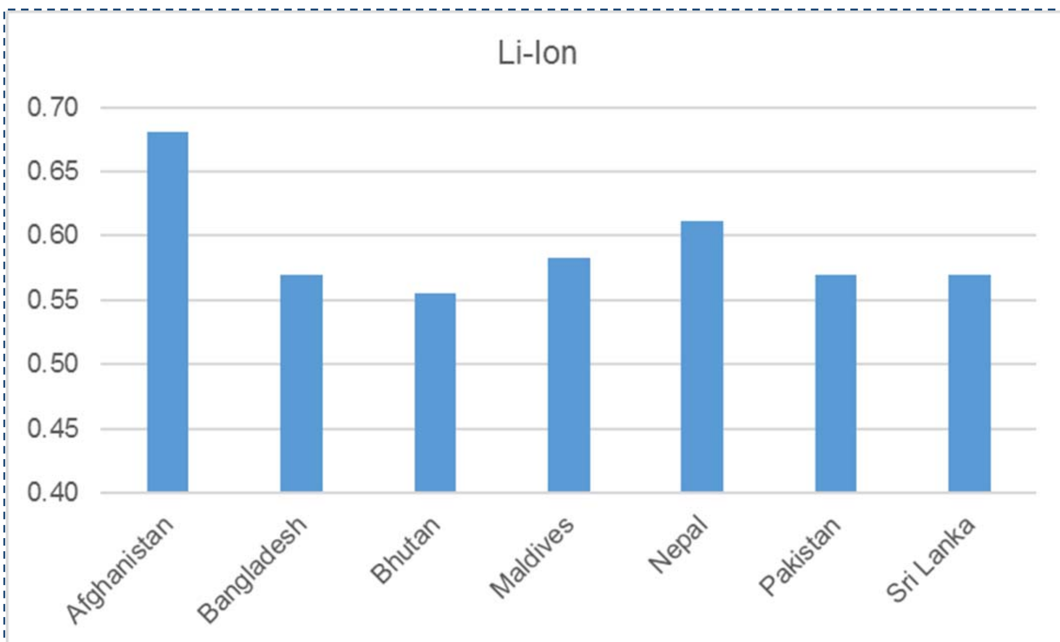
Li-Ion
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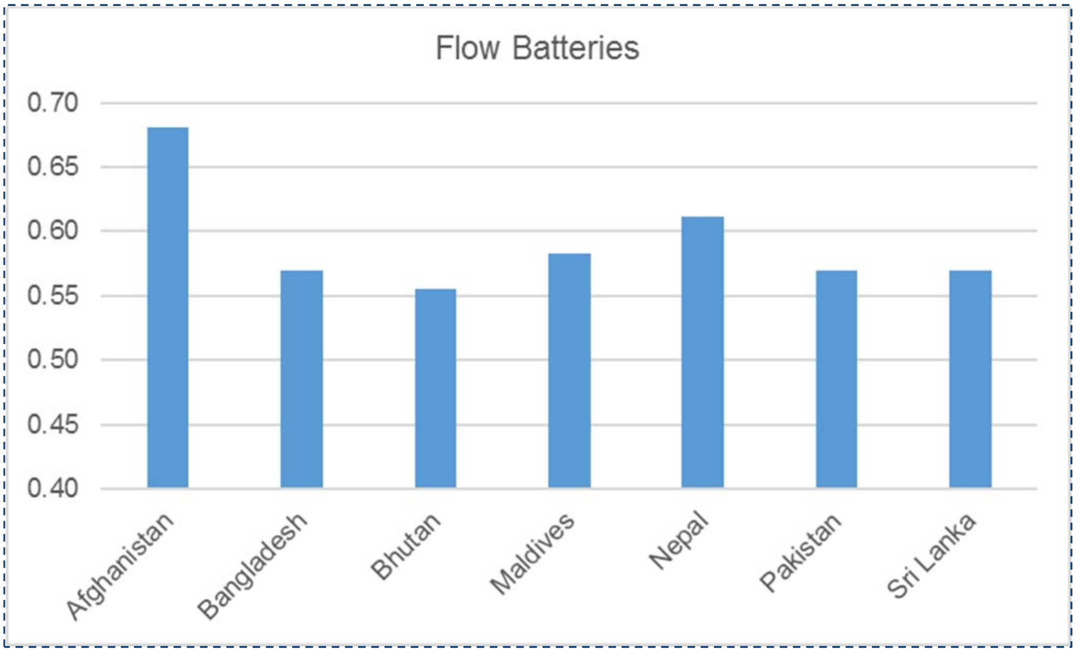
Flow Batteries
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Maldives
Nepal
Pakistan
Sri Lanka

## 4.4 Future Need Assessment

One of the most important factors that will influence the future role of Energy Storage technologies in the SAARC Region will be the regional connectivity within the SAARC Region.

The SAARC Energy Centre envisions the formation of a SAARC Energy Ring. The Power Grid envisioned in the SAARC Energy Ring for the region is presented below:

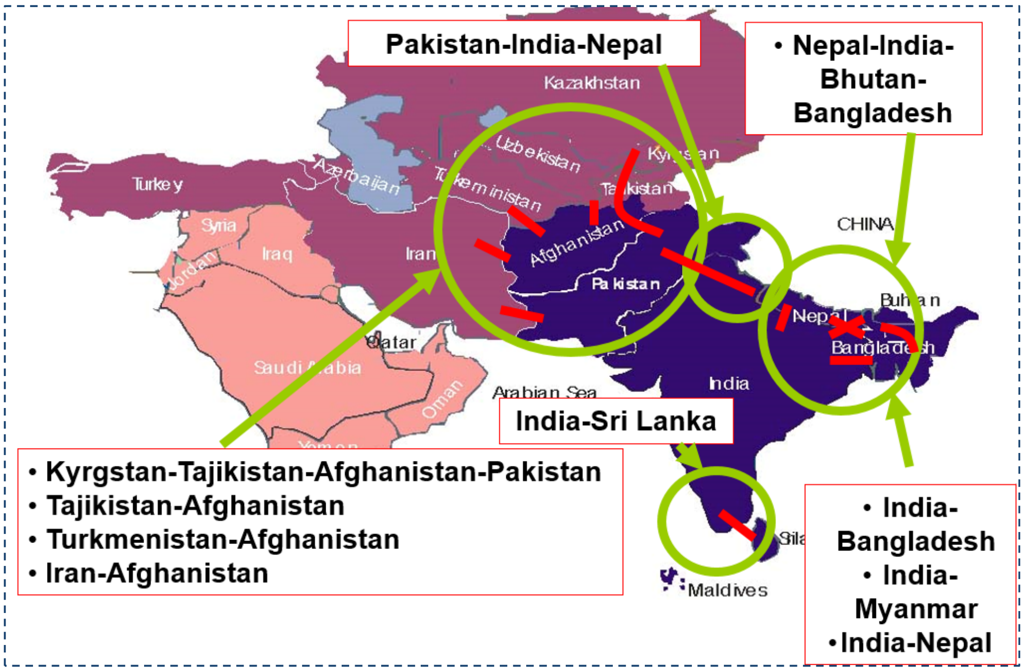



*Figure 4.34 SAARC Power Grid (Pervaz, 2013)*

The details of some of the connectivity options presented for the region are:

| Grid Interconnection | Capacity (MW) | Est. Cost (Million USD) | Annual Benefit (Million USD) |
|---|---|---|---|
| **India-Bhutan** | 2,100 | 160 | 1,840 |
| **India-Nepal** | 1,000 | 186 | 105 |
| **India-Sri Lanka** | 500 | 600 | 186 |
| **India-Bangladesh** | 500 | 250 | 389 |
| **India-Pakistan** | 500 | 150 | 491 |
| **CASA 1000** | 1,000 | 970 | 906 |

(Usman, 2015)

The impact of the connectivity of the SAARC Region on the storage sector is difficult to assess in the context that regional connectivity may reduce the need for energy storage through increasing the generation pool available or increase the need if sufficient nodal and temporal differences exist in consumption profiles. This will ultimately depend on the energy mix of the and how the demand profile of the countries evolves. Such exercises would require detailed integrated energy modelling to be done for the interconnected countries. In general terms, this has the potential of making energy exchange either more lucrative by energy arbitrage. On the other hand, if interconnectivity across the region becomes strong and there are sufficient variations in load profiles (i.e. the peaks for each of the interconnected country are sufficiently separated in the time) this will allow the existing generation infrastructure in the countries to be shared more efficiently to the point that the need for storage in the electricity sector may decline alongside the need for peaking capacities.

The other significant factor that can impact the deployment of storage include the trend of increasing renewables in the grid. Finally, the development of energy exchanges and overall sector reform would lead to increased valuation of storage based resources as they gain additional routes to market through services such as frequency regulation, reserve provision and energy arbitrage for which compensation mechanisms are lacking in the broader SAARC region at the current stage.

Chapter 5

# *ESTES in INDIA*

# Chapter 5: ESTES in India

## 5.1 Energy storage – An emerging necessity for India

Energy storage is emerging as a necessity in the rapidly evolving economies of the world and India is no exception. Renewable energy (RE) capacities are already being rapidly scaled-up due to their environmental benefits and the rising demand for electrical energy.

The cost-benefits of distributed generation vis-à-vis centralised generation for less populous areas have always been known. Various technologies like biogas, micro-hydel plants, biomass plants etc. have been tried in India in the past decades to generate electricity very close to the demand area in such places. However, the often tricky operation and maintenance requirements of such plants have generally proved to be a deterrent to rapid scaling-up and extensive deployment.

With the costs of solar PV plants dropping almost dramatically in the very recent years, distributed solar PV is being recognised as a cost-effective and low-maintenance source of energy at places that are far from the grid and have only a limited initial requirement of electricity. The costs of wind-based power have already achieved a degree of stability and are in a position to compete with the delivered cost of grid supply in remote areas. With the cost of generation from solar PV also coming down to levels where it almost has parity with fossil fuel power, the very fundamental architecture of an electricity supply grid is being turned on its head.

On the flip side, the lack of stable and predictable output from RE sources likes wind and solar due to their high intermittency reduces their attractiveness for un-served areas. This also results in weak schedulability, thus making them inimical to the requirements of a stable grid. This would tend to have a negative impact on their rapid deployment.

As in most other parts of the world, it is now increasingly being recognised in India that this lack of predictability of output can be effectively met with the use of energy storage technologies. Cost-effective ways of storing electrical energy can help compensate for the inherent wind and solar variability and make distributed off-grid as well grid-connected RE energy more efficient and reliable.

India currently has pumped storage capacity of the order of about 6,000 MWs, of which a little over 2,500 MWs is in use for grid balancing. Limitations of gas availability as well as closed cycle designs severely limit the use of gas turbines in India for grid balancing purposes. There is a good case for thermal cycle coal-fired plants to be used for ramping up and down, though with limitations on acceleration / deceleration. Compressed air storage is yet to be used in India but some attempts are being made in this direction.

Large sized batteries are currently inordinately expensive and may thus take a few more years before serious deployment could materialise. The currently available charge / discharge cycles on large batteries are also very low. Though battery storage technologies are available at capital cost levels of less than USD 500 per kWh and less than USD 0.10 per kWh/discharge cycle (electrical storage), focused support through appropriate policies, programs, incentives and infrastructure needs to become available to facilitate larger adoption of such energy storage technologies in India and the region.

On a region-wide basis, it may also be feasible to look at utilising the diversities that exist in the technologies for electricity generation in each country for the purpose of storage. However, this would call for strong inter-ties between the respective transmission networks. The financial and commercial challenges there would be dependent on several other pressing issues besides energy storage.

## 5.2 Most Suitable ESTES Technologies for India

Prima-facie, from the point of view of technical viability, the most suitable ESTES technologies for India would be pumped hydro storage, latent heat storage and battery storage. All these technologies involve significant capital expenditure.

Pumped hydro, while being very cost effective on an energy use basis due to its very long life of at least 30 years, calls for specific geography and topography. Its use is therefore highly restricted in India. The minimum economically viable size is also very high, usually in excess of 100 MWs.

Latent heat storage is in use to a limited extent with solar thermal power plants in India, of which the currently operational capacity is about 200 MW. This technology is perhaps more suitable in the Indian context, given the thrust for the large-scale utilisation of solar energy and the ability of materials like molten salt to effectively store energy for several hours. The cycle life of such technologies is also very high. Deployability of such applications however calls for a minimum size, at least in the MW range.

Battery storage is particularly amenable to both distributed kW scale use as well as concentrated MW scale applications. Lead-acid batteries coupled with inverters have been in use in India for decades as a means of providing power back-up during grid outages. While the quality of commercially available lead-acid storage batteries has improved significantly in recent years, the life these batteries typically does not exceed 5 years. With the advent of lithium ion and other technologies for battery storage on a larger scale, and given their much longer cycle life, battery storage solutions appear poised to find an increasingly larger space in the energy storage market in India. This would be very relevant in the context of electric vehicles too.

## 5.3 Technical Potential

The technical potential for energy storage applications in India can be gauged from some of the key developments and related challenges that the Indian power system has been seeing of late. These are as follows:

- **Operational flexibility demanded from conventional power plants** – While India has traditionally experienced nation-wide power shortages, the situation has taken a fairly dramatic turn in the last two to three years. There is now a mild electricity surplus at the bulk level in India, driven partly by the huge increase in generating capacity (India added about 1,30,000 MW of power generating capacity in the last seven years alone), partly by the globally weakened economic scenario reducing the demand for power from industries and partly because of the financial condition of the monopoly distribution companies forcing them to purchase less power.

  This has not only reduced the power offtake from generating plants but has also forced generators to begin focusing on operational flexibility as an important parameter. Not only do conventional thermal power plants have to operate efficiently at full load, they are also now expected to deliver high efficiency at lower power output levels, as well as to be able to ramp up or down quickly. This operational flexibility is poised to be further aggravated by the variable power output from renewable energy sources like wind and solar PV which usually have a "must-run" status. Technical potential for bulk scale energy storage systems is therefore immense.

- **Increasing attention to decentralised power systems** - In order to reduce delivery costs and improve system efficiency, there is a trend towards shifting from a centralized power system to a more decentralised one. This includes remote as well as rural areas where the cost to serve from a centralized grid is understandably high and also includes industrial areas where smart local grids are being experimented for integration with the utility grid. This creates space for technical solutions with smaller scale energy storage systems, especially batteries.

- **Solar Photovoltaic (PV)** – There is a large and steady increase in Solar PV capacity in India. The rate of increase in solar PV installations has not slowed down with the reduction or withdrawal of government subsidies. This is perhaps due to the drop in PV panel prices and also due to the reduced risk perception which has resulted in competitive funding support. The market for PV is thus growing steadily.

Net metering is slowly being introduced across several Indian States while Feed-in Tariffs (FiTs) are being withdrawn. As the assurance of FiT no longer supports the financial viability of a Solar PV project, net metering seeks to increase the reach of the energy output beyond the initial buyer of energy (whether a home, commercial building or factory) and rope in the local distribution entity as a secondary buyer. Higher capacity behind-the-meter battery storage would thus find technical feasibility in widening the options for Solar PV, at both bulk and retail levels.

**Electric Vehicles may become part of the solution for grid balancing by using them as mobile battery storage systems.**

- **Onshore Wind -** Onshore wind is a well-established technology with increasing efficiencies as well as capability to operate efficiently at low speeds too. Investment patterns however continue to depend on government subsidies in the form of Generation Based Incentive (GBI) and Feed-in Tariffs. There is huge resistance from the wind developer community in India to open up the industry to tariff-based competitive bidding, though Solar PV has moved to that regime in a much shorter period.

  Wind investments in India have so far been restricted to a few geographic regions, mostly on the coast and in the open desert areas. Because of their concentrated impact on certain parts of the grid, wind power output has also been brought under the scheduled dispatch regime by the national grid operator, albeit on relaxed norms. This raises the stakes for energy storage as a technical solution to the risks of wind output intermittency.

- **Electric Vehicles and related infrastructure -** Electric Vehicles (EVs) are also now being seen as a significant part of the solution to providing cleaner air in cities and are thus attracting government subsidies and other benefits. There are significant limitations currently on the mileage per recharge of batteries, as well as on the cost per kilometre of batteries. With developments in battery technology and widespread availability of charging points, adoption of EVs could take off significantly in the next five years in India. Since it may be very difficult to charge vehicles whenever there is excess power from renewables in the system, this is likely to spur the development of battery storage services in a big way. EVs may also become part of the larger solution for grid balancing by using them as mobile battery storage systems.

- **Ancillary Market Mechanisms –** Ancillary market mechanisms which allow power system managers to purchase capacity in order to ensure peak demands are met, are proposed to be introduced gradually in India from later this year or early next year (2017). Spot purchases and spinning reserves would be extensively used for this purpose. However, due to their variable nature of supply, renewables are prevented from joining such ancillary market schemes. Energy storage applications could therefore find an additional market either directly or as partners to renewable resources for such applications.

- **Concentrated Solar Thermal Power –** Operating Concentrated solar thermal power (CSP) capacity is now of the order of 200 MW in India. More such capacities are under various stages of development. The key advantage of CSP is that the use of an intermediate heat transfer medium like molten salts acts as an almost phenomenally recyclable (as compared to batteries) energy storage mechanism that enables generation of power even when the sun isn't shining. This reduces the variability of energy output and makes it a schedulable energy source, thus giving this form of energy storage a competitive edge.

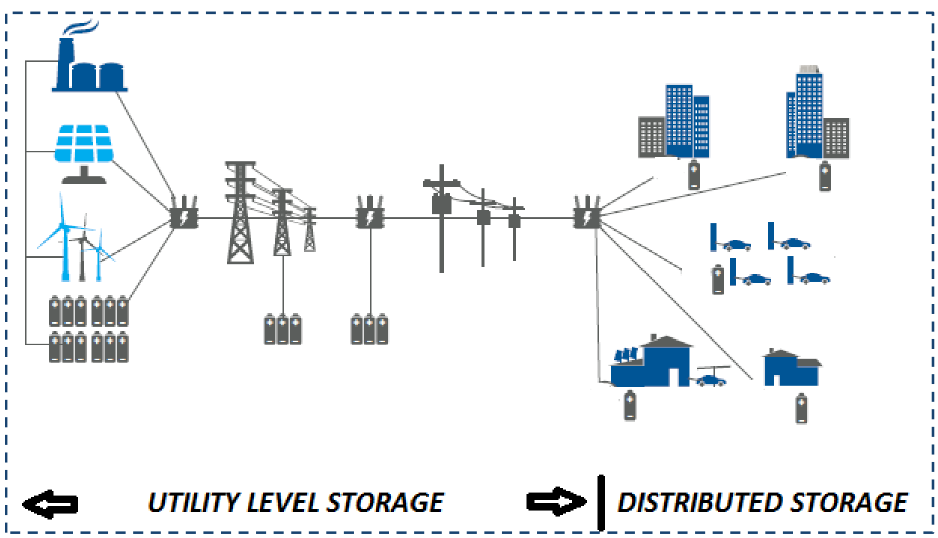



*Figure 5.1 Utility level / distributed storage*

***Opportunities for Energy Storage applications*** – Due to their intermittent nature of output, especially for onshore wind and solar, the increase in renewables as part of the energy mix creates an issue for the transmission system. Therefore, as briefly outlined above, a lot of attention is being paid towards developing technically suitable methods to store surplus energy. This includes pumped-storage facilities and HVDC lines to connect areas with large hydro power capacity with areas that have large demand and / or significant locally available intermittent generation resources. Battery storage facilities both at the bulk level in conjunction with large solar PV farms as well as at the retail level are being facilitated through Government initiatives. There is also some thought being given to the use of deep caverns to store compressed air, though any demonstration projects are yet to come up.

Successful development of energy storage devices, particularly batteries, will also lead to the expansion of technical requirements as well as opportunities in areas like energy storage software, battery components, Battery Management Systems, inverters etc. This will also incentivise increased innovation in the electric mobility and electric transportation space, including battery electric vehicles, hybrid vehicles, material handling equipment etc.

## 5.4 Techno-Economic Analysis

The large scale deployment of energy storage could bring about dramatic changes to electricity markets. Not only the way grids are operated but also the way different sources of energy get dispatched could alter very fundamentally. From priorities driven by least incremental cost (unless over-ridden by policy), dispatches could become based on the speed of entry or exit and also the ability to sustain fluctuations and thus easing pressures on the grid. Approaches such as this would however, always have an economic criterion in nearly all cases.

Recent developments indicate that energy storage is already being considered a key player in providing ancillary services to smooth out discrepancies between generation and load. This has hitherto been provided by centralized bulk generation traditionally. India has launched ancillary services in its national grid already. While still in its early stages, the service is expected to provide quick response from the grid to load and generation fluctuations in the next few years. Given the state of technologies and costs, this facility is presently to be served by large thermal and hydro plants only. However, energy storage is well suited to provide such ancillary services and, as costs drop, this could provide much greater support to the grid, displacing power plants.

The first logical step may be to act in conjunction with intermittent renewables and enable them also to participate in providing ancillary services. However, with intermittent renewables just having attained grid tariff parity, addition of storage costs would push them out of the reckoning and place them back in the queue for policy support. This may not be palatable to many stakeholders including policy makers and climate warriors. Economics may, therefore, indicate that storage capacities be deployed directly as contributing elements to the grid and perform the dual role of a source and a sink as the situation demands. In such case, it would be possible to socialize the costs of storage across all grid users rather than burden only the customers of the renewable resources that storage might otherwise have to be paired with.

While India has not yet gone in for discrete grid level storage elements beyond some pumped storage assets (as indicated earlier), concrete steps have been initiated to induct limited storage capacities in a paired manner with solar and wind resources. Economic implications currently limit the induction of storage largely to a level where it provides a little more time to grid operators to deploy conventional balancing solutions.

For a proper techno-economic analysis of suitable energy storage technologies for a given application, it is critical to whether the application calls for a requirement of a lot of energy for a short period (referred to as power applications) or of lower amounts of energy for longer periods (energy applications). These characteristics would usually determine the suitability of specific energy storage technologies across the grid, from large utility-scale installations to transmission-and-distribution infrastructure, as well as to individual commercial, industrial, and residential systems.

Also for example, in an Indian context, it has been observed that in certain applications that offer compatibility to both lead-acid and lithium-ion batteries, lead-acid may prove a more economical option despite of its lower expected life (and therefore more frequent replacements) as compared to lithium-ion due to significant costs differences. However, the same comparison may indicate the opposite result in a few years when lithium-ion prices expectedly drop much faster than lead-acid.

It is also very important to match the performance characteristics of different types of storage technologies to the application. For a given application, one technology or design could well be much more economic than the another because its ability to charge and discharge more quickly as it could result in significant additional avoided costs.

Recent analysis in Europe has shown that for large-scale balancing of wind power, flow cells are currently more economic than lithium-ion cells for all but short periods of less than an hour. Such a situation is predicted to continue at least until 2020, after which the economics might potentially undergo a change.

It is therefore evident that for a proper techno-economic analysis of storage systems, besides the technical suitability, it is also necessary to go in for an in-depth assessment of the cost aspects of the specific application, which would involve close tracking of storage requirements. Any averaging of generation / consumption cycles would quite possibly give skewed results as the specific characteristics of the storage technology that are called for may well get masked. Variations may therefore need to be recorded at one-minute (or lesser) intervals rather than hourly or daily patterns and such data would then need to be analysed to see the techno-economic suitability of the right storage system.

### 5.5 Socio-Economic Analysis

One of the most obvious socio-economic benefits of using energy storage would be obtained through its being paired with renewable energy sources like solar, wind, geothermal, marine, biomass or biofuel to replace diesel generators in remote areas including islands. Whether it is in rural micro-grids, telecom tower locations or on islands that are not easily amenable to centralised generation and distribution, the biggest limiting factor for reliable supply of electricity (especially when it is needed most as in supply to communities) from renewables is usually the unpredictability of output which is solved by proper storage.

Local capabilities can be developed to maintain and operate storage systems and make economic use out of them by integrating with new energy sources. In many places where society is keen on more solar and wind resources, the grid is often unable to handle such additional resources without any additional reinforcement. The cost towards more transmission capacity can be replaced with cost towards storage, thus bringing social benefits at comparable economic costs. This would also improve the energy security of the community, besides reduced emissions.

In urban settings, consumers are usually isolated from fluctuating prices in the market. Distribution companies, faced as they are with delicate financial situations, are increasingly keen to pass on some of the risks to consumers. While fuel cost variations are being passed through for some years now in most parts India for example, distribution companies are also looking for ways to pass on the additional costs of procuring renewable power, besides imposing higher tariffs for peak-time usage just as they do for industrial and commercial customers. To cope with this, domestic consumers would soon need to become more flexible in their energy demand, something that is easier said than done. Household demand for energy depends on numerous influences. Energy storage can therefore provide a very viable solution by allowing consumers to store more when they need less and use the same during periods of their own choice. The social and economic benefits of such a solution would be very significant for communities.

## 5.6 Environmental Considerations

Energy storage deployment and regulation are still in early stages of evolution. However, besides the obvious benefits of electrical energy storage systems, the risks are not merely related to affordability and scale but also due to the environmental considerations that need to be kept in mind.

Pumped storage hydro in its conventional form calls for creation of a large water storage area which would give rise to all the issues that crop up with storage hydro projects viz. impact on local population whose livelihoods may be affected due to the impact on river flows, displacement of people and farm animals, loss of cultivable land, impact on flora and fauna that are supported by a flowing stream that might now be curtailed due to the creation of additional storage, impact on ground water levels in the areas surrounding the river's path that might now be rendered dry on account of impounding and evaporation of water in the storage body etc. etc. Just as anywhere else in the world, India has also seen a reasonable amount of local discontent against the perceived impact of a hydro storage facility. The design and locational aspects of poundage for pumped storage hydro needs adequate care even if it means adding to the time required to develop such facilities.

With regard to batteries, there are risks relating to the safety of various battery chemistries when these storage devices are located near highly populated areas or near critical grid infrastructure where storage is needed most. Lithium, for example, is a very volatile element, making lithium-ion batteries prone to thermal runaway in the event of over-charge, over-discharge, short circuits, mechanical impacts and from use in locations with high ambient temperature.

When water is used for extinguishing charged or partially-charged electrochemical devices, there are environmental risks as the runoff water has been shown to contain high concentrations of toxic materials. This could cast doubts about the suitability of lithium-ion for applications where the energy storage system must be located close to significant populations or near critical grid infrastructure.

Flow batteries contain vanadium and bromine. Vanadium can be toxic in large quantities like those contained in a flow battery. Handling of vanadium by maintenance technicians, like that occurring during electrolyte replacement, needs to be done wearing special suits by technicians trained in the handling and disposal of hazardous materials. Likewise, personnel transporting hazardous materials like vanadium and bromine would also need to be adequately trained to handle risky accidents.

Besides toxicity, the chemical electrolyte of a vanadium flow battery tends to break down at higher state-of-charge (SOC), creating a potentially hazardous outgassing scenario. Research on vanadium redox flow batteries has shown the potential for chlorine gas to form in the system as the SOC approaches 100 percent. Bromine is also hazardous in both gas and liquid form. Both chemicals are also used in electrolyte solutions that are highly acidic and would be harmful to both people and the environment if they ever leak out of the storage tanks. The caustic and toxic nature of these chemical electrolytes may render such technologies unsuitable for deployment in densely-populated areas even if safety precautions are taken.

Researchers have surmised that an alternative flow battery electrolyte composed of zinc and iron could be a solution to circumvent safety issues associated with many battery technologies. Zinc-iron electrolyte is non-toxic, non-flammable and non-explosive. These systems have much greater flexibility in where they can be located and how they can be utilized and thus may not pose risk to human population, wildlife or the environment.

Environmental aspects of energy storage technologies therefore call for close analysis and for development of proper procedures for handling both normal as well as abnormal operating situations.

## 5.7 Current Status of Electrical Power System in India

The power generation industry in India has grown from a level of about 1700 MWs of installed capacity in 1950 to about 65,000 MWs in 1991 when private ownership was given a fillip, then to about 1,12,000 MWs when power generation was de-licensed in 2003. As of June 2016, the total installed power generation capacity (grid-connected utilities) in India was of the order of 3,03,000 MW.

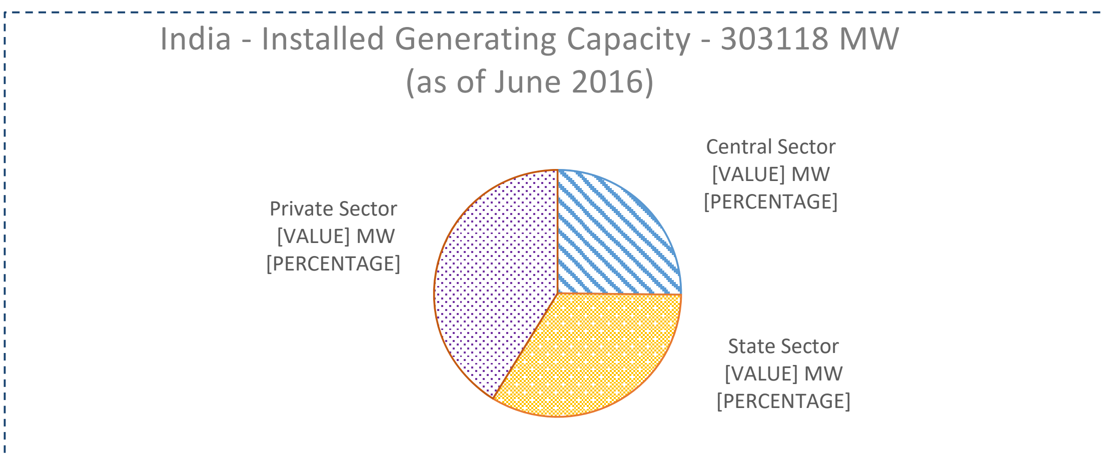



Figure 5.2 India Installed Power Generation Capacity - Ownership-wise – as of June 2016 (*CEA)*

The private sector's contribution in India's power generation capacity as of June 2016 is 41%, followed by State sector (34%) and Central Sector (25%). This increase in contribution from private sector has been because of various policy initiatives taken by the Government and increased investor interest. This includes the Mega Power Policy introduced in 1998, the Electricity Regulatory Commissions Act of 1998, the Electricity Act 2003 and the Tariff Policy.

Majority of the power generation capacity in India is coal-based, followed by hydro and renewables.

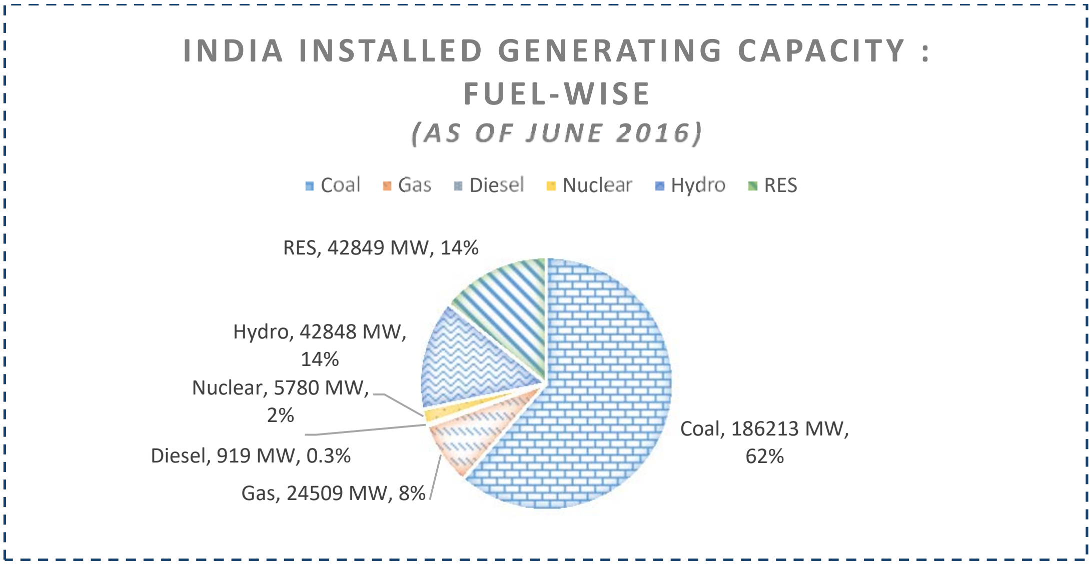



*Figure 5.3 Installed Power Generation Capacity - Fuel-wise – as of June 2016 (MoP, CEA)*

The Electricity Act 2003 replaced the Electricity Act 1910, Electricity Supply Act 1948, and the Electricity Regulatory Commission Act 1998. It had three clear objectives:

- Introduce Competition
- Protect Consumer's interest
- Provide power for all

For the power generation industry, the key change facilitated by the Electricity Act was to de-licence power generation. This led to substantial investments from the private sector. The Electricity Act also formally recognised power trading as a licenced activity, giving a further fillip to increased power generation through creation of a power market.

The following diagram illustrates the structure of the Indian power industry for generation, transmission, distribution and consumption:

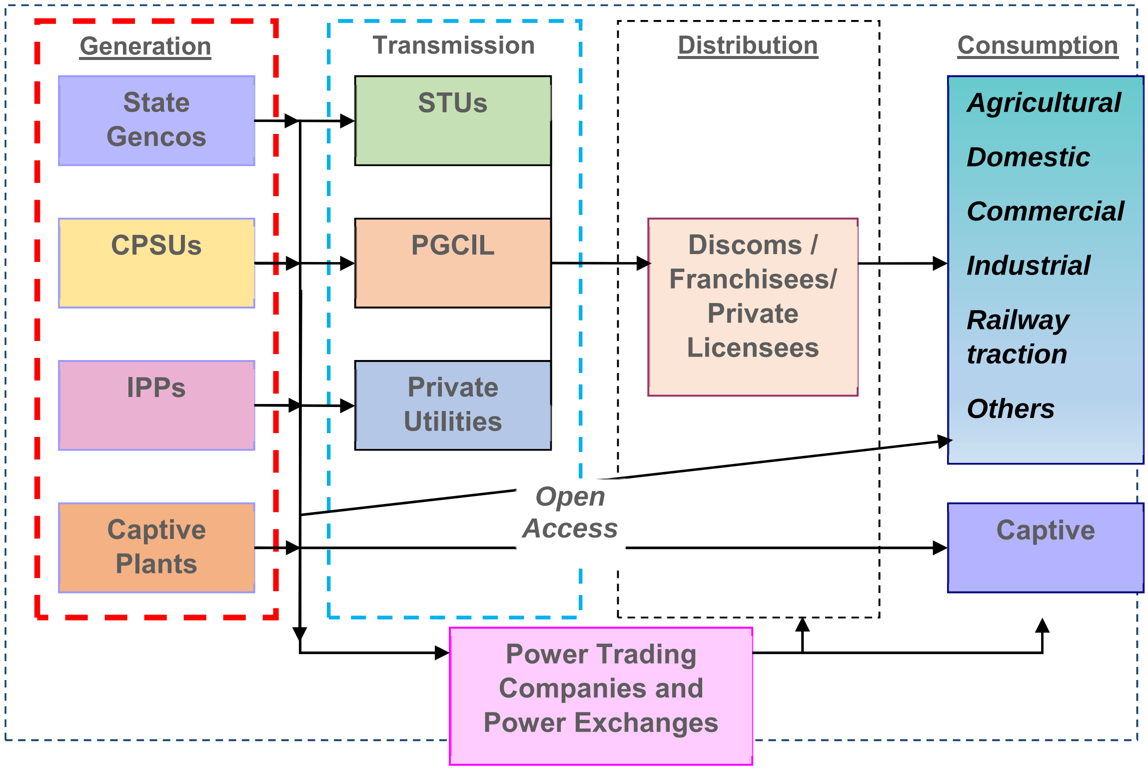



*Figure 5.4 Structure of the Indian power industry*

State Gencos: State Government owned Generation Companies

CPSUs: Central Public Sector Units - Central Government owned Generation Companies

IPPs: Independent Power Producers

STUs: State Government owned Transmission Utilities (intra-State lines)

Discoms: Distribution Companies (State Government owned and privately owned)

PGCIL: Power Grid Corporation of India Limited - Central Government owned Transmission Utility (inter-State lines)

## The Growing Trust Towards RES Sources in the Energy Mix

The growing share of renewables in the energy mix and a decrease in fossil fuel consumption appears to be an almost certain trend in India, as it is in most parts of the world.

The current installed capacity of renewables in India includes 6560 MW of Solar PV, 200 MW of Solar Thermal, 4270 MW of small hydro, 26,800 MW of wind power. 4830 MW of biomass and about 115 MW of Waste to Energy, thus totalling to about 43000 MW. The capacity with intermittent output is therefore already of the order of 33,000 MW. Though the number does not appear dramatically high with reference to the total installed generation capacity in the Indian power system, the fact that many of these assets are concentrated in certain geographical segments of the country has already resulted in significant constraints from the grid in those areas, including curtailment of output.

The Government of India has given a mega thrust towards renewables by deciding to add 1,75,000 MW of renewables by 2022. The power generation and supply scenario is therefore poised to take a different turn. The impact is not only likely from the point of view of cleaner generation but also in shifting of peak loads on the grid. It is expected that solar power, of which 1,00,000 MW is to be added by 2022, would cater to much of the afternoon peaks in the grid.

This renewables capacity addition target of 175 GWs includes 60 GW of ground-mounted solar, 40 GW of rooftop solar, 60 GW of wind, 10 GW of small hydro and 5 GW of biomass based power. Seen against the fact that the current installed capacity in India of all forms of grid-connected power is about 300 GW, the renewables target is indeed huge.

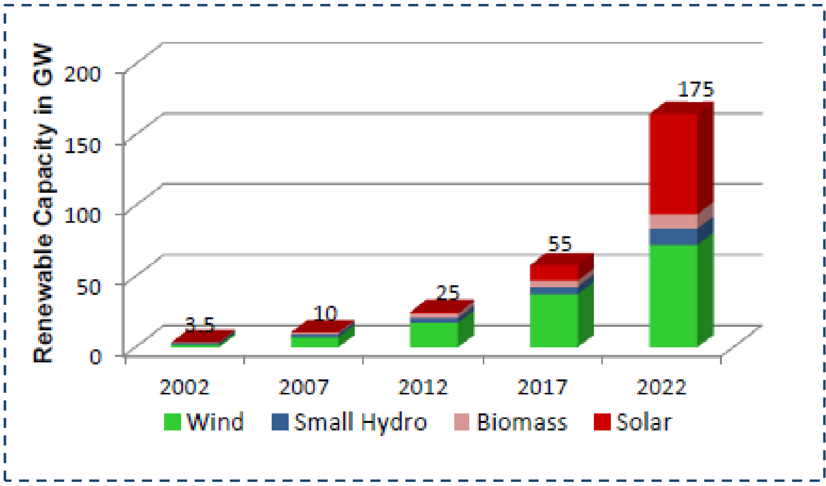



*Figure 5.5 India – Renewables capacity addition trajectory (MoP, CEA)*

The Government of India also proposes to raise the solar purchase obligation to 8% by 2022, a substantial increase from current levels of about 1%. All new coal and lignite based generation projects would also have a renewable generation obligation for which the quantum would be stipulated. Also, no inter-State transmission charges and losses are to be levied for solar and wind power. However, this exemption may last only for some years until the renewables sector establishes itself. It is also possible that these policies could vary at the intra-State level.

## 5.8 ESTES Applications in India

There is a reasonably wide range of ESTES applications that would be suitable for the SAARC Region. The more pertinent applications for each SAARC nation would be the ones more conducive to the current and state of their power systems, the plans for the coming decade or so and the economic and technical feasibility of their introduction.

### Technical criteria

As would be evident from previous paragraphs, India and other SAARC nations would be looking at certain specific categories of applications based on assessment of their emerging energy future.

The technical criteria being looked at for ESTES applications in India / SAARC include:

i. Solar/Wind energy Time Shift

ii. Firming up/ Stabilization of Solar/Wind energy capacity

iii. Pairing with locally available renewable energy resources for off-grid and remote locations

iv Spinning Reserve capacity/ Transmission support

v. Power Quality

vi. Demand side management

The key parameters identified for the technologies that would be suitable cover the following:

i. Low self-discharge

ii. Long lifetime with large charge and discharge cycles

iii. Low auxiliary power consumption

iv. Ease of maintenance

v. Low impact on environment

vi. Compact foot-print

vii. High Humidity & Temperature tolerance

For storage systems that would be integrated with individual power generation capacities, seamless integration of energy management system of the storage solution with the power plant level SCADA is also seen as a key parameter.

## Financial benefits criteria

Following are some of the key criteria for expected financial benefits that would go into the decision on investments in energy storage in a SAARC context:

1. Benefits through increased use of energy arbitrage, especially in countries like India where there is a reasonably active electricity market, through purchase of larger quantities of less expensive electricity available during low demand periods to store then use or sell later when the electricity price is high. Storage could also be used by all SAARC nations to time-shift the energy generated by renewables and thus earn higher revenues.

2. Avoiding costs of additional Generation Capacity: For countries that are experiencing gaps in the power generation capacity especially during the daytime, energy storage could be used to offset the need to either install new generating capacity or to rent power plants (Sri Lanka, Bangladesh, Pakistan).

3. Reducing the costs of maintaining Ancillary Services, through the deployment of bulk energy storage that can provide several types of ancillary services like spinning reserves and load following.

4. Reducing the costs Avoid or Revenue Increase for Transmission Access/Congestion by the use of energy storage to improve the performance of Transmission and Distribution systems by giving the utilities the ability to increase energy transfers and stabilize voltage levels and reducing congestion.

5. Customer's ability to reduce Demand Charges by curtailing peak drawals and thus obviating the need to have a contracted demand matching with peak load.

6. Avoided costs of ensuring reliability and power quality, particularly for commercial and industrial customers for whom power outages as well as power quality anomalies cause significant losses.

## 5.9 Evaluation of ESTES for India

The power sector across most of the SAARC nations including India is characterized by mature technologies and a reasonably stable legal framework that seeks to guarantee the profitability of the business. Entities in the sector, whether government owned or private, have traditionally been managed according to technical criteria.

Due to the often low reliability and also the quality of power supply, industries maintain diesel powered back-up generators. Similarly, households have inverters with lead-acid batteries as backup for unscheduled power cuts. Low voltage scenarios for homes are solved through the use of step-up transformers. Varying frequency usually does not have solutions that are affordable for the average consumer.

However, due to the sector's economic and social impact, power utilities have been under strong pressure especially over the last decade to improve their efficiency to achieve not only greater cost competitiveness, but also with a significantly lower environmental impact. This situation has evolved over the years in India based on varying growth patterns and resource challenges.

Advancements in renewable energy technologies are facilitating more rapid adoption both at the grid level as well as at the distributed level. However, the intermittency in output from commonly deployed renewables like Solar PV and Wind has impacted their increased adoption.

Solutions like net metering for Solar PV resources and energy banking for Wind resources have somewhat helped in their greater deployment, but not to a large scale. Distribution companies are usually hard put to meet load demands during peak periods. They do not, therefore, look very kindly upon Wind resources that may generate more output at night when their customers do not need it and so choose to bank the energy with the grid and then allow their customers during the day.

The moment time of use is linked to time of production (perhaps just split between multiple peak and off-peak periods) for utilisation of banked energy, the economics for renewables may become difficult. This is where an increasing role for energy storage applications is seen.

While key stakeholders are slowly coming together to achieve better synergies, price reduction of energy storage technologies will play a key role in promoting their widespread use on the grid scale. Price reduction needs to be achieved through innovations in materials processing techniques, manufacturing methods, as well as improvements in performance characteristics (such as cycle life, calendar life, energy density) so that there could be a reduction in the levelized cost of the system, similar to what has been seen over the last five to eight years with Solar PV and with wind power in the last two decades.

Several companies operating internationally have started their India operation and some Indian entities have created energy storage verticals to leverage this opportunity in India. Several companies in India are working on improving battery management systems, charge controller systems, monitoring software and battery recycling to advance this overall ecosystem. Work is also underway on incentivising solar thermal systems because of their inherent storage capabilities through the use of heat transfer mediums that play this role.

As of now, the Lead Acid battery accounts for more than 90% of the Indian energy storage market. However, advanced technologies like Li-ion, Flow batteries (Vanadium Redox, Zinc Bromine) and Sodium Sulphur are also entering this market with a few pilot projects and in limited segments.

While pumped storage hydro systems as well as reservoir based hydro systems are also being looked at afresh as their technologies are well established, there are ground level challenges that need to be surmounted. These include the impact on environment as well as on local populations.

Gas-based power plants are also being seen as a useful solution to meet ramping requirements of the grid on account of intermittent output of wind and solar. Storage here would be in the form of gas in the supply pipeline. India has about 25,000 MWs of such capacity, most of which were operating at very low capacity levels due to unavailability of gas earlier and reduced demand of late. While the solution would appear very appropriate, the difficulty is that almost all of this capacity is based on a closed cycle mode where the exhaust heat from the gas turbine is fed into a heat recovery boiler connected to a steam turbine. The steam cycle is resistant to rapid changes of output. While the design adopted in many such power plants allows for isolation of the boiler, the operational experience has rarely been very happy.

## 5.10 Future Need Assessment till 2030

India has already set the ball rolling for scheduling of wind and solar power output by drawing these sources also into the regime of scheduling and dispatch. The initial step is only for power flows on the National Grid (inter-State grid). It would therefore affect the generating entities only indirectly as they are all connected at present to the local State Grid (intra-State grid) due to their relatively small individual capacities. However, this is a very significant step as newer wind and solar capacities are planned at much higher sizes and many are proposed to be connected directly to the National Grid. Indian States may also take a cue from the inter-State regulations and extend the same to smaller wind and solar plants within their State power grids.

The impact of the above is that wind and solar generators will become liable to pay penalties for shortfall in output vis-à-vis their pre-declared output schedule. This means a much greater need to have more accurate output forecasting solutions. However, since output is determined by a not-so-predictable input, there is now a great need to manage the output in a much better manner, giving rise to the criticality of energy storage.

With a targeted capacity of 60,000 MW of ground mounted and grid-connected Solar PV, 40,000 mw of rooftop Solar PV and 60,000 MW of wind capacity by 2022 alone, the need for energy storage is humongous. Renewable capacity is proposed to be further enhanced to a cumulative of 3,00,000 MW by 2030.

The required energy storage capacity in grid-applications in India is currently estimated at about 20,000 MW by 2020 and 35,000 MW by 2030. Off-grid applications including rural micro-grids, telecom towers etc. are expected to form another substantial chunk. A major installation process is already under way for telecom towers where back-up diesel generation is being replaced where feasible with solar PV combined with Lithium ion storage batteries. This is expected to even take the total storage capacity market size to as much as 70,000 MW by 2022 itself, though the cost of storage would play a major role in realization of such numbers.

An Electric Mobility Mission was launched by the Government in 2013 to improve national fuel security by promoting electric and hybrid electric vehicles. In 2015, the Government launched a scheme for Faster Adoption and Manufacturing of Electric Vehicle (FAME) under which subsidies are to be provided in the form of cash discounts on the purchase of electric vehicles and also for installation of charging stations. The scheme expects to achieve deployment of about 6 million electric vehicles in India by 2020, ranging across two-wheelers, four-wheelers and heavy vehicles.

## 5.11 Political Will

The Government of India made a powerful demonstration of political will in 2015 by announcing the very challenging plan to take renewable generation capacity to 1,75,000 MW by 2022. Since this would form a very major part of the total installed power generation capacity in India by that time, it was imperative that steps be taken to enable smooth integration of the new capacities and to achieve effective grid balancing so as to ensure the reliability of the grid.

The key reasons behind the setting of this humongous target for renewables-based generation were to contribute towards mitigation of climate change, to reduce dependence on imported oil and to enhance energy security. The launch of the National Electric Mobility Mission was also another step in this regard which seeks to shift the energy source for transportation from oil to electricity. A National Energy Storage Mission is also expected to be launched sometime later in 2016.

These programmes for renewables development as well as increased utilisation of electricity through replacement of oil-based energy both require the expensive deployment of viable energy storage solutions. Given the federal structure of the Indian polity, success of programmes is usually incumbent upon enthusiastic support from various Indian States. While this calls for the Central Government to play a coordinating and knowledge sharing role, it usually requires the Central Government to take the lead by spearheading flagship programmes that demonstrate the viability of any new schemes. This assists State level entities to take faster steps to implement such schemes within their domains after tailoring them to suit local needs.

The success of the wind as well as the solar power generation programmes have both been due to decisive business models and incentives from the Central Government that were taken up by a couple of States initially. Once the early projects succeeded, others were less hesitant to follow suit. This demonstration of political will is expected to again play a key role in the development of energy storage projects.

India's Intended Nationally Determined Contribution (INDC) for mitigating climate change will see a fivefold increase in renewable energy in the world's third largest electricity market by 2022, driving significant further cost reduction and innovation. India has formally committed to lift renewable energy installations from the current 36GW fivefold to 175GW by 2022. In addition, India has announced a significant new target to take renewable installations to 40% of installed capacity by 2030, relative to only 13% today.

Such an increase in India's renewable base will drive technology, innovation and cost reduction not just in the renewables-based generation space but also very much in the energy storage space. India has already seen a 70% drop in the installed cost of solar in the past five years, with early tariffs being in the range of INR 15 against current levels in the range of INR 4.50. It is expected that similar political will would be needed to support the scaled up requirements for deployment of energy storage systems.

The transformation involves a rapid diversification of the electricity grid away from its current reliance on coal fired power generation. The INDC involves building renewable energy capacity to 40% of India's total by 2030. With additional emphasis on expanding both hydro-electricity and nuclear in addition to renewables, thermal generation capacity will decline to 55% of the total by 2030, relative to its current 70% share.

The Ministry of New and Renewable Energy (MNRE) of the Government of India has constituted a Standing Committee on Energy Storage and Hybrid Systems. MNRE has also released the draft outline for National Energy Storage Policy and is currently in the process of gathering inputs from various stakeholders to introduce specific policies to fast track the adoption of storage technologies in India.

As part of this effort, MNRE released an Expression of Interest for demonstration projects in September 2015, which received tremendous response from stake holders. MNRE is currently in the process of evaluating over 40 proposals and is expected to announce the shortlisted projects soon. These projects would be for demonstration of both off grid / micro grid as well as large scale renewable integration applications.

These demonstration projects would further provide guidance to the Government and the political leadership and assist in adapting the policy environment to enable large scale integration of storage at the least possible cost into the energy systems of the country. This should also help create policies to encourage manufacturing of energy storage systems in India and the rapid evolution of technologies.

### 5.11.1 Policy Framework

Energy storage technologies have begun to gain recognition from Indian policy makers as one of the crucial enablers for renewables integration, for the success of electric vehicles, for the reliability of rural micro-grids that facilitate greater energy access and also to an appropriate extent in efficiently meeting the energy needs of smart cities.

In recognition of the critical importance of energy storage particularly for integrating renewable energy, the Indian Ministry for New and Renewable Energy (MNRE) has set in motion the process for some demonstration programs to support the deployment of energy storage projects.

These demonstration projects are expected to be of help in acquiring the desired technical knowledge, economic and market insights on the approaches needed for developing a sustainable energy storage market in India. They are also expected to generate awareness amongst users on the performance and economic benefits of energy storage technologies and models for their application. It is also expected that these will help in developing innovative approaches to finance energy storage technologies and also develop capacity to test and verify performance. The program will assist the selected applicants identify and select the best fit energy storage solutions for applications based on lifecycle cost of energy delivery while at the same time aim to limit the upfront investment burden on the end users.

The key program objectives are:

- To demonstrate technical performance of various energy storage technologies across a wide variety of application areas.
- To establish the value of energy storage solutions for various end use energy applications.
- To develop new and innovative business models that support energy storage market expansion.
- To leverage the experience from demonstration projects to understand the potential market size and ways to scale-up deployment in key application areas.
- To identify key policy measures to enable scale up of energy storage technologies, and reduce the need of direct public support or subsidies.
- To develop protocol for effective validation of technical performance of energy storage technologies.
- To engage with a variety of end users and concerned stakeholders through their participation in the demonstration program and make them aware of the benefits of energy storage technologies, market potential and innovative business models.

The expected outcomes from the demonstration program are:

- ✓ Identify applications to make renewable energy more competitive or scalable by identifying applications for future support where energy storage can improve effectiveness of RE integration, improve reliability of energy supply, and reduce cost of energy supply/usage and/or enhance the scalability of these technologies.

- ✓ Establish performance of new energy storage battery technologies like Sodium Sulphur, Redox, Lithium Ion, Ultra Battery, etc. which are commercially available but have not been deployed on a large-scale despite of improved life cycles and efficiencies, better depth of discharge and lower energy storage cost over the lifetime. The demonstration program is expected to facilitate the adoption of new and improved technologies by improving the knowledge of their lifecycle costs and technology performance so that they can meet user requirements and provide most competitive value propositions.

- ✓ Develop new business models for deploying energy storage solutions to support renewable energy generation, potentially through the design and deployment of service based business models which introduce either a strategic investor or a storage service supplier.

## 5.12 Favourable Scenario

Due to not-so-uncommon power outages in most parts of India due to supply and maintenance constraints, there has been a huge market for electrical energy storage for several years. This is mainly in the form of lead-acid batteries connected through an inverter and caters mainly to the commercial and residential segments as a power back-up source.

The storage market is however undergoing a transformation due to several reasons. One of these is the need for renewable energy integration as a result of the 1,75,000 MW target for renewable energy capacity addition. As intermittent sources of energy like solar and wind-based power generating capacity gets added to the grid, it becomes an increasingly difficult challenge to manage the grid due to the obvious constraints in forecasting and dispatch.

The other favourable area for energy storage lies is microgrids. Over 300 million Indians lack access to electricity despite of various efforts made over the last few decades. Distributed power generation through microgrids using renewable energy sources is already being seen as a viable solution. The success and reliability of such microgrids requires the use of energy storage devices as users would lose interest in the new sources of energy if it is not available when needed. The National Smart Grid Mission (NSGM) has set aggressive targets for microgrids and thus provides a policy framework.

The third growth area for energy storage is electric vehicles. The Government's National Electric Mobility Mission (NEMM) targets 6-7 Million Electric Vehicles by 2022. Almost 0.3 million battery operated electric rickshaws operate in India already. Besides large players with international ambitions like Tesla, Indian entities have also started development and commercial deployment of electric vehicles albeit on a small scale. Institutes of higher learning like IIT Madras have also set up separate departments for research and development in the area of electric vehicles including establishment and support of incubation centres.

Besides these, the policies for rooftop solar PV across some Indian States would also incentivise the deployment of energy storage by the consumer end. This would be particularly true where virtual net metering allows people to collaborate and establish larger solar generation capacities and utilise them with some time flexibility.

### 5.12.1 Promotion of hybrid renewable generation systems

The Government of India has come out with a draft National Wind-Solar Hybrid Policy in June 2016 for promotion of renewable energy based power generation on a larger scale. The draft policy has a target of implementing 10 GW of such hybrid capacities by 2021-22. The objective of this policy is to promote a large grid connected wind-solar PV system for optimal and efficient utilisation of transmission infrastructure and land. It also aims at reducing the variability in renewable power generation and thus achieving better grid stability.

With critical infrastructure such as land and evacuation network for wind or solar project accounting for about 10-12 per cent of the overall project cost, hybrid projects are likely to benefit from a reduction in capital cost to some extent. Common infrastructure like inverters may add to the savings.

The variability in generation profile is also likely to be reduced to some extent by the hybridisation of wind and solar projects at the same site, particularly at the seasonal level as peak output of each is in complimentary seasons. This could partially address the concerns of distribution utilities over the grid balancing due to the intermittent nature of wind or solar generation.

Since output imbalances would most likely be reduced, the role of storage systems could become much more cost effective as the storage capacity required for hybrid systems should be significantly less. Besides more predictable and stable scheduling and actual operations, storage systems would also result in a significantly higher level of utilisation of reserved transmission capacity, thus reducing the per unit cost of delivered electricity.

### 5.12.2 Grid curtailment of intermittent renewables

The spread of grid curtailment is starting to threaten the credit worthiness of renewable energy projects in India and has the potential to impede capacity addition. While this phenomenon has already impaired the operational strength and therefore the revenues of some wind projects, the impact may soon be visible on solar projects especially in States with large concentration of this resource.

Due to the overall weaker load demand, there is often a surplus situation in the grid. At such times, when intermittent renewables like wind and solar are given priority in despatch due to their ‘must-run’ status, there is often a constraint on the capacity of the transmission asset closest to the energy resource. Grid curtailment is a consequence. Given that the uncertain input supply creates a revenue loss when input is lower, this becomes a double whammy when the evacuation of output is curtailed when the input is higher.

In India, the Southern State of Tamil Nadu which leads in Wind capacity has significantly curtailed wind generation output in the last three years. This story is now seen in the Northern State of Rajasthan also in recent months.

This opens up significant avenues for deployment of energy storage capacities to assist the renewable project owners as well as the grid managers in balancing the output and increasing overall energy flows through avoidance of grid curtailment to some extent. This, of course, would depend very much on the cost impact of storage and the related revenue improvement.

With the average annual grid availability for wind assets in Tamil Nadu being less than 80% from 2013 -14 to 2015 – 16, the revenue implications have been significant. While grid availability has significantly improved in the first few months of 2016-17, the opportunities for large scale repowering of old wind turbines (with around 1900 MW installed up to 2003) may be impacted positively by the inclusion of a strategic portion of energy storage in the new capacity addition.

Keeping in view the technical and commercial challenges that are emerging in Germany and Belgium for distribution utilities because of changes in the energy mix, the opportunities for a significant role for energy storage in conjunction with Wind and Solar generation in at least some resource rich parts of India appears inevitable.

The current lack of reliable technology aids to predict the resource risk and the resultant impact of the costs of integration of renewable energy in the grid creates a favourable space for storage technology deployment.

### 5.13 Institutional Installations of ESTES

Though still in early stages, India is also getting into the energy storage era through various installations.

An Indian business group ACME, that is also a major player in the solar power generation space, has taken the lead in energy storage installations and converted its main office building in the National Capital Region into a one-of-its-kind ‘Battery-Operated-Building’ in

India. An advanced energy back-up solution has been successfully implemented here. The building uses a stack of Lithium-Ion batteries with a capacity of 270 KWh.

The battery gets charged fully from deep discharge condition in about two hours. This solution does not consume any further electricity to sustain itself till the next use. It goes into sleep-mode and conserves electricity to deliver complete power back-up. The major components of the installation are the Lithium Ion batteries, Battery Management System and a hybrid inverter.

This battery is being charged from the grid only. It can, however, be connected independently with a renewable energy source or in an integrated mode with both grid supply as well as renewable energy generation.

This system can work very well for residential, commercial and industrial segments and has demonstrated the scope of lithium-ion batteries as an effective and operational energy storage solution.

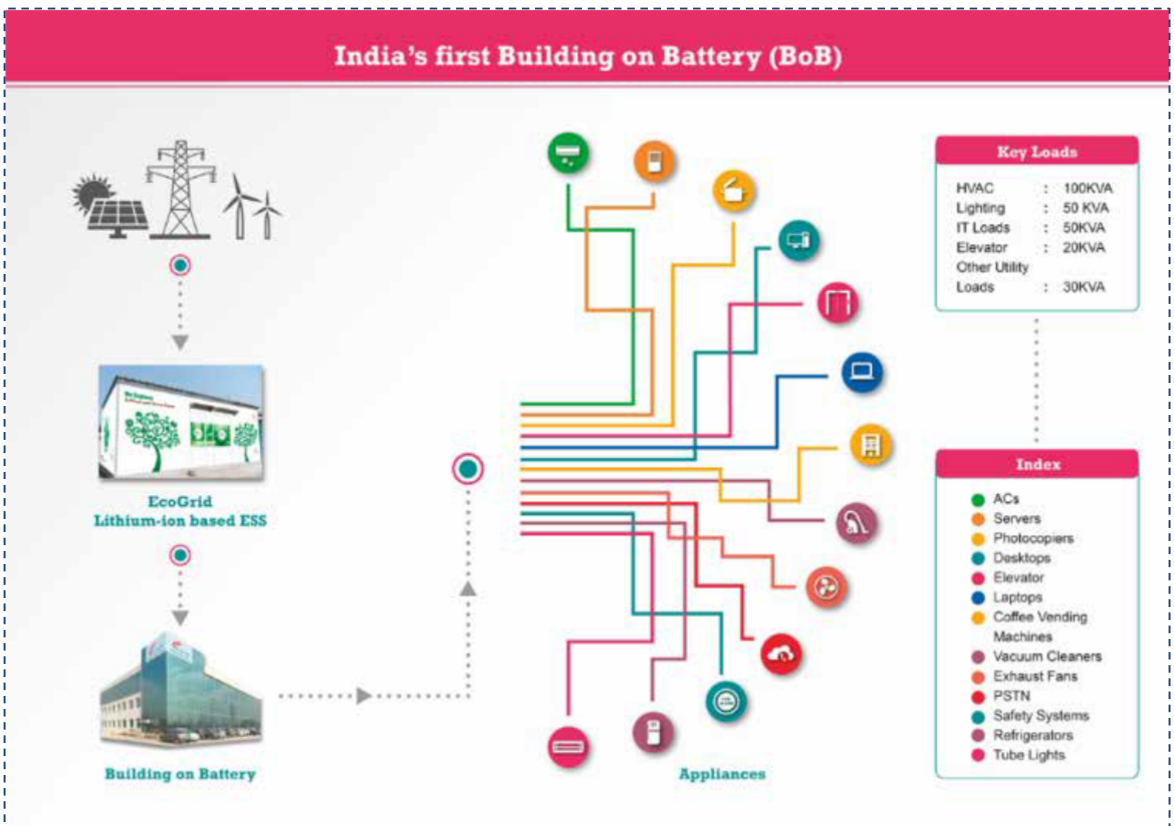



*Figure 5.6 India's first building on battery (BoB)*

As stated previously in this study report, the Indian Ministry of New and Renewable Energy (MNRE) has begun the process of demonstration projects to assess the feasibility of energy storage technologies for both small-scale and grid-connected MW-scale renewable energy applications. In recognition of the need to develop technical knowledge and economic and market insights as well as generating awareness amongst users, MNRE has supported a project that is expected to help demonstrate how the grid can absorb a large penetration of variable wind and solar PV generation.

IL&FS Energy Development Company Limited (IL&FS), is evaluating the development of integrated wind and solar photovoltaic (PV) projects with energy storage, to enable the supply of dispatchable utility-scale renewable energy to meet the Indian grid system's needs. IL&FS has signed a grant agreement with the U.S. Trade and Development Agency (USTDA) to partner on the development of innovative Wind Integrated Solar Photovoltaic Energy Storage (WISES) projects.

IL&FS has chosen General Electric (GE) to examine the feasibility of integrated wind, solar and energy storage projects at its site in the State of Andhra Pradesh. As part of the study, GE will design an integrated wind, solar and energy storage plant, estimate its capital and operating costs and develop a business plan that includes the viability gap funding that will be required for the commercialization of the project. The project is expected to be completed in 2017.

In another effort, India has begun taking first steps towards utility scale energy storage for the Indian solar market through the Solar Energy Corporation of India (SECI). In July 2016, SECI announced the release of tenders for solar project developers to install storage solutions along with their projects. In prospective tenders for 100 MW capacity in the Indian State of Andhra Pradesh and another 200 MW in the State of Karnataka, it is proposed that for every 50MW chunk of the solar projects, there would be a connected storage capacity of 2.5 MWh. The primary commercial objective of these tenders is stated to be the desire to attract leading battery manufacturers in the world to look at India as an upcoming market for utility scale energy storage solutions.

Assuming the solar plant to operate for 10 hours a day, the storage capacity would cater to only 3 minutes of full load operation. For the proposed specifications, it is expected that the inclusion of storage may lead to an increase of 0.3 US cents in tariff. While the technical benefits of storage of this relatively small size (with respect to the solar project size) are not expected to be very significant, the key takeaway would be an assessment of the benefits to grid operators with proximately located utility scale storage.

Another storage installation, on a distributed scale, is already happening in the telecom space. Most telecom towers in India, outside the main metros, suffer from frequent power outages from the grid. As a result, they have had little choice but to back up the energy needs with lead acid batteries or with diesel generators.

British Fuel cell technology company Intelligent Energy proposes to invest £1.2 Billion to power telecom towers through deployment of over 10,000 hydrogen fuel cells. Essential Energy, a subsidiary of Intelligent Energy, will handle power management of over 27,400 mobile telecom towers, a number that is close to 50% of telecom towers in the United Kingdom. The fuel cells are to be initially manufactured in Japan, and as the supply chain is developed in India, the products will be made in India under licence. Besides zero emissions, hydrogen fuel cells would not only produce very little noise compared to diesel generators but are also expected to reduce the cost of ownership over their economic life.

On a similar note, with a different technology solution, one of the world's leading battery manufacturers Saft has begun installing Lithium ion battery solutions in India's telecom market rolling out them out to over 16,000 4G/LTE BTS sites across India. These are being provided through SAFT's Indian arm, AMCO Saft and will provide backup power to ensure continuity of the mobile network.

AMCO Saft is also positioning itself for other Li-ion Energy Storage System projects in India, with a focus on integration of large solar PV schemes as well as microgrids based on PV, diesel generation and energy storage that will significantly reduce fuel consumption as well as maintenance costs.

There is thus a reasonable variety of institutional installations that are under deployment in India and the numbers, sizes and complexities are very likely to increase significantly in the coming years.

### 5.14 Energy Storage Technologies – Infrastructure

## And Expertise in ESTES and Human Resource

One of the leading organisations on the promotional and knowledge building front that is also making strong attempts to integrate all energy storage enthusiasts on a common platform for mutual benefit and for policy advocacy is the India Energy Storage Alliance IESA. IESA has been organizing several seminars and workshops while also working with policy makers to steer a more optimal course for this nascent industry.

Besides this, there are organisations working under grants from the India - United States partnership programmes which are conducting generalized studies and also engaging in capacity building exercises. These include entities providing services under the Partnership to Advance Clean Energy (PACE) programme. The program has achieved many major milestones including strengthening institutional and human capacity, improving the enabling environment, mobilizing finance for clean energy and increasing awareness and understanding of new clean energy technologies. The PACE programme has been expanded to include a new track on smart grids and energy storage under the Joint Clean Energy Research Development Center.

There are also many institutions and companies engaged in technology development as well as applications development. Some of them are as follows:

### CSTEP, Bangalore

The Centre for Study of Science, Technology and Policy, CSTEP is an institution in Bengaluru in India that is engaged with several resource development activities in the area of energy storage. These include techno economic feasibility studies on select aspects of storage systems and grid integration scenarios, prediction of new electrode and electrolyte compositions using quantum mechanical/molecular dynamics approaches, fundamental research work on Lithium-ion batteries in collaboration with the Defence Research and Development Organisation DRDO etc.

CSTEP is also collaborating with the Carnegie Mellon University and the Washington University at St. Louis as part of the Solar Energy Research Institute for India and the United States (SERIIUS). The ongoing work is mainly in autonomy, battery sizing and grid integration studies including geographical smoothening of solar.

### IIT Bombay, Mumbai

IIT Bombay, a premier engineering institute in India has been conducting experimental research for development of novel nanostructured materials for Lithium-ion batteries, Sodium-ion and Magnesium-ion batteries, Lithium Sulphur and room temperature Sodium Sulphur batteries for large-scale storage. Novel hybrid ionic electrolytes are also being researched for safe lithium battery systems and work is being undertaken for the design of optimized battery electrodes and novel fabrication techniques.

### National Chemical Laboratory (NCL), Pune

The National Chemical Laboratory has developed an efficient, low cost membrane which is crucial to build hydrogen fuel cells. The Indian Government had unveiled a hydrogen economy plan in 2014 that envisaged a million hydrogen--fuelled vehicles on India's roads by 2020.

### Indian Institute of Science (IISc), Bangalore

Researchers at the Indian Institute of Science (IISc) have developed a hybrid super-capacitor that can charge faster and withstand many more charging cycles than the currently available batteries. The device is a variation of an existing alkaline battery technology. The researchers started with the widely available nickel--iron battery and then replaced the nickel electrode with a carbon electrode. This is because nickel is both costly and toxic. The new technology combines the high cycle life and high power capability of capacitors with the high energy density and low self--discharge of batteries.

### Start-ups Scenario on ESS technology:

RCube Storage is a start-up located in Pune working on batteries using Sodium Nickel Chloride technology. Through technology transfer, RCube Storage has a plan to manufacture this energy storage system in India, which could potentially lead to high reduction in energy storage price in this sector. Ojovati A.E. is a Coimbatore based start-up working on lithium polymer based battery technology for distributed energy. They have a collaboration with a cutting edge technology supplier from Japan.

There is thus a small but dedicated spread of expertise in the form of institutions and human resources for development of energy storage technologies and applications on India. As the market for ESTES picks up, driven perhaps by the strong thrust towards deployment of renewables on a massive scale and also by the Government's push to provide 'power for all' over the next few years, there is already a core human resource base that can develop further to meet future needs. Much will also depend on the ability to scale technologies and applications based on local needs rather than let technologies come in from world leaders alone and then find applications and the human resources to work on them.

## 5.15 Market Climate for ESTES

A good market climate for ESTES is already being created through the launch of demonstration projects, as already described earlier. The outcomes of these projects would most likely impact the speed with which the market for ESTES develops in India. While the current size of projects may be too small for battery makers such as Tesla Motors Inc., Samsung SDI Co. and Panasonic Corp to look at India as a large market, the sheer size of the country and the reasonably well developed state of its power market could very well enthuse international majors as well as local entrepreneurs to establish capacities for the emerging storage market.

In India's off-grid market, low-cost renewable generation devices like solar lanterns are already catering to basic needs. These devices will need to be replaced with stronger systems as households start using higher-wattage appliances such as fans and televisions. Considering the size of India's off-grid population of around 300 million, the storage market needs just the right push from Government and industry together, perhaps with the right financing solutions that incentivise faster adoption. Besides this, there is already a growing market for energy storage in the telecommunications space.

The grid-connected market dynamics are driven by new policy changes, increased privatization, relaxing of Foreign Direct Investment (FDI) norms in the sector, new capital investments in renewable power projects by both public & private sector, increased use of smart metering and the emergence of smart grids to better manage services & reduce transmission losses, and growing electricity demand. While rooftop solar penetration is slowly increasing in India, demand-side management is often tricky and currently has to depend on the availability of net metering policies that enable export of solar power to the grid during surplus conditions and import during deficit periods. Lower costs of energy storage technologies will definitely make it easier for consumers to reduce their dependence on the distribution network and related policies, thus enabling them to treat electricity as any other commodity that can be inventoried.

On the large storage front, the Government has very recently announced plans to set up around 10,000 MW of new pumped hydro storage capacity over the next five to six years. While the timelines may be a bit ambitious, the very fact that pumped hydro is again in the sights of policy makers sets the right tone for the market climate for ESTES.

Frequency Control Ancillary Services are now being introduced in India and contracts have been signed by the grid operator with some bulk power generators. The Energy Storage market for this application does not exist at this stage because of costs as well as some uncertainty about performance parameters of available technologies. But this market has huge potential for ESTES considering the size of the Indian grid that is over 3,00,000 MW. At the very least, a market for 2000 MW could open up in the ancillary services space within the next five years as prices drop and technology becomes more reliable.

## 5.16 Financial Models currently positioned for ESTES

Energy storage systems are currently in an in-between land, neither identifiable with generation or with transmission/distribution or with consumption. As storage systems scale up and customers look for finance, it could therefore meet a fate more difficult than solar power did in India about five odd years ago when investors and lenders were wary of deploying their funds as the risks were unknown. The high initial tariffs of solar power and the lack of long-term product warranties added to the difficulties.

Solar power has now crossed the threshold and climate change pressures are making it easier to obtain financing. Energy storage systems could therefore possibly look for support from those who have invested in or lent to the renewables industry. Just like renewable energy, storage too promises to fulfil a number of objectives for India, particularly in increasing energy access and improving the air quality by helping replace polluting energy sources. Due to their hopefully low operating costs, storage resources may also be deflationary and thus enhance the sustainability of economic development. They would also further aid the success of renewables and reduce dependence on fossil fuels where prices are often controlled by global market forces, besides their negative impact on climate.

A good initial financial model for storage systems could therefore be akin to ‘Green Bonds’ that have been used with considerable success in recent months to support renewables financing. Some major Green Bond issues to raise capital for renewables have been successfully concluded in recent months in India by renewables companies like ReNew Power Ventures and Hero Future Energies. Several banks and financial institutions like the Government owned Indian Renewable Energy Development Agency (IREDA), private banks like Axis Bank, Yes Bank and IDBI Bank and also India’s Exim Bank have also conducted successful ‘Green Bond’ issues totalling to over USD 1.85 bn as of June 2016.

The bond issue by ReNew Power Ventures was the first to be done under a credit enhancement scheme of the Indian Infrastructure Finance Company Ltd providing the first loss partial credit guarantee to the bondholders along with an irrevocable back-stop guarantee with the Asian Development Bank. The bond issued in 2015 matures in 17.5 years, giving a significantly longer tenure than commonly available long-term bank credit.

Hero Future Energies, a leading renewables company, issued the country’s first certified climate bond in February 2016 and raised the equivalent of USD 44 million by issuing nonconvertible debentures certified by the Climate Bonds Standard, an international certification standard for green bonds.

Yes Bank, one of India’s private sector banks, issued its first green infrastructure bond in February 2015. The Euro-denominated INR 10 billion ($161 million) 10-year issue received a AA+ rating and was oversubscribed by almost over two times, demonstrating a huge demand. The issue proceeds are being utilized to fund renewable energy infrastructure projects. Yes Bank then issued another 10-year INR 3.15 billion ($50 million) green bond in August 2015. The entire issue was subscribed by the International Finance Corporation

(IFC), part of the World Bank Group. IFC then issued an AAA- rated “Green Masala Bond” on the London Stock Exchange for the same amount. This essentially capitalized the Yes Bank green bond and lowered the cost of lending to green projects.

Export-Import Bank of India (Exim Bank) issued India’s first ever and Asia’s second dollar-denominated green bond in March 2015. The sale, initially aimed at $300 million, raised $500 million for a five-year green bond to international investors. The BBB- rated issue was oversubscribed by more than three times, attracting a total of $1.6 billion in bids. The issue was priced at 147.5 basis points over benchmark US Treasury Bonds, for a coupon of 2.75%.

The Exim Bank did not get an external green certification, but provided a series of detailed investor updates and assured audit certification of the use of proceeds. The issue proceeds are directed toward funding eligible green projects in Bangladesh and Sri Lanka. The Exim green issue followed close on the heels of a standard $500 million issue.

In July 2016, India’s largest power company NTPC mandated a group of banks for an offering of Green Masala bonds. This is the first corporate Masala bond offering to commit proceeds to Green projects. NTPC had planned to raise Rs 1000 crore ($149 million), plus a greenshoe option. The bonds will be denominated in Indian Rupees but settled in US dollars. The bond issue received tremendous response from the market and was oversubscribed heavily. NTPC therefore revised the issue size to $ 300 million. The bonds are priced at an annual yield of 7.48% with a 5-year tenure.

There is thus a healthy dose of green bond issuance in India both onshore and offshore. This route could therefore very well be used for energy storage projects too, especially when their cost and reliability levels become more acceptable to long-term investors. The example of the Exim Bank where a ‘green bond’ issue was preceded by a colour-free bond also shows that the ‘green’ colour of the bonds is not necessarily an added incentive but may help enhance market perception. The other key element of this bond issue was that it was meant for projects in third countries, thus giving a leg-up for future SAARC level projects.

## 5.17 Challenges faced in ESTES Deployment

The foremost challenge faced in ESTES deployment in India is obviously the cost. Had the cost been low, many other existing uncertainties could well have been ignored. Given the cost levels, it becomes extremely important to optimise the design of an energy storage solution with specific regard to the application. Oftentimes, the application is itself not understood very well. The extent of power that may be required, the rapidity with which it may be required, the time for it is needed, the time available for recharge before the next requirement etc. become critical.

At the grid level, it has been established that daily or even hourly variations in the demand-supply pattern are of little use in determining the sizing and parameters of storage solutions. A minimum time interval of one minute is required for grid level storage assessment and much smaller time intervals for storage related to critical applications.

Besides the sizing and design of the storage system to meet specific applications, the system's operational procedures and corresponding safety requirements are also crucial to ensuring it functions properly and operates to its forecasted lifetime. The other challenge is linked to the question of storage location, whether it is needed at the generation, transmission, distribution or consumer level.

Another challenge that ESTES deployment would likely face is in grid integration as it will eventually compete and also complement other methods to improve grid flexibility. There would always be an economic and technological choice between large centralised storage and small decentralised storage on the one hand and with flexible generation systems & back-up capacities on the other.

## 5.18 India - Gap Assessment

Rapid developments are taking place in India in the technology space in power generation as well as distribution. There is a renewed thrust for reaching electricity to the unserved segments, particularly in rural and otherwise remote areas through reasonably reliable distributed generation rather than the hitherto tried grid-based delivery. The threat of climate change in a larger sense and atmospheric pollution in cities in a concentrated sense are creating an urgency to reduce the ever-growing number of combustion engine based vehicular traffic. Energy Storage systems are thus expected to play a key role in the emerging energy ecosystem in India.

Going by current trends and the outlook for the future, some of the major gap areas for ESTES deployment in India over the next five to ten years are assessed to be the following:

**Rapid growth of intermittent sources of electricity generation** - India is heading towards rapid adoption of clean energy technologies with a targeted capacity of 60 GW of wind capacity and 100 GW of solar capacity by 2022, all of which would be dependent on intermittent resources.

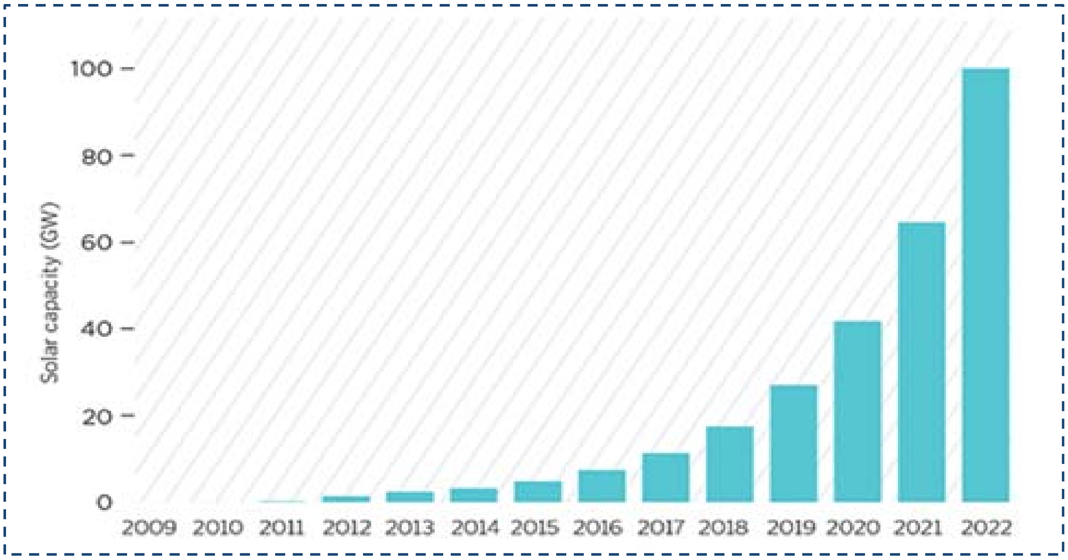



*Figure 5.7 India Solar capacity addition path (MNRE, India*

As this huge addition of solar and wind generation capacity takes place, the impact of intermittency of their output on the grid, whether the larger grid or a microgrid, would need to be balanced. This balancing would not only need to be of adequate capacity but also of sufficient enough duration. It would also need to discharge and charge fairly rapidly.

The national level electricity regulator in India has already introduced scheduling of the output of renewable resources to the national grid, which would entail penalties for deviation. Irrespective of penalties, it would become more and more onerous for the grid operators to handle the sudden fluctuation caused by dips in wind and solar PV output. Grid balancing would place increasing demands on quick response storage resources.

Besides this, the national electricity regulator has already introduced ancillary services in the national grid where generating assets are paid to remain on standby or are kept as a spinning reserve in order to stabilise the grid. Storage resources could become independent suppliers to such services or could be integrated with intermittent sources, thus making wind and solar resources eligible to earn revenues by providing such services. In a grid that is expected to reach a capacity of over 7,00,000 MW within the next five years, the need for energy storage resources would be of the order of at least 25 to 30,000 MW.

Therefore, the MW / kW capacity, the MWhr / kWhr capacity as well as the rate of discharge, rate of charge and the depth of discharge would all be important.

**Reliable electricity supply to unserved areas and to major cities** - Various initiatives are being taken for providing energy access through microgrids for the nearly 300 million people who are currently without access to reliable grid electricity.

The Indian Government is looking at transforming 100 cities into 'Smart Cities' within the coming decade where energy storage technologies may need to be a vital element. Storage technologies can serve as a backbone for the better power quality and reliability that would form a part of the standards set for such cities.

A National Smart Grid Mission (NSGM) is also being implemented where Energy Storage is one of the key enablers. Given that the load demand in these 100 cities and in new microgrids would be of the order of about 30,000 MW, the space for storage capacities would be at least between 3000 to 5000 MW.

**Large scale introduction of Electric Vehicles (EVs)** - An ambitious Electric Vehicles (EV) programme, the National Electric Mobility Mission Plan - 2020 with a goal of over 6-7 Million EVs by 2020 is already being implemented with the objective of reducing oil import bills. India has more than 3 lakhs (0.3 million) electric scooters and battery operated e-rickshaws operating across a large number of cities.

Many car companies have already launched electric hybrid cars besides a few who have started delivering compact all-electric cars. In fact, new companies have sprung up to provide leased services of such emission-free cars for corporate car pools, especially for IT software service companies that operate on a 24 x 7 basis and need dedicated pick-up and drop services on fixed routes for their employees.

Battery storage in EVs can be a potential solution to high solar power supply during afternoons and high wind power supply coupled with low grid demand during night hours by getting charged at such times. As EV adoption multiplies in India, they could act as a large scale distributed medium of storage to level the load curve and also provide an excellent solution to the backing down of RE generation. With the current target of about 6 million EVs in India by 2020, the demand for energy storage is estimated to be of the order of 7 to 10,000 MWs.

**Back-up measures to address weaknesses of local grids** – India's national grid has already achieved a high degree of robustness. However, gaps remain in the State level grids where allocation of funds is sometimes an impediment and serious problems exist in the local level distribution networks in most areas.

India is already one of the largest markets for conventional Lead Acid flooded and VRLA batteries, with an estimated installed capacity estimated as much as 40,000 MWs. Besides automobiles, these are typically used in homes and small offices across the country in conjunction with inverters in order to provide respite from power cuts that have been prevalent. Though the grid power reliability has improved dramatically in some Indian cities in recent years, the situation in most other places (except Delhi and Mumbai) continues to remain conducive to behind-the-meter back-up systems inspite of the overall national power surplus. This is because the local distribution company is usually in a delicate financial state and therefore often prevented from making available sufficient quantities of electricity particularly when demand peaks. The requirement of batteries for such uses would continue to increase, besides the market created by distributed solar generation for homes with larger roofs. This combined market is estimated to provide a need for at least another 10,000 MW over the next 5 years.

## 5.19 Bridging the gap

The main constraints in large scale deployment of storage are cost and technical feasibility. Alternatives to storage 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 current deployment of electricity storage technologies is limited. Compared to 5700 GW of installed electricity generation worldwide, there is less than 175 GW of electricity storage capacity installed, most of which is pumped hydro.

Given the status of currently available Pumped Hydro Storage (PHS) in India, with less than 2600 MW of the nearly 8000 MW installed capacity PHS actually operating, it is very unlikely that this will be able to cope with the emerging demand at the large scale grid level. Challenges with regard to land acquisition, displacement of people and their livestock, loss of cultivable areas, impact on flora and fauna and other social and environmental factors appear likely to be very difficult to overcome.

The other solution is open cycle gas turbines which can ramp up and down rapidly. While India has an installed gas-based power generation capacity of around 28,000 MW, all of this is of combined cycle design that does not permit quick ramping due to the involvement of steam water cycle. While many of these plant can be operated on open cycle through the use of a bypass stack, past experience in India has not been encouraging at all. Though gas prices for the sub-continent have come down in recent months and the low oil prices on the international market appears to make gas an attractive option, it is unlikely that investors and lenders would take significant risk at the moment.

This scenario by and large leads to the third option of storage batteries, which have the added advantage of being used in small capacities also. However, there are two key concerns with batteries. One of them relates to safety, which to a large extent is already being addressed quite effectively in the design stage and in the factory. The other relates to cost, which for most battery technology options is still very expensive except for a few applications where the current cost of operations is very high. Besides this, except for the use of lead-acid batteries, most electricity storage technologies are at early development stage and commercial applications are only just beginning to be deployed.

Current projections are that battery storage deployments for buses are already viable and can therefore pick up significantly.  This is due to the already competitive cost of grid electricity (even from relatively expensive RE sources) combined with batteries vis-à-vis diesel engines. The fuel cost of an Electric AC bus is estimated at under INR 17 / Km (INR 14 per kWh for electricity with storage and 1.2 kWh per km) compared to Rs 22 / Km for a Diesel city bus (2.5 Kmpl at a diesel price of Rs 55/L).  For a car, the comparative numbers are much closer currently and are further constrained by the weight of batteries.

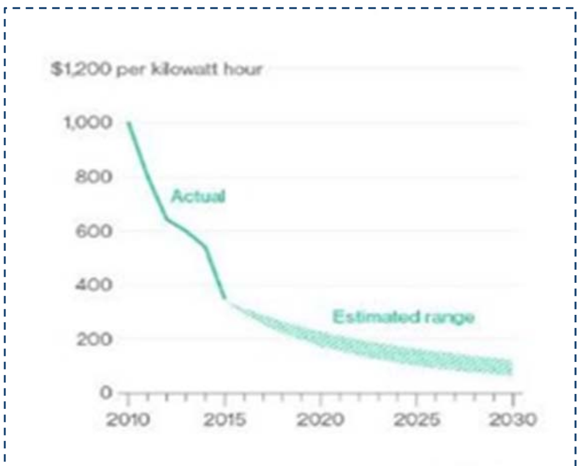



*Figure 5.8 Falling costs of Lithium Ion battery packs for EVs (BNEF Bloomberg)*

For grid level applications, the cost factor is still fairly prohibitive when viewed in the light of requirements of rapid discharge capabilities, design and sizing constraints for MW level storage, cycle life and depth of discharge. A study conducted in 2014 had examined the option for energy storage systems to reduce constraints in transmission capacity in the Southern State of Tamil Nadu, where for 9 months per year the transmission capacity is by and large underutilised. Based on the capital costs for strengthening of the transmission network for the remaining 3 months, it was found that battery storage systems were not cost-effective and needed a cost reduction of around 80% in capital costs. Though battery costs have come down significantly over the last two years, they are still not a competitive solution except in specific situations.

One other issue that needs to be borne in mind is that international experience with various emerging yet vital technologies shows that economies of scale with increasing demand does not necessarily lead to reduction of costs of the products. It has instead been found that in an unregulated market, prices can considerably increase as markets extract the best possible price for a product that is highly in demand and therefore end up slowing down its deployment.

## 5.20 Plan of Action for Implementation of Suitable ESTES in India

### 5.20.1 Recognition of Potential Application Areas

There is a clutch of potential application areas for energy storage technologies for the electricity sector in India, as would be evident from the discussions in previous portions of this study report. These cover on-grid as well as off-grid applications on the one hand and stationary as well as mobile applications on the other.

There are also a few pilot programmes taken up in India in the recent past and these give an indication of what are the already recognised application areas considered significant enough by some key stakeholders and decision makers.

India's national level transmission company Power Grid Corporation of India Ltd. has successfully conducted RFPs for selecting 3 different storage technologies of 500 KW for ancillary service demonstration projects. These are part of their Frequency Response Pilot Project and include an advanced lead-acid project, a lithium-ion project, and possibly a flow battery project.

The Indian Ministry of New and Renewable Energy (MNRE) has also floated some Energy Storage projects to support renewable integration. These are demonstration projects and are targeted to cover:

- Rural microgrids, both off-grid as well as grid connected
- Grid interactive microgrids
- Large standalone systems
- Integration of large scale renewable farms

The projects are being selected based on parameters such as the cost of energy saved, the cost of storage as a percentage of the cost of energy delivered, innovation, scalability, demonstrability, impact of application and business model for the delivery of energy storage solutions and on the financial strength of the host agency. MNRE also plans to assist selected companies through technical and financial support.

One such project involving design, development and demonstration of a pilot project for integrated operation with Solar PV has been taken up by IL&FS and GE. An Energy Storage Mission is also proposed to be launched by the Government sometime around September 2016, which is expected to provide greater structure and direction to the whole process.

India's leading power generation equipment manufacturer BHEL has recently started a process to empanel reputed vendors who have demonstrated capability to design, manufacture, install and commission energy storage systems and also to offer post-commissioning services/maintenance of such energy storage system. Vendors are also being offered the opportunity to participate in joint bidding together with BHEL on a case to case basis. One of the aims of this process is also to encourage and develop capabilities to take up manufacturing, assembly and testing of an increasing number of sub-components in India itself.

Under the FAME India Initiative (National Electric Mobility Mission Plan) the Government of India has set up a target of achieving over 6 million electric vehicles on the road by the year 2020.

The bottleneck for large scale incorporation renewables generation and electric vehicles is the same. It is energy storage. There is no control on whether the sun always shines or the wind blows and hence it would be increasingly difficult to integrate solar and wind power seamlessly into the electricity grid.

Effectively and efficiently addressing the inherent intermittency of renewable resources is a key enabling factor for large scale adoption. Several energy storage technologies are currently available and continuous developments in this area need to focus on the objective of providing more reliable clean energy.

For electric vehicles, having batteries with long cycle life, light weight and appropriate safety characteristics can bring electric vehicles within the reach of the common man. This will need support from the appropriate agencies and government bodies for developing the required ecosystem and charging infrastructure.

### 5.20.2 Important Prerequisites

#### 5.20.2.1 Political Preconditions

The history of technology policy across the world teaches us that policy design is not just dependent on expected policy outcomes but also on political preconditions, since investment programmes lacking popular or top level support may perhaps never have gone beyond discussion rooms.

The success of any endeavour as humongous and widespread as the deployment of energy storage depends very much on the support that it receives from the political level. This is even more important when the need is for a sustained campaign not only to bring in the most optimal resources over a period of time at the right places but also to try and ensure that the focus is not lost midway.

Some of the key drivers for political backing for the energy storage policy and implementation would be:

- The primary need to work towards energy security for the country in the medium term
- The criticality of reducing dependence on imported oil, even if prices stay low
- The massive push towards a renewables led electricity sector
- The continued pressures of climate change necessitating reduction of fossil fuel based energy
- Commitment to reach electricity for all (the current target for India is 2019)
- Ensuring adequate support to the economy through reliable electricity supply
- Do all of the above within the limits of funding that are feasible over a reasonable period

India's Intended Nationally Determined Contribution (INDC) for mitigating climate change will see a fivefold increase in renewable energy in the world's third largest electricity market by 2022, driving significant further cost reduction and innovation. India has formally committed to increase its renewable energy installations from the current 36GW fivefold to 175GW by 2022. In addition, India has announced a significant new target to take renewable installations to 40% of installed capacity by 2030, relative to only 13% today.

Scaling up to the indicated target levels will require technology improvements, innovation, and cost reduction particularly in the area of energy storage technologies. India's INDCs mention energy storage technologies for bulk storage and Renewable Energy integration, frequency regulation, utility Transmission & Distribution applications and for community scale projects.

The fact that the INDC has been finalized and committed by the Government is a major positive factor amongst political preconditions. The other political preconditions would also include a careful assessment of public reaction to any specific technologies or locations or environmental risks. Another key consideration would be sources of technology and of funding, where the possible existence or creation of a reasonably balanced inter-country relationship through other forms of trade or commerce could be given weightage.

The crux of any such gigantic effort to induct energy storage technologies on a large scale over the next several years is the resolution of a common political dilemma. If energy storage measures are introduced too quickly, the price of electricity will rise quickly and potentially trigger a backlash from consumers including industry. If energy storage measures are introduced too slowly, major renewable energy resources will either not become as reliable as fossil fuels or will risk becoming commercially too risky due to output curtailment.

Political establishments would also want to understand as to how much of the thrust for energy storage deployment needs to come through public investment and how much could be left to private funding albeit through strategic signals in the form of incentives and subsidies. This is where the role of think tanks and unbiased studies would prove handy in offering advice to support the political levels in setting the agenda for energy storage.

#### 5.20.2.2 Legislation

India is already considering a National Storage Mission to complement its highly successful National Solar Mission (NSM) and the Ministry of New and Renewable Energy (MNRE) is likely to come up with a draft document in 2016 itself.

As a precursor to support the implementation of energy storage technologies in India through legislative measures, the MNRE has already announced the second phase of its Solar Parks policy, which will mandate solar developers to setup energy storage systems to complement Solar PV.

Since energy efficiency, reduction of losses and promotion of renewables is already covered in the Electricity Act in India, the fundamental enablers for energy storage through legislation are already available.

What is required to be done now is more in the area of subordinate legislation, through recognition of storage systems as energy consumers as well as energy sources thereby enabling them to participate in the grid.

Subordinate legislation would also need to be brought in to ensure the setting of continually updated standards for design, manufacture, testing and operation of energy storage devices, besides safety standards.

Besides this, any tax incentives or specific subsidies for specific storage equipment or systems would need to be enabled through appropriate subordinate legislation. This could also cover restrictions on tax incentives to certain renewables if they are not supported by a specified minimum quantum of storage.

While finalizing subordinate legislation in the form of storage regulations, electricity regulators need to assess the fit that the various storage technologies may have with the planned energy mix. Regulators also need to consider the policies that will enable and incentivise storage adoption within their jurisdiction.

### 5.20.2.3 Policy Regime

There is now recognition that energy storage technologies are becoming increasingly critical to the integration of renewables and that commercial deployment of these technologies calls for a robust regulatory framework, besides other enablers. The flexibility and cost reductions that energy storage technologies provide to grid infrastructure would allow India to achieve an efficient, low-carbon intensity trajectory.

Government support through financial contributions, tax credits, standard setting and market creation is important for effective technology development, innovation and deployment. Large public investments into technology innovation and infrastructure are not new. It is also known that today's electricity sector is the result of long years of policy support for conventional energy resources, building of transmission networks and control of retail tariff levels.

Government investments come in a variety of forms, from outright subsidization to contracting and procurement to various tax deductions, subsidies, and other mechanisms aimed at starting, financing and otherwise supporting industries deemed important either to the national economy, energy security, or both. Many successful new technologies cannot become commercially viable without public investment in the form of government procurement.

Many alternative approaches and strategies are possible for achieving an effective Energy Storage policy. There would, however, be some key guiding principles which we consider to be as follows:

- **ESTES to be considered a resource of national and strategic importance**

The economic and environmental benefits of large-scale adoption of ESTES would benefit the entire power sector. A major thrust from the Central Government in support and coordination of ESTES is therefore required, failing which its advantages may not be realised fully.

**• ESTES to be mandated as a critical component of the power sector**

Long years of experience as well as financial, legal and technical support from Governments and their institutions have created the current power system. Just like the support given to RE in recent years, it would be critical to give ESTES the required legal and policy support by making it a mandatory component of the power sector.

**• Take a co-ordinated approach to power sector planning, including energy storage also as an integral component**

Even though fuel prices have softened in very recent times and demand has also come down in many countries including India, it is important not to be carried away with the expectation that balancing requirements of the grid can be met in a conventional manner through despatch control and stronger transmission networks alone. It would be important to recognize the critical value that energy storage would bring both in front of the meter and behind the meter and develop the future power system accordingly.

**• Reduce large tariff impacts for distribution companies between procurement from standalone RE resources and those combined with energy storage until storage requirements are better understood and their prices come down.**

At the current moment, not only are grid level storage costs fairly high, their optimal specifications for each specific requirement are also not well known. How much capacity for how much time and at what rate of discharge as well as the time to recharge would determine unique costs for specific systems. Until storage costs come down well enough to make the cost of overdesign benign, it would be useful for the Government, particularly at the national level, to offer targeted subsidies so as to eliminate the impact on retail tariffs.

It would also be important to replicate the dramatic costs reductions achieved by India in the procurement of LED lights by ordering them in humongous quantities at the Government level and then distributing it to various entities nation-wide. Bulk procurement of storage by Government would likely have the same effect and bring down costs in a shorter period of time.

**• Give small-scale/distributed Energy Storage close to end-users the same priority as large-scale/centralized storage**

Policy needs to give equal treatment to small-scale distributed storage capacities from legal and financial perspectives to enable the rapid deployment of storage wherever appropriate.

### 5.20.2.4 Institutional Requirements

One of the issues that besets the electricity sector in India, as perhaps in all the SAARC Nations, is the inherent conflict on whether to treat the power sector as a commercial enterprise with cost recovery and return on investment being investment drivers or as a social enterprise with social and economic development as the drivers.

The other issue is that electricity is an item under the Concurrent List in the Indian Constitution and therefore the Central Government as well as the State Governments have jurisdiction over the sector. This calls for efficient co-ordination between Governments. This also involves inter-State issues where the deployment of a resource in one State could have an impact on another State, necessitating legal and commercial co-ordination.

It is therefore very clear that strong institutional mechanisms need to be set up and for a nascent component like energy storage, even the very institutions would need to be specifically identified or created.

India's electricity sector has been developed along regional lines for inter-State matters and national level load despatch is also carried out that way. Until 2011, pricing of inter-State transmission services was also based on a regional postage stamp method. Thereafter, it gave way to a Point of Connection principle where major generating entities on the one hand and each State on the other were nomenclatured as unique injection or drawal points on the grid and usage charges and losses apportioned accordingly. Since most RE sources are likely to be connected to the State level grid, it would be essential to bring about greater granularity into the institutional framework for management and utilisation of energy storage resources.

At the Central Government level, there needs to be effective co-ordination and information sharing between the Ministry of Power (MoP), the Ministry of New and Renewable Energy (MNRE), the NITI Aayog (which is the key national level policy making body) and key institutions like the Central Electricity Authority (CEA), the Power Grid Corporation of India Ltd. (PGCIL), the Power System Operations Corporation (POSOCO), the Solar Energy Corporation of India (SECI) etc. Entities like NTPC which plans to build 25,000 MWs of Solar PV generation capacity would also be critical elements of the energy storage chain.

At the State level, besides the Energy Department of the Government, there is usually a Renewable Energy Development Agency that co-ordinates the planning and implementation of RE sources. Such an agency would be a natural player in the institutional structure for storage.

Most RE generation capacity in India has thus far been developed and owned by private companies. Since solar and wind resources already set up by them are already facing the heat of despatch constraints due to local load mismatches at certain times of the day, they would be looking for succour through deployment of energy storage capacities. Commercial implications may however impede their decision making since on the one hand the cost of storage would not be a pass-through in tariff for retrofits and on the other hand price them out of competition for new builds. For such private sector entities, the State-level Renewable Energy Development Agency may need to play the institutional role in enabling a level playing as deployment of concurrent storage capacities begin to get mandated by planners.

The other institutional area to be catered to would be related to testing and standards. This would at the very least require a national level entity to be identified and its capacity developed and also for State level sub-divisions to be set up.

Funding would be another critical area calling for institutional responsibility. Though there is a dedicated Indian Renewable Energy Development Agency IREDA that is tasked with funding RE capacities, it may be necessary to set up an independent financial institution to cater to funding of energy storage. Since the varieties, technologies, costs and market size (both on the supply side and the demand side) could be quite multifarious, a separate institution that quickly develops data resources and expertise could be crucial for the early and successful implementation of ESTES.

### 5.20.2.5 Financial Requirements

The requirement of energy storage capacity in India over the next 10 to 15 years is estimated at between 35 and 50 GW on a conservative basis and up to 70 GW otherwise. Current costs of storage technologies vary between about USD 350 per kW to over 1000 per kW. Assuming that investments would be made over time and that costs would necessarily need to come down before storage becomes economically viable vis-à-vis the negative costs of business-as-usual scenarios, an average cost of about USD 300 per kW appears rational given the affordability levels.

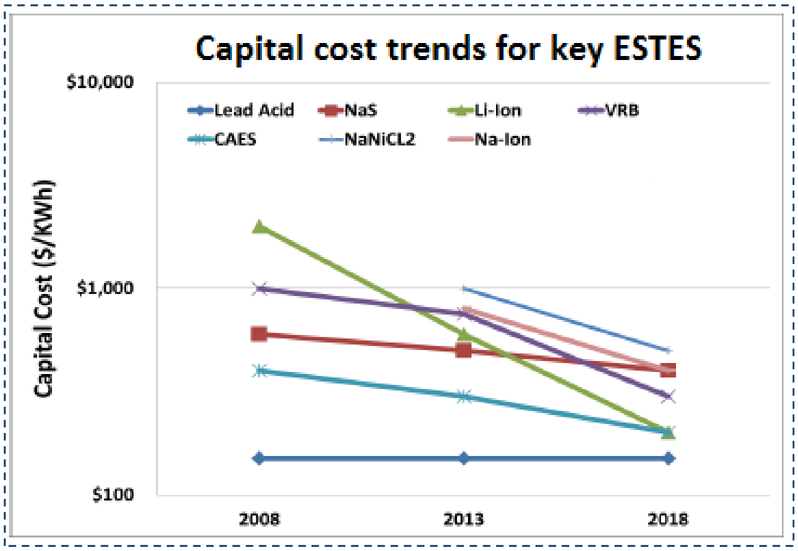



*Figure 5.9 Capital cost trends for key ESTES (IESA)*

Assuming a conservative implementation level of 20 GW of storage and an average discharge duration of 2 hours, the financial requirements would of the order of USD 12 bn or about INR 80,000 crores. Considering that India added about 100 GW of power generation capacity alone in the last five years at a cost that is over 7 times this number, besides investments in transmission and distribution, the financial requirements for storage implementation appear well within reach.

The next question would be the source for such financing. Besides limited promoter capital, India's recent private sector power generation investments have been funded by private equity funds and Banks. Majority of the debt funding has been from India itself. While Banks still have funding appetite, there is a strong possibility that their approach to funding decisions could be very tentative given the lack of knowledge of the storage business and the associated lending risks.

Until the learning curve is significantly crossed, non-Governmental funding may need to come through other instruments backed by strong balance sheets. One of the significant markets for such financing would be the 'Green Bond' market. A 'Green Bond' is a fixed-income financial instrument for raising capital through the debt market, like traditional corporate bonds. Besides standard conditions for bonds which they need to fulfil, green bonds need to specifically indicate the end use of the funds proposed to be raised and which raise funds for projects with environmental benefits, such as renewable energy, low carbon transport or climate adaptation. The same could well be extended to storage applications.

Several banks and financial institutions in India have successfully conducted 'Green Bond' issues of over USD 1.5 bn in international markets in recent months. NTPC has also successfully closed a USD 300 mn issue in August 2016.

Coupon rates on bonds are often a little higher than regular debt offtake rates. The key difference however is that bonds are usually redeemable in a much shorter term than conventional debt. Once storage technologies mature and some operating experience is gained in India and the region, it should be possible to raise long term debt from traditional sources at lower rates.

### 5.20.2.6 Commercial Requirements

Commercial requirements for energy storage systems need to keep in mind the future market needs, industry capability, and the best use of storage in as many situations as feasible.

The key outcomes expected from a storage facility include:

- Shifting of capacity from low demand periods to high demand
- Smoothing/firming out the output of intermittent generation resources
- Assisting with utilisation of surplus RE generation more effectively
- Adding MW capacity to the system
- Providing additional electricity ramp up and ramp down services
- Helping in managing transmission constraints
- Providing contingency response and energy reserves

Since storage is a relatively nascent technology when it comes to grid level applications, it would be important that the commercial mechanism provides a financial backstop to bridge any gap between market revenues and the total required costs. It would also be essential to incentivise the facility to operate when it is economic to do so, so that the facility is effectively integrated into the prevailing market. In a similar fashion, there should also be penalties for lower system availability.

It would be prudent for the MW capacity of the facility to be paid on a periodic (monthly) basis. Market revenues would need to be offset from the monthly fixed capacity payment. Where the market revenues are less than the monthly fixed costs, the storage facility would be paid the difference and where the market revenues are more than the monthly fixed costs, the facility owner would give back a share of the excess revenue to the entity that provides the financial backstop.

Each Energy Storage project should also be able to reverse the direction of its electricity flow within pre-specified periods and also be able to supply electricity for the pre-specified time and at the desired ramp rate as specified in their contract. Failure to do so should also attract graded penalties.

For grid level storage, the Power System Operator (load dispatch agency) should have priority control of any Energy Storage facility and the associated right to provide dispatch instructions so long as the facility is capable of meeting the operational requirements as specified.

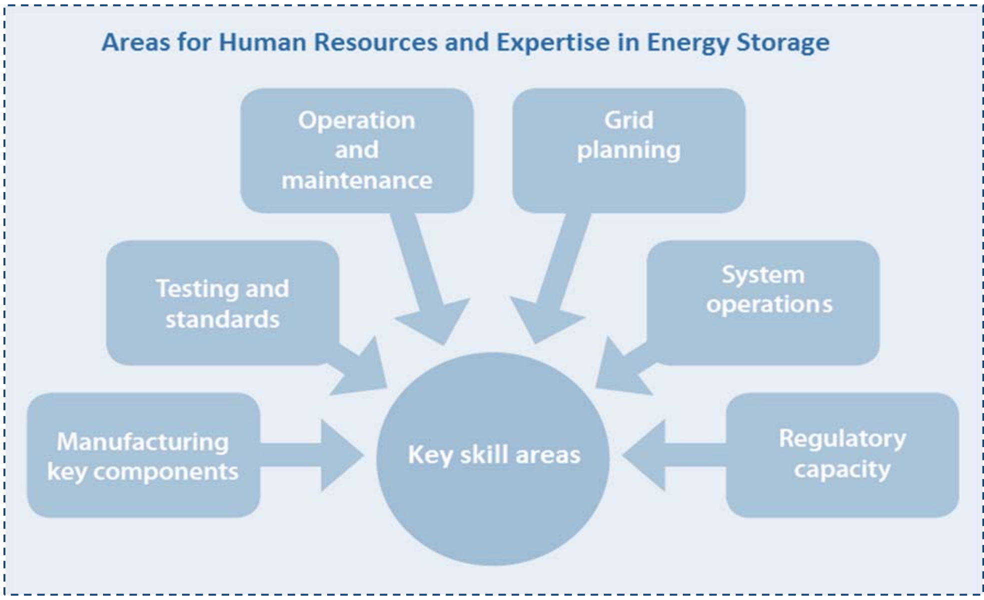
It would also be important to identify and exempt the facility from any of the applicable power market rules that are not conducive to its operations and have been so identified specifically in their commercial service contract.

### 5.20.2.7 Human Resource

The emergence of an energy storage market in India represents an opportunity not only to address the variations in energy output from some renewable sources but also to support the growth of existing as well as unserved parts of the country's population. Besides opening up areas of research and development, growth of new industries, new enterprises including small businesses that would engage in marketing, installation and maintenance of storage systems etc., there is also a large scope for job creation.

This will necessitate significant skill development in some areas and partial re-skilling in others. A key challenge therefore will be the development of adequate trained human resources. While this will help in expansion of manufacturing as well as research and development, it would also create considerable value for the economy while supporting and sustaining a vibrant energy storage sector.

The availability of trained manpower, some of it specialist, attracting and retaining talent, training and capacity building for those in the sector, and the necessary expansion of energy storage curricula in universities to ensure the sustained supply of quality manpower would be very essential.




The key skill areas, as depicted in the diagram, include:

- In manufacturing of components
- Testing, standards and safety requirements
- Installation, Operation and maintenance
- Grid planning, particularly on matching technology with locational needs
- System operations
- Regulatory capacity

India has strong manufacturing and service capabilities when it comes to Lead Acid batteries. The same is true of pumped hydro storage projects too and also to a limited extent for thermal storage. However, when it comes to other storage technologies like CAES, other battery technologies like Lithium Ion, Redox Flow, Sodium Sulphur, Metal Air etc., the skill sets are very limited.

Foreign companies have constantly been encouraged to operate in India and the emphasis has been on local manufacturing even if the ownership is foreign. While some key personnel would come in from the already established bases of these companies, a substantial number of personnel would still need to be recruited locally. At the very least, a certain amount of re-training may be required even for those who have experience in precision chemical or assembly work including dealing with hazardous materials.

India is now in the process of smoothening out the sharp ends of testing and standards organisations for Solar PV. A similar process for energy storage technologies needs to be taken up in right earnest, maybe with identification of nodal institutions that would take the lead. Large manufacturing companies like BHEL and large generating companies like NTPC that have strong technology teams would also need to step in and establish the necessary expert services.

Operation and maintenance requirements may perhaps have a mixed learning curve from a human resource perspective. There is already a large pool of grid management experts in India which could quickly adapt to the specifics of storage systems. What might a bit more onerous could be the installation and maintenance aspects as they would be closely linked to a core understanding of the design and construction, a domain that may very well be controlled by manufacturers for some years to come. Training centres for installation and maintenance may therefore need to be established by such entities, with end users also slowly getting into the game.

Grid planning capabilities vis-à-vis storage would need to be developed over a couple of years or so, where the learnings of world-leaders like the U.S. and Japan would prove very useful. System operations are unlikely to create major demands except for the duration of the early stage learning curve on storage.

Regulatory capacities for storage would perhaps take a little long as international experience in this area is still evolving. However, given that India has only very recently gone through the process of integration of the national grid (One Nation, One Grid, One price) and also that the learnings from Wind and Solar operations are hitting home already, regulatory capacity building may evolve quicker than other places in the world.

Entities like Centre for Study of Science, Technology and Policy (CSTEP), Indian Institute of Technology (IIT) Bombay, National Chemical Laboratory (NCL) and the Indian Institute of Science (IISc) that are already working in India in the area of promotion and development of energy storage technologies and applications can play a leading role in creating the required expertise and human resource.

### 5.20.2.8 Infrastructure Requirements

The economics of energy storage is improving significantly with recent advancements in materials and manufacturing. Traditional storage technologies such as pumped hydro and compressed air seem to have limited applicability and appear to be losing market share to emerging battery technologies, many of which are leveraging experience in the transportation and consumer electronics sectors to compete in the power sector.

Some storage technologies can provide power quickly while others may be able to deliver it over an extended period. Infrastructure requirements for storage could therefore vary widely.

Even though Pumped Hydro Storage and CAES appear to be very feasible options for bulk energy storage, they both depend on the availability of suitable topology or geology, which would be a significant constraint. CAES plants may also lack the desired operational data to assess the risk of long-term investments. Conventional as well as some emerging battery technologies thus emerge as viable options in the Indian context.

A very different form of infrastructure would be required if Electric Vehicles adoption outpaces grid storage due to its other benefits especially on climate change parameters. In terms of aggregated volumes even in limited geographical areas, EVs could emerge as significant players in balancing the load-generation gap caused by the intermittency of renewables output.

The infrastructure that India needs to develop for energy storage should be considered alongside other methods that can support the integration of renewables into the grid infrastructure, such as prevailing power quality, time of use and time of the day pricing etc. When assessed in a comprehensive manner, the multiple benefits of energy storage could be brought out, including the monetary value that otherwise may not exist or may be too meagre to make a business case for energy storage use. Energy storage infrastructure 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.

Infrastructure requirements for ESTES would include:

- Manufacturing infrastructure
- Safe transportation methods, particularly for hazardous materials
- Ease of access not just for initial installation but also for operation and maintenance, including component replacements
- Charging stations and associated equipment and accessories, including meters and switching devices that respond to price signals and of course time-of-day record keeping
- Testing laboratories for certification and compliance validation of components and systems
- Training centres for skill development

Keeping in view the substantial storage requirements that India will need, it is imperative that multiple and large scale manufacturing infrastructure be created over the next three years. While multiple R&D efforts are under way in India on several technologies, it appears likely that countries like China may again take the lead in breakthrough developments, especially in innovative processes that can bring down costs dramatically. With India's own push for manufacturing growth and through tax measures, there would be a major effort to get factories located in India even if they are owned by foreign entities.

It would be very important to create access infrastructure like roads and railheads and other enablers like technical training institutes and skill development centres close to areas where land could easily be earmarked for large manufacturing facilities. It would also be necessary to get local levies and national taxes streamlined. India is very likely to be ready for the tax part since it appears well on its way to implement a unified and seamless nation-wide Goods and Services Tax regime by 2017.

### 5.20.2.9 Quality and Standards requirements

Energy storage technologies will be a game changer for the energy market and would offer increased flexibility, reliability and efficiency in the sourcing and delivery of electricity. Energy storage will also complement the accelerated deployment of renewable energy in its various forms. As storage technologies evolve and get installed, the need for the availability and enforcement of robust quality and related standards would be critical.

In order to achieve the huge manufacturing volumes that would be required and to bring down costs to enable their large-scale adoption, the energy storage industry needs to organize for scale based on comprehensive and compatible technology standards. This would enable vendors, utilities and system planners to focus on delivering more efficient and cost-effective storage systems.

Besides reducing system costs and installation times, these standards also need to address how the energy storage system would communicate with the utility's grid control equipment and also extend these communication specifications to aggregators and facility energy management systems that monitor and control storage assets. Standards also need to address how energy storage components would be packaged and arranged, electrically connected and be able to communicate with each other and with other operational components.

Current utility-grade energy storage systems are usually project-specific, one-off solutions, built using proprietary components which may not necessarily be modular or interoperable. Connecting these proprietary systems with the control software of utilities could be time-consuming.

Some energy storage technologies are covered by recognised international standards, which simplify system procurement, installation and operation. Other technologies (e.g. batteries) may be subject to inappropriate standards, because the standard-making process may not have kept up with the rate of technical development. For technologies that are on the brink of commercial viability, it is important that comprehensive and adoptable standards and operation protocols, workforce training programmes, performance and safety testing and consumer awareness programmes be developed. These international standards need to be established in a manner that allows for easy updating with technology advancements.

Before an energy storage system can function, the batteries, power converters and software must be intelligently connected to each other and to the electrical network that the storage system is to serve. The storage system as a whole must then be intelligently plugged into the utility's existing information and operations technology. Without established standards, components and systems may offer their own proprietary connectors which could create barriers to development of better and cheaper individual components and also lead to avoidable interface engineering and installation challenges akin to re-inventing the wheel for each project.

The storage system customer should not become dependent on a single storage system supplier, with few options to upgrade, expand or re-purpose their energy storage investment. The vendor would also stand to lose through limitation of market growth despite the presence of willing buyers of their products and other willing sellers of components that they may not be supplying.

There is already a major effort under way internationally to create Modular Energy Storage Architecture through an open, non-proprietary set of specifications and standards developed by an industry consortium of electric utilities and technology suppliers. Such standardization is expected to accelerate interoperability, scalability, safety, quality, availability, and affordability in energy storage components and systems.

India and other SAARC Nations would perhaps do well to join up and participate in this combined process so that the benefits could be reaped by all. This would also assist in more efficient financing.

Safety, operation and performance of grid-connected energy storage systems needs to be ensured through development and implementation of robust quality norms that are accepted as industry standard.

Common standards would help in at least the following ways :

- Standardize communications and connections, which will accelerate interoperability and scalability
- Give electric utilities more choice by enabling multi-vendor, component-based energy storage systems
- Reduce project-specific engineering costs, enabling a more robust energy storage market
- Enable technology suppliers to focus on their core competency, facilitating quality, safety, and cost-effectiveness
- Reduce training costs and improve safety for field staff through standardized procedures for safety and efficiency

### 5.20.2.10 Mass Awareness Requirements

As electric generation shifts away from central, thermal plants to more distributed and variable renewable sources, the ability to flexibly store energy will play an ever more critical role.

While there is a certain degree of familiarity with behind-the-meter energy storage like batteries in India and other SAARC Nations due to their use in homes and offices to deal with load shedding, there is little awareness of storage applications that are in-front-of-the-meter. The RE deployment exercise in India had created significant discomfort initially through worries about the cost impact and low energy output. Introduction of CFL lamps in place of incandescent bulbs and later the introduction of LED lights also created the same kind of discomfort that planners are experimenting at people's cost. Energy storage is also likely to be seen initially as yet another fancy idea and a mere cost element.

Energy storage companies and utilities would be keen to send out a clear message that storage products provide value to the grid even perhaps if it's a value that the markets currently aren't designed to compensate. The rules written before this technology came into its own would need to be amended for storage providers to recoup investments that yield tangible services to the grid and to its customers.

A well planned and sustained mass awareness campaign is therefore necessary to set out the benefits of energy storage systems before the people and also the elected representatives. It is necessary to get the storage story out to more people and help push the policy conversation in a direction that creates opportunities for storage to provide flexibility, reliability and renewables integration to the grid.

This would also be useful in a context where the Central Government may be keen to introduce energy storage in a large way but the key implementers could be entities controlled by State Governments who may not see the benefits outweighing the costs especially if these costs are high and the cash flows are already constrained. A strong mass awareness campaign would then put added pressure on the State Government and its agencies to act faster.

Besides awareness campaigns through print and electronic media and through the use of knowledge dissemination workshops as well as pilot demonstration projects, it would be essential in today's age to effectively use social media. The use of mobile apps may also be very effective, as an endeavour on disseminating power market prices in India has shown. Besides power sector personnel and the media, the app is being used by the common public to find out how much surplus power is available on the power exchange at any point of time and at what price. Whenever there is a power cut, common people are able to question the local utility as to why they are not buying power from the market when its available. Similar apps could also be used to highlight the benefits of energy storage and to let people calculate for themselves the economic benefits and costs of a variety of storage forms if they are or were to be deployed at various locations on the grid.

### 5.20.2.11 Academia Involvement

Universities, other research institutions and academia can contribute tremendously by getting involved in the energy storage debate. This would not only raise the level of the debate beyond purely commercial matters but would also help create an environment where young people who study or work at such institutions would get motivated to work on storage projects as researchers or innovators or business developers.

Collaborations between academia and industry offers advantages to both entities and is a means by which academic institutions and industry can address challenges to their mutual benefit. Academia-industry partnerships can facilitate research discoveries reaching the people who need them and serving the purposes for which they are required, at affordable prices.

Academia must also work with governments, scientific bodies, non-governmental and inter-governmental organisations to help realise a more sustainable energy future through unbiased advocacy of appropriate technologies and applications of energy storage systems. This will also help bring together the resources and players necessary to bring about a balanced and minimally wasteful deployment of storage.

Knowledge dissemination is the top purpose of universities whereas in industry, knowledge could be subordinated by its ability to provide competitive advantage. Members from academia typically bring insights and strategies from very different contexts. The cultures of academia and industry are quite different and it essential for that very reason that both must work and collaborate closely with each other and with government and other stakeholders to increase the complementary exchange of knowledge resources. Academia promotes intellectual contributions, technological skills and provides competent and well-educated employees for industry.

Some of the valuable contributions of academia involvement would include the following:

- Accelerate R&D efforts focused on optimising the integration of energy storage technologies in the energy system
- Work on efficiency and reliability of existing systems
- Push technologies beyond their current limits in order to bring down their costs and/or widen their potential applications
- Work on improving storage management systems through integration of academic research and feedback from industry
- Provide an overarching and non-partisan voice in industry debates without being bogged down by corporate loyalties or commercial gain.

In India, several technology institutions like IIT Bombay and the Indian Institute of Science are involved in collaborative efforts with industry to develop new energy storage products. They are also supporting projects in their incubation centres by young start-ups to try out new technologies where an enabling environment including funding is made available.

Chapter 6

# INTERNATIONAL PERSPECTIVE

# Chapter 6: International perspective

## 6.1 Energy Storage Applications – An International Experience

Globally, Energy Storage Applications are positioning themselves as one of the most important technologies for more reliable and sustainable energy systems in the future. With stronger economic efforts, particularly coming from the United States of America, China, Japan, and EU member states, energy storage projects are increasingly being diversified and implementations are gradually becoming feasible both in terms of investment and political will (IEA, 2014; IEC, 2014; IESA, CNESA, ESA, IESA, & NECA, 2015). Hence, the importance of envisioning the most promising energy storage deployments today and outlining some of the best practices that can be adjusted to regional and national needs.

Chapter 5 focuses on the most relevant international experiences in terms of projects and installed capacity so far, both at a grid and at a domestic level. As it has been discussed in previous sections, grid scale applications often relate to technologies such as pumped hydro storage and battery-based storage. On the other side, domestic or micro grid scale applications can easily be related to specific commercial solutions like Tesla's Powerwall and Australian firm ZCell.

Whilst the world-wide scenario of ESTES deployment is reviewed, correlations among certain variables will be discussed. Nevertheless, the overall context (socio demographic, historic, and geographic), and the political ecosystem towards energy generation, transmission, and distribution will be key for further understanding.

## 6.2 World-wide Scenario of ESTES Deployment

As mentioned before, Energy Storage Technologies (ESTES) are, undoubtedly, receiving constant and increasing support across different actors such as regulators, suppliers, distributors, customers, and so forth (Zucker et al., 2013). However, it is still relatively true that the clear majority of projects are often unique and that they are usually quite specific solutions. Thus, and according to the U.S. Department of Energy, flexibility and even the replication of projects remain as challenges for stakeholders around the globe (ESN, 2014b; Huff, 2014).

Given that the U.S.A., China, and Japan are not the only participants in the market anymore, other prominent countries and regions, for current and future energy storage market size growth, have been outlined. These include Germany, France, the United Kingdom, and Australia. France and the United Kingdom have both an ongoing history of, arguably, positive diversification of their local energy matrix. Germany and Australia remain as extremely interesting case studies considering their strong interest for renewables deployment and the immediate effect these policies have in ESTES adoption and later expansion. As a caveat, data shown next has been compiled from different but complementary sources including the U.S. Department of Energy, Enerdata, and the U.S. Central Intelligence Agency.

### 6.2.1 United States

Until 2015, the United States of America had the largest energy storage market in terms of installed capacity. A position now potentially surpassed by China and Japan. Yet, the country remains as the reference pole of the world if the increasing number of deployment projects is to be considered. Led by interconnectors, especially PJM, policies now stress on the introduction of energy storage solutions within the wholesale markets.

For instance, it is estimated that since 2011 more than 14 bills related to energy storage were introduced in at least 10 states (IESA et al., 2015). Most of them oriented towards utility-scale storage and, particularly, pumped hydro storage and lithium-ion batteries, which according to the U.S. Department of Energy account for almost 90% of latest deployments. As seen in *Figure 6.1*, other popular technologies include latent heat storage and supercapacitors.

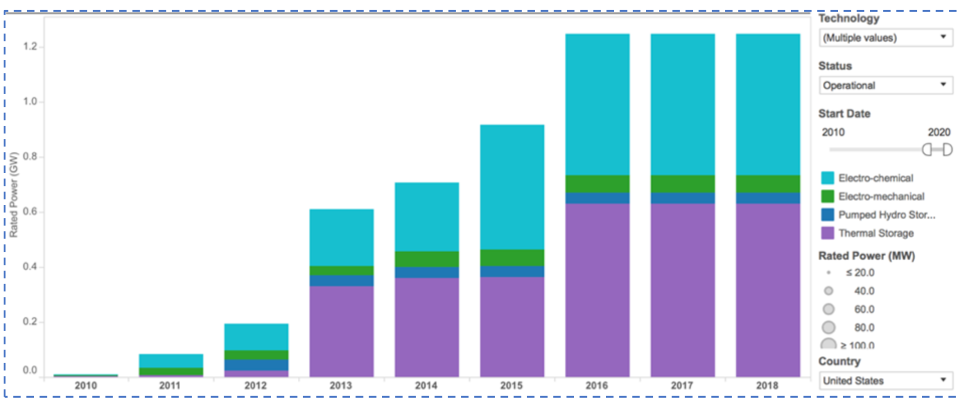



*Figure 6.1 USA - Installed Energy Storage Capacity per technology, over time*

As *Figure 6.2* shows, grid or utility scale over micro-grid scale ESTES, as well as distribution and transmission over domestic applications, are the most mature segments within the North American market. However, energy management or ‘behind the meter’ applications are expected to grow dramatically in the upcoming years.

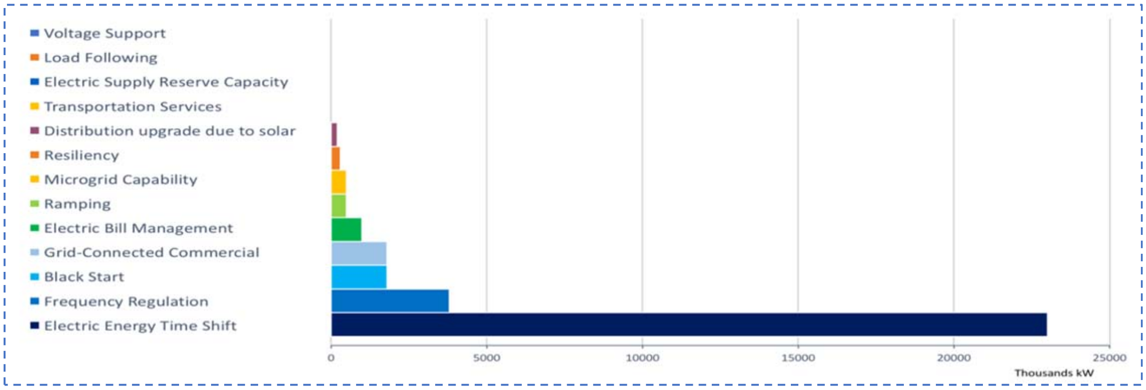



*Figure 6.2 USA - Installed Energy Storage Capacity per segment (service use)*

Table 6.2.1 United States Profile Summary

| General Considerations | United States |
|---|---|
| **Installed generating capacity (GW) (2014 - 2015 est.)** | 1,063 |
| **Population (July 2015 est.)** | 321,368,864 |
| **Electricity Consumption (KWH) (2012 est.)** | 3,832,000,000,000 |
| **Electricity Consumption (KWH) per capita** | 11,924 |
| **Share of renewables used for electricity production (% including hydro) (2015 est.) (Enerdata)** | 14% |
| **Share of renewables used for electricity production (% only wind and solar) (2015 est.) (Enerdata)** | 6% |
| **Climate (CIA WFB)** | Mostly temperate, but tropical in Hawaii and Florida, arctic in Alaska, semiarid in the great plains West of the Mississippi River, and arid in the Great Basin of the Southwest; low winter temperatures in the Northwest are ameliorated occasionally in January and February by warm chinook winds from the Eastern slopes of the Rocky Mountains |
| **Geographic Conditions (Terrain) (CIA WFB)** | Vast central plain, mountains in west, hills and low mountains in east; rugged mountains and broad river valleys in Alaska; rugged, volcanic topography in Hawaii |
| **Infrastructure (Media / Press)** | In 2014, 66% of total capacity was administered by PJM alone |
| **Political Support (Media / Press)** | Mixed ownership model |
| **Quality of Investment (DoE Dataset)** | 24.12 GW to be installed |

### 6.2.2 China

China has lately received strong financial incentives and a general directive from the government to increase its ESTES market size. It is no secret that the largest electricity network in the world is heavily investing in renewables' R&D, improving battery-based storage performance through the procurement of projects, both locally and abroad, and even by defining the role of electric vehicles in future oil-off roads (IESA et al., 2015).

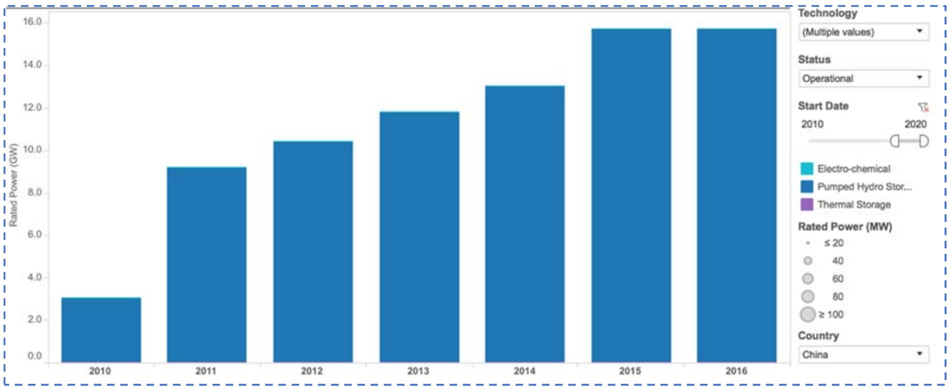



*Figure 6.3 China - Installed Energy Storage Capacity per technology, over time*

However, as opposed to the case of the United States, most of China's storage applications are domestic or 'behind the meter'. This expansion through home-based applications has been only possible due to the balanced mix of lead-acid and lithium-ion batteries, according to CNESA. As seen in *Figure 6.3*, other popular technologies include pumped hydro storage and flow batteries.

Moreover, as *Figure 6.4* shows, ESTES have been historically attached to the type and size of renewable technologies installed. This considering that deployment is increasingly being distributed as well. On a broad level, demand side management and other ancillary services are directly affecting ESTES too. The most recent example is the consolidation of China's peak shifting and frequency services in Beijing.

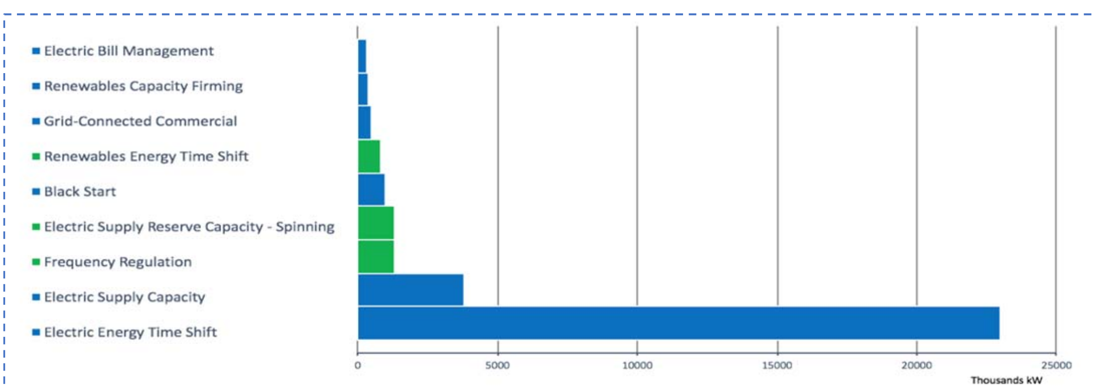



*Figure 6.4 China - Installed Energy Storage Capacity as consequence of RE (green)*

Table 6.2.2 China Profile Summary

| General Considerations | China |
|---|---|
| **Installed generating capacity (GW) (2014 - 2015 est.)** | 1,505 |
| **Population (July 2015 est.)** | 1,367,485,388 |
| **Electricity Consumption (KWH) (2012 est.)** | 5,523,000,000,000 |
| **Electricity Consumption (KWH) per capita** | 4,039 |
| **Share of renewables used for electricity production (% including hydro) (2015 est.) (Enerdata)** | 25% |
| **Share of renewables used for electricity production (% only wind and solar) (2015 est.) (Enerdata)** | 4% |
| **Climate (CIA WFB)** | Extremely diverse; tropical in South to subarctic in North |
| **Geographic Conditions (Terrain) (CIA WFB)** | Mostly mountains, high plateaus, deserts in West; plains, deltas, and hills in East |
| **Infrastructure (Media / Press)** | Policies barely oriented towards energy storage deployment. More of a side-effect produced by renewables' targets |
| **Political Support (Media / Press)** | Third Party Owned |
| **Quality of Investment (DoE Dataset)** | 32.10 GW to be installed |

### 6.2.3 Japan

Japan's energy policy is perhaps one of the most active and encouraging sets of directives for ESTES deployment. According to IESA (2015), the country does not only have "ambitious targets to produce half of the world's batteries by 2020" but also a subsidies program for domestic and commercial energy storage applications e.g. lithium-ion batteries, anchored by the Ministry of Economy, Trade and Industry (METI). This of course considering the ongoing 'off-nuclear' campaign and other recent energy needs i.e. PV expansion as well. Its COP21 renewable targets also figured among the highest proposals of any other UN member state.

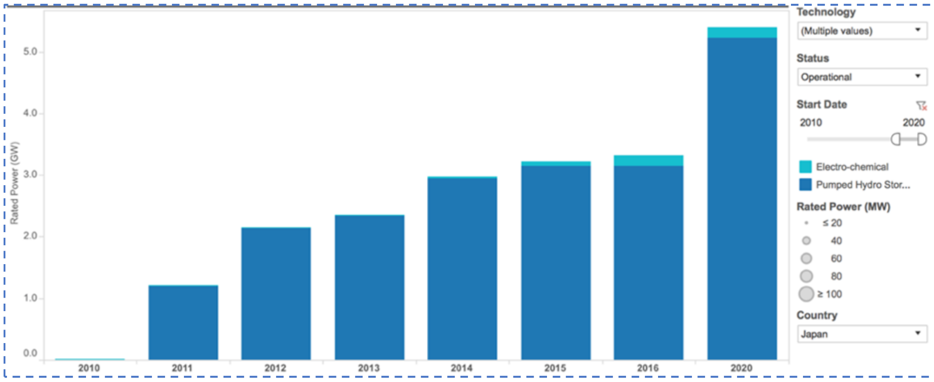



*Figure 6.5 Japan - Installed Energy Storage Capacity per technology (including subsidies), over time*

Moreover, since local manufacturers concentrate most of the supply in need, battery mass production, even without METI's subsidy program, has been cost effective so far. As seen in *Figure 6.5*, aggregated demand of batteries, regardless of the chemical compound, has not been significantly affected by financial mechanisms from the government. In an effort to correlate the size of the market, the type of the energy storage technology, and climate or geographic conditions, *Figure 6.6* shows location-wise deployment of Japan's most important ESTES projects as reported by multinational AECOM in 2015.

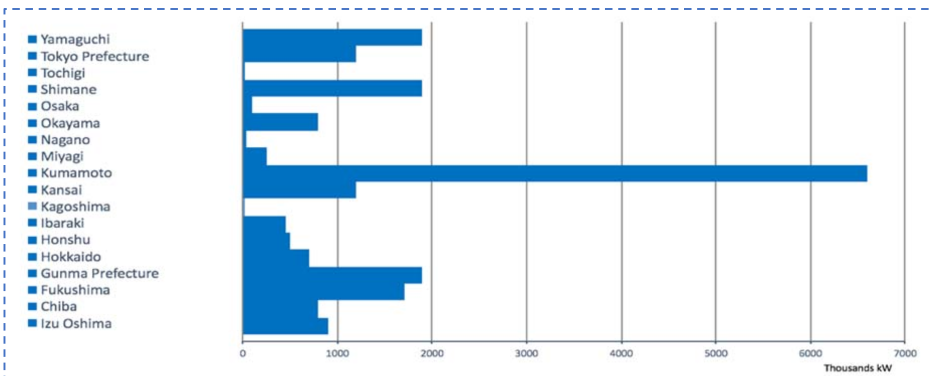



*Figure 6.6 Japan - Installed Energy Storage Capacity per region*

Table 6.2.3. Japan Profile Summary

| General Considerations | Japan |
|---|---|
| **Installed generating capacity (GW) (2014 - 2015 est.)** | 293 |
| **Population (July 2015 est.)** | 126,919,659 |
| **Electricity Consumption (KWH) (2012 est.)** | 921,000,000,000 |
| **Electricity Consumption (KWH) per capita** | 7,257 |
| **Share of renewables used for electricity production (% including hydro) (2015 est.) (Enerdata)** | 18% |

| | |
|---|---|
| **Share of renewables used for electricity production (% only wind and solar) (2015 est.) (Enerdata)** | 4% |
| **Climate (CIA WFB)** | Varies from tropical in South to cool temperature in North |
| **Geographic Conditions (Terrain) (CIA WFB)** | Mostly rugged and mountainous |
| **Infrastructure (Media / Press)** | Most of the infrastructure deployed stresses on off-shore renewables (PV) and several battery-based storage technologies for domestic applications |
| **Political Support (Media / Press)** | Customer Owned |
| **Quality of Investment (DoE Dataset)** | 28.51 GW to be installed |

### 6.2.4 Germany

Within the Europe Union, Germany is the most dynamic member state for renewables transition / penetration (e.g. PV, wind) and integration of energy management services (e.g. wind curtailment, demand side management, and other frequency services) to its national grid system. Nonetheless, arising policies remain clashing with economic impediments such as land price and dilution of energy revenues in Europe.

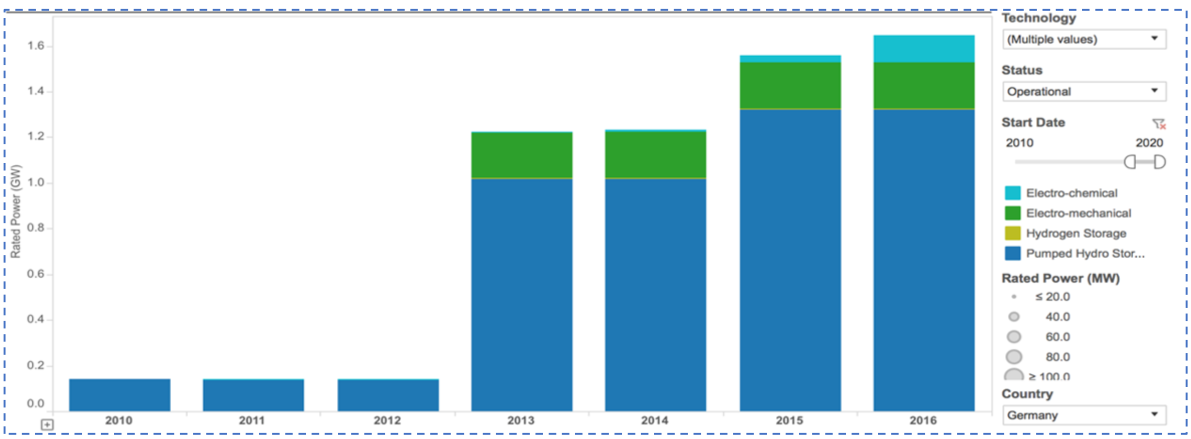



*Figure 6.7 Germany - Installed Energy Storage Capacity per technology (attached to solar and wind RE), over time*

As seen in Chapters 2 and 3, real-time responding and 'load shifting' energy storage capacities are critical when fluctuating renewable technologies like PV and wind are deployed. Thus, *Figure 6.7* graphs the installed energy storage capacity per technology as a consequence of REs and the need to guarantee the security of the grid.

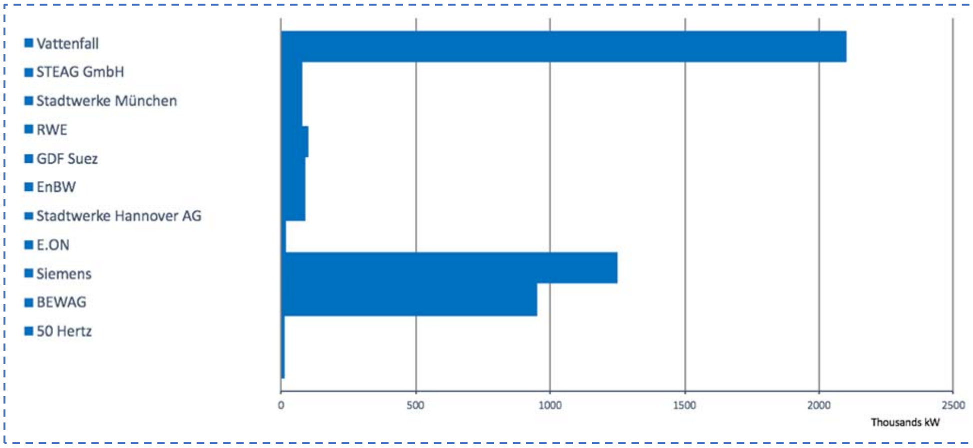



*Figure 6.8 Germany - Installed Energy Storage Capacity per player*

Amidst domestic / micro-grid level applications, German ESTES solutions also represent an important business case for other regions to consider. Since its conception, the German market began to optimize energy storage by creating loan programs with low-interest rates. Siemens and other manufacturers have benefited the most out of policies such as.

*Figure 6.8* shows the installed energy storage capacity per player. As it can be seen, among Siemens et al., new 'digital' players are also entering the market by offering software solutions for distributed storage applications instead of physical assets.

Table 6.2.4 Germany Profile Summary

| General Considerations | Germany |
|---|---|
| **Installed generating capacity (GW) (2014 - 2015 est.)** | 177 |
| **Population (July 2015 est.)** | 80,854,408 |
| **Electricity Consumption (KWH) (2012 est.)** | 540,100,000,000 |
| **Electricity Consumption (KWH) per capita** | 6,680 |
| **Share of renewables used for electricity production (% including hydro) (2015 est.) (Enerdata)** | 32% |
| **Share of renewables used for electricity production (% only wind and solar) (2015 est.) (Enerdata)** | 20% |
| **Climate (CIA WFB)** | Temperate and marine; cool, cloudy, wet winters and summers; occasional warm mountain wind |
| **Geographic Conditions (Terrain) (CIA WFB)** | Lowlands in North, uplands in centre, Bavarian Alps in South |
| **Infrastructure (Media / Press)** | Strictly in accordance to the open market expectations of the EU |

| | |
|---|---|
| **Political Support (Media / Press)** | Utility Owned |
| **Quality of Investment (DoE Dataset)** | 7.57 GW to be installed |

### 6.2.5 France

France is almost an equivalent for the Germany's current state of ESTES potential, but national strategies focus on transmission and distribution applications rather than micro-grid or lower-level uptakes. Another key difference is the ownership model and the grid system coordinator. In Germany's case, although led by the government, utilities own most of the infrastructure installed. In the French case, the coordinative and the ownership roles are reserved for the public sector.

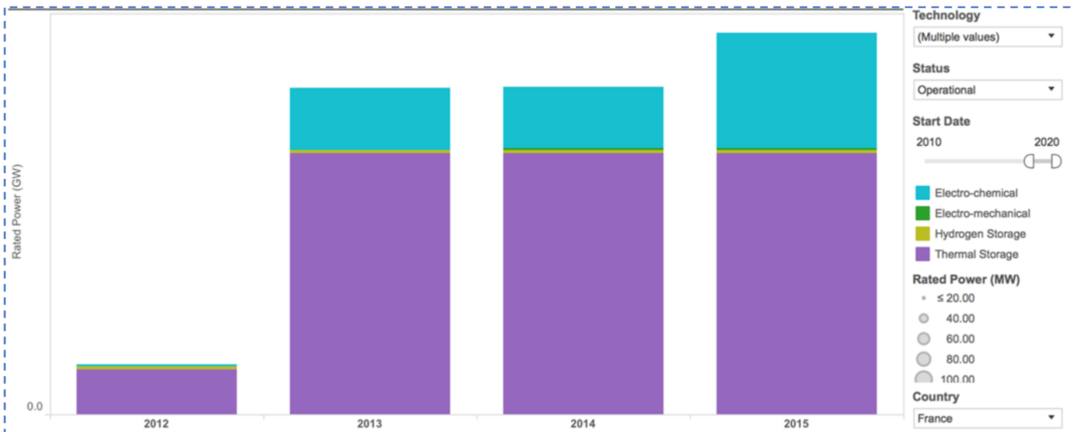



*Figure 6.9 France - Installed Energy Storage Capacity per technology, over time*

For real-time responding, 'load shifting', or any other specific purpose energy storage capacities, France heavily depends on pumped hydro storage. *Figure 6.9* shows the installed energy storage capacity per technology as of 2015. It is important to state that the country's policy is unbalanced towards other services over storage per se.

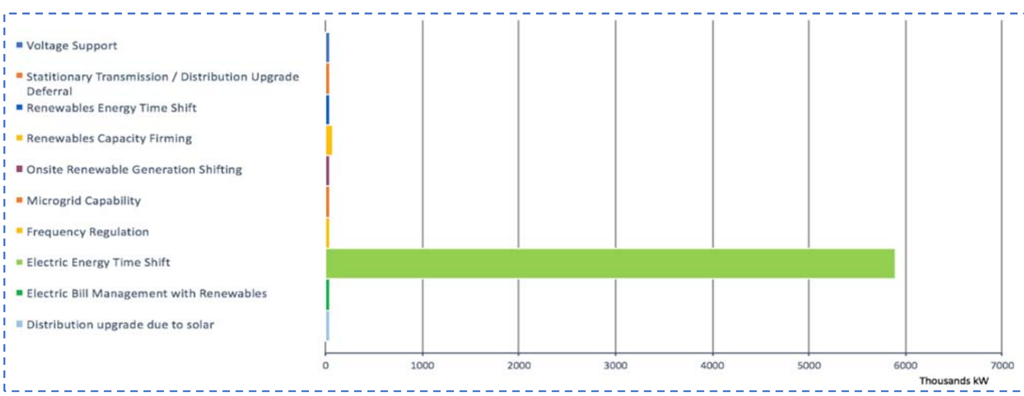



*Figure 6.10 France - Installed Energy Storage Capacity per segment*

As mentioned before, France focuses on the transmission, distribution, and energy management segments when thinking about energy storage. Yet to give a fair interpretation of the aggregated numbers shown in *Figure 6.10,* the fact that there are no specific financial incentives nor ambitious renewable targets linked should be reflected.

Table 6.2.5 France Profile Summary

| General Considerations | France |
|---|---|
| **Installed generating capacity (GW) (2014 - 2015 est.)** | 129 |
| **Population (July 2015 est.)** | 66,553,766 |
| **Electricity Consumption (KWH) (2012 est.)** | 451,100,000,000 |
| **Electricity Consumption (KWH) per capita** | 6,778 |
| **Share of renewables used for electricity production (% including hydro) (2015 est.) (Enerdata)** | 17% |
| **Share of renewables used for electricity production (% only wind and solar) (2015 est.) (Enerdata)** | 5% |
| **Climate (CIA WFB)** | Generally cool winters and mild summers, but mild winters and hot summers along the Mediterranean; occasional strong, cold, dry, north-to-north-westerly wind known as mistral |
| **Geographic Conditions (Terrain) (CIA WFB)** | Mostly flat plains or gently rolling hills in North and West; remainder is mountainous, especially Pyrenees in South, the Alps in East |
| **Infrastructure (Media / Press)** | Not necessarily in accordance to the open market expectations of the EU |
| **Political Support (Media / Press)** | Third Party Owned |
| **Quality of Investment (DoE Dataset)** | 5.83 GW to be installed |

### 6.2.6 United Kingdom

The United Kingdom, beyond the recent Brexit event, is still a front runner for a broad range of energy-related emerging technologies and innovation. Specifically, in regards of ESTES, a recent report from the Carbon Trust & Imperial College London (2015) estimated how much money (at least £2.4 billion) can the kingdom save if energy storage potential is effectively reached.

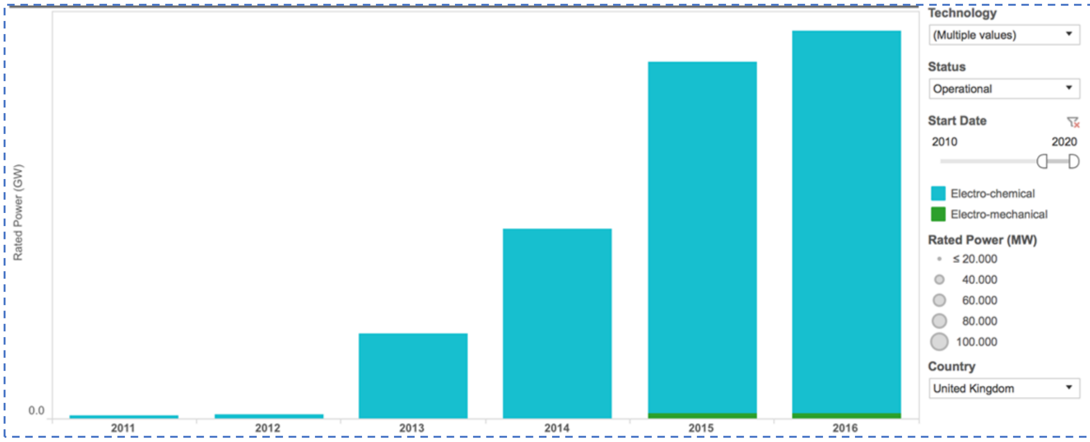



*Figure 6.11 UK - Installed Energy Storage Capacity per technology, over time*

From the political ecosystem side, DECC and Ofgem, UK's energy regulators, seem to be keen to acquire and deploy as many innovative and clean energy solutions as possible and as fast as economic constraints allow investment portfolios (TSO, 2010). *Figure 6.11* estimates the state of installed energy storage capacity per technology as of today (ESN, 2014a; LCICG, 2012).

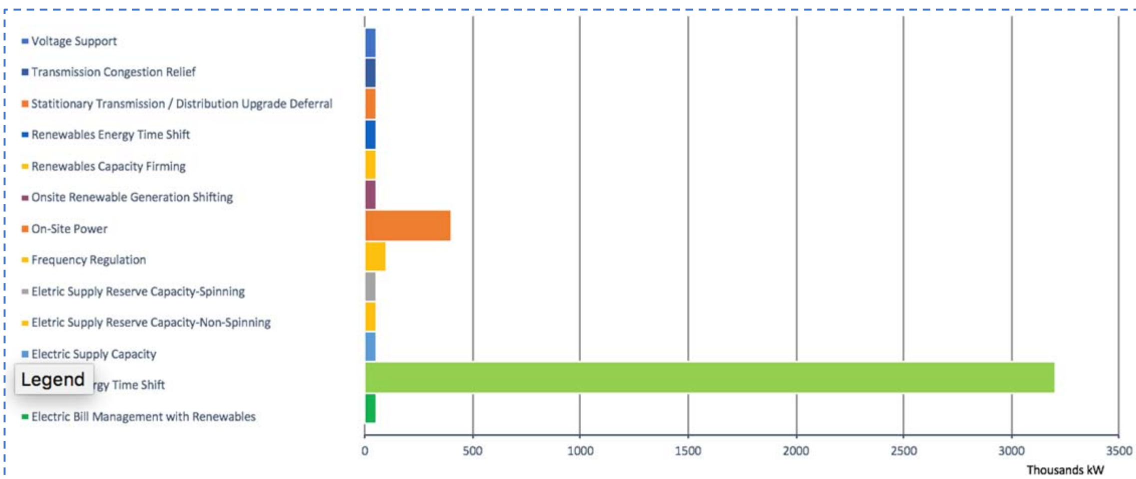



*Figure 6.12 UK - Installed Energy Storage Capacity per segment*

Per segment, a preliminary analysis does not show any promising figures. For instance, if considered that the segment that has the highest penetration of ESTES today is not a consequence of a priority-based decision, the reader may infer that penetration so far could be considered more of a 'market accident' (e.g. stoRE project) and not a truly coordinated uptake from regulators or the system operator. Some of these takeaways are highlighted in *Figure 6.12*.

Table 6.2.6 United Kingdom Profile Summary

| General Considerations | United Kingdom |
|---|---|
| **Installed generating capacity (GW) (2014 - 2015 est.)** | 85 |
| **Population (July 2015 est.)** | 64,088,222 |
| **Electricity Consumption (KWH) (2012 est.)** | 319,100,000,000 |
| **Electricity Consumption (KWH) per capita** | 4,979 |
| **Share of renewables used for electricity production (% including hydro) (2015 est.) (Enerdata)** | 26% |
| **Share of renewables used for electricity production (% only wind and solar) (2015 est.) (Enerdata)** | 14% |
| **Climate (CIA WFB)** | Temperate; moderated by prevailing Southwest winds over the North Atlantic Current; more than one-half of the days are overcast |
| **Geographic Conditions (Terrain) (CIA WFB)** | Mostly rugged hills and low mountains; level to rolling plains in East and Southeast |
| **Infrastructure (Institution of Mechanical Engineers, 2014)** | Diversified applications: transmission, distribution, customer services, conventional generation, and renewables |
| **Political Support (Media / Press)** | Utility Owned |
| **Quality of Investment (DoE Dataset)** | 3.25 W to be installed |

### 6.2.7 Australia

As the final case study, Australia's profile can be condensed in one of a diversified but standardized market. Although some argue that baseline and total numbers are not comparable to other environments where storage has been successful on its own, Australia is a great example of a rich, flexible and integrated energy grid.

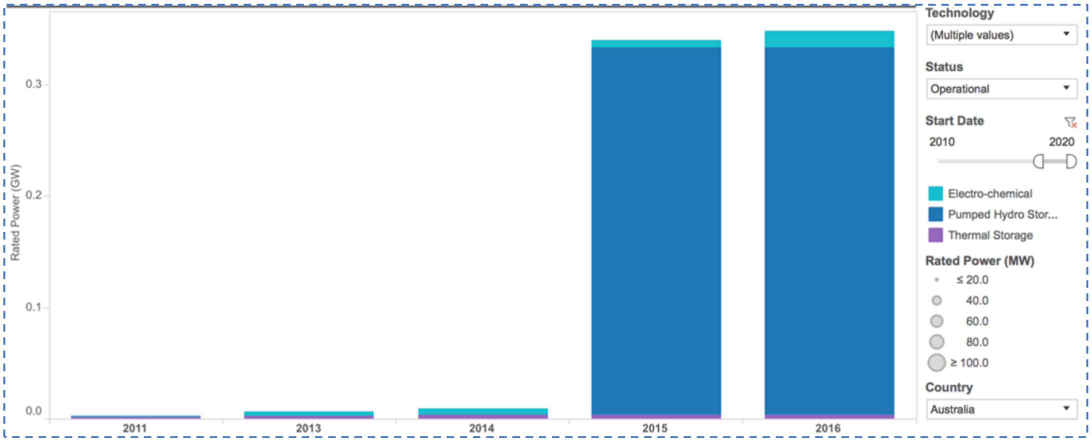



Figure 6.13 Australia - Installed Energy Storage Capacity per technology, over time

Ranging from several types to off-grid applications and some on grid projects, the Australian ecosystem has been able to sort economic limitations through subsidies, and market limitations through energy efficiency directives and domestic storage applications such as ZCell and other 'cost-effective' batteries. *Figure 6.13* gives an estimate of the currently installed energy storage capacity per technology.

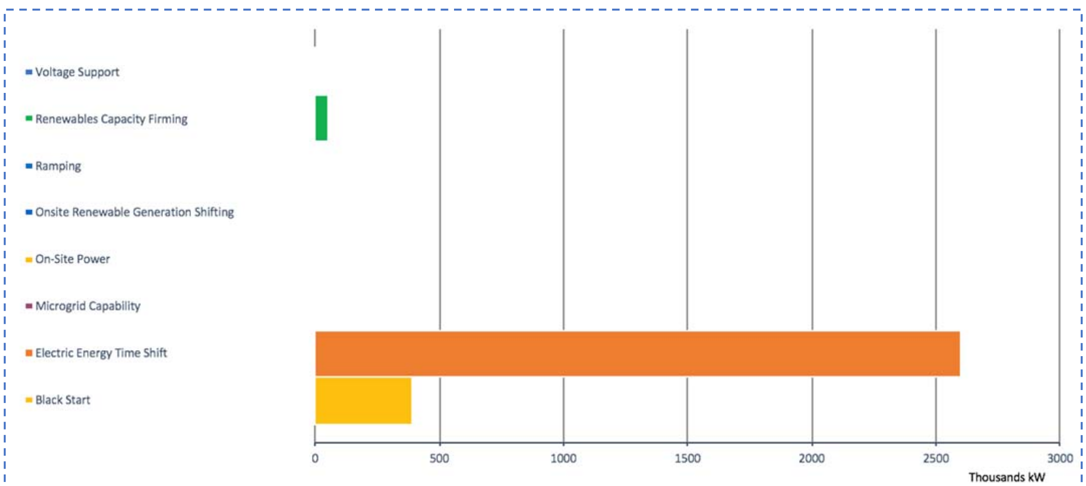



Figure 6.14 Australia - Installed Energy Storage Capacity per segment

Finally, *Figure 6.14* shows the installed energy storage capacity per segment. As it can be seen, between 2014 and 2015 the "ongoing political review of the country's renewable energy target" affected the market, especially at a consumers' level (IESA et al., 2015).

Table 6.2.7 Australia Profile Summary

| General Considerations | Australia |
|---|---|
| **Installed generating capacity (GW) (2014 - 2015 est.)** | 63 |
| **Population (July 2015 est.)** | 22,751,014 |
| **Electricity Consumption (KWH) (2012 est.)** | 222,600,000,000 |
| **Electricity Consumption (KWH) per capita** | 9,784 |
| **Share of renewables used for electricity production (% including hydro) (2015 est.) (Enerdata)** | 15% |
| **Share of renewables used for electricity production (% only wind and solar) (2015 est.) (Enerdata)** | 7% |
| **Climate (CIA WFB)** | Generally arid to semiarid; temperate in South and East; tropical in North |
| **Geographic Conditions (Terrain) (CIA WFB)** | Mostly low plateau with deserts; fertile plain in Southeast |
| **Infrastructure (Media / Press)** | Diversified applications: transmission, distribution, customer services, conventional generation, and renewables |
| **Political Support (Media / Press)** | Mixed ownership model |
| **Quality of Investment (DoE Dataset)** | 2.89 GW to be installed |

## 6.3 Political Will

As described before, ESTES expansion, as a result of its cost reduction, is generally tied up to the energy mix that a given nation or region has. Thus, it is often the case that governments are interested in diversifying their energy matrix and in moving away from conventional energy resources (Zucker et al., 2013). In this sense, *Table 6.3* offers a succinct tool and, at the same time, a political timeline to better understand governmental support towards energy storage.

Table 6.3 Political timeline per country or region (Renewable Energy Association, 2016)

| Country / Region | Political Timeline: ESTES relevance |
|---|---|
| United States | Storage Technology for Renewable and Green Energy Act of 2013 or the Storage 2013 Act<br><br>• Similar to the Storage Act of 2011 this act promotes deployment of energy |

| | |
|---|---|
| | storage technologies by recognizing the benefits of renewables and consumers and the benefits to the grid. The Act aims to level the playing field of energy tax incentives (U.S. Senate Committee, 2013).<br>• The Act provides 20% investment tax credit of up to $40 million per project connected to the electric grid and distribution system. Additionally, the Act provides 30% investment tax credit of up to $1 million per project to businesses for on-site storage (ibid).<br>• An important change from the Act of 2011 is that the minimum size of system eligibility had been lowered from 20kWh to 5kWh. This change helps promote deployment of systems from small businesses to the grid and it is expected to incentivize storage companies to create leasing models for residential users (ibid).<br>• The Act also provides 30% tax credit for homeowners for on-site storage systems to store off-peak electricity from solar panels or from the grid for later use (ibid).<br><br>Federal Energy Regulatory Commission (Orders)<br><br>• Order 755 increases the pay for “fast” responding sources like batteries or flywheels that are bidding into frequency regulation service markets. “Fast-ramping, more accurate resources are now given greater compensation in the wholesale frequency regulation markets” (DOE, 2015). The FERC is ensuring that it’s providing just and reasonable and not unduly discriminatory or preferential rates of frequency regulation.<br><br>• Order 784 expands Order 755 and focuses on the third-party provision of ancillary services and accounting and financial reporting for new electric storage technologies (ibid). According to the Order public utilities must take into account the speed and accuracy of regulation resources, which opens the door for greater efficiency in transmission customers' purchase of regulation resources. Additionally, the order eases the barriers for third-party entry into ancillary service markets and by revising accounting and reporting requirement to improve market |

| | |
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| | transparency.<br>• The incentives for systems that provide summer on-peak demand reduction are \$2,600/kW for thermal storage and \$2,100/kW for battery storage technologies (ibid). Proposed incentives are capped at 50% of installed project cost plus bonus incentives are available for large (>500kW) projects.<br><br>Master Limited Partnerships Parity Act<br><br>• A Master Limited Partnership (MLP) "is a business structure that is taxed as a partnership, but whose ownership interests are traded like corporate stock on a market" (Library of Congress, 2013). However, it has only applied for fossil fuel- based energy partnerships within the internal revenue code.<br>• The MLP Parity Act "Amends the Internal Revenue Code, with respect to the tax treatment of publicly traded partnerships as corporations, to expand the definition of "qualifying income" for such partnerships to include income and gains from renewable and alternative fuels (in addition to fossil fuels), including energy derived from thermal resources, waste, renewable fuels and chemicals, energy efficient buildings, gasification, and carbon capture in secure geological storage" (Lib. of Cong., 2013).<br>• The MLP Parity Act expands MLP eligibility to an array of renewable energy sources, including "electricity storage devices" (DOE, 2015). If the Act is enacted, it will allow for more equitable taxation methods across all energy sectors and will allow for new ownership and taxation models for energy storage device partnerships (ibid).<br>• MLP Parity Act was introduced in 2012 and then in 2013 (with expanded qualifying resources) and still awaits approval. |
| China | Central Government<br><br>• There have been funding for demonstration projects such as the Zhangbei project in Hebei, which has 36KWh lithium-ion battery capacity, in order to evaluate the value energy storage would have when providing |

| | |
|---|---|
| | electricity gird flexibility.<br>• The National Energy Administration (NEA) released around 13 energy policies in 2015, which included large capacity energy storage and EV charging infrastructure (almost 400% yearly increase in EV sales).<br>• Since 2015, the National Reform and Development Commission (NRDC) has been implementing time-of-use pricing mechanisms. |
| Japan | Ministry of Economy, Trade and Industry<br><br>• Government support to demonstrate the ability to time-shift demand by 10% in conjunction with expanded use of renewable generation resources. Within the next seven years METI funding is aiming to decrease the total cost by providing funds up to 75% of the total storage system cost.<br>• METI is planning to spend around 81 billion yen to resolve grid related issues and to increase renewable energy. Additionally, the Ministry is aiming to provide incentives for energy storage systems, which can be implemented in solar power stations or substations. The budget is awaiting parliament approval.<br><br>Ministry of Environment<br><br>• Up to 50% subsidy for storage battery for renewable energy generation (<1MW)<br>• Subsidy for renewable energy in local areas (Total 1bn JPY) |
| Germany | Federal Ministry of the Environment, Nature Conservation and Nuclear Safety<br><br>• Since May 2013, part of the support scheme for solar-plus-batter, the state-owned bank Kreditanstalt für Wiederaufbau (KfW) has granted low-interest loans with an aggregate value of €163 million for 10,000 energy storage projects combined with PV installations with a power up to 30kW.<br>• The Ministry also covers 30% of the storage system costs. Eligible PV systems should feed maximum 60% of installed capacity into the grid. |

| | |
|---|---|
| European Union | European Commission – Framework Research Programme<br><br>• The 'stoRE' project, co-funded by the Intelligent Energy Europe Programme of the EU, aims to create a framework that will allow energy storage infrastructure to be developed in support of higher penetration of variable renewable energy resources. Target countries to identify a series of improvements/application include Austria, Denmark, Germany, Greece, Ireland, and Spain. |

## 6.4 Political framing

There are several mechanisms that have been developed to analyze political ecosystems around energy policies. One of the most common structures used to understand the way institutions work towards a specific goal is the TAIDA framework. Under this five-staged model, interests from the public sector can be more easily described, discussed, and, eventually, put into action with operators and technology providers.

However, there are other means to structure the way negotiations can lead to effective energy storage policy making. So, while there is a lot of noise around policy framing, *Table 6.4* offers a synthesis on how countries are currently leveraging opportunities and threats to clarify investment and deployment of energy storage.

Table 6.4 Political framing per country

| Country | Political framing |
|---|---|
| United States | • Mixed ownership model<br>• On policy making: Negotiations mainly led by interconnectors<br>• Increasingly mature market for transmission and distribution applications |
| China | • Third Party ownership model<br>• On policy making: Negotiations mainly led by the government<br>• Even market across several energy storage applications |
| Japan | • Customer ownership model<br>• On policy making: Negotiations mainly led by utilities and technology providers<br>• Increasingly mature market for micro-grid and domestic applications |
| Germany | • Utility ownership model<br>• On policy making: Negotiations mainly led by utilities and technology |

| | |
|---|---|
| | providers, but always under national and supranational (EU) coordination<br>• Increasingly mature market for micro-grid and domestic applications |
| France | • Third party ownership model<br>• On policy making: Negotiations mainly led by utilities and technology providers, but always under national and supranational (EU) coordination<br>• Increasingly mature market for transmission and distribution applications |
| United Kingdom | • Utility ownership model<br>• On policy making: Negotiations mainly led by utilities and technology providers, but always under national and, recently, supranational (EU) coordination<br>• Increasingly mature market for transmission and distribution applications |
| Australia | • Mixed ownership model<br>• On policy making: Negotiations mainly led by utilities and technology providers<br>• Increasingly mature market for transmission and distribution applications |

In general, these actions should follow a strategic roadmap, as proposed by IEA & OECD (2014). A summary of policy and regulatory frameworks with a short-term mock-up milestones is shown in *Table 6.4.1*.

Table 6.4.1 Political framing roadmap (IEA, 2014)

| Actions recommended | Milestone |
|---|---|
| Eliminate price distortions and increase price transparency for power generation and heat production, e.g. time-of-use pricing schemes, pay-for-services (heating, cooling, quick response, etc.) models | 2020 |
| Enable benefits-stacking for energy storage systems | 2020 |
| Government support of energy storage use in off-grid and remote communities | 2025 |
| Support of the rapid retrofit of existing energy storage facilities to increase efficiency and flexibility, where these retrofits appear warranted | 2030 |

| | |
|---|---|
| Inclusion of energy storage technologies as options for supplying energy and power services, and support for their continued development through government-funded R&D programs | 2030 |

## 6.5 A favourable scenario

Among the country profiles reviewed, the United States, China, and Japan are the most relevant candidates to be a subject of further analysis and consideration (See *Figure 6.15*). These three nations have been in the loop of energy storage deployment as well as with many other services within the industry since the late 90s. Moreover, the three together account for more than 70% of this profitable global market (General Electric estimates that the value of this market could reach $6 billion USD by 2020).

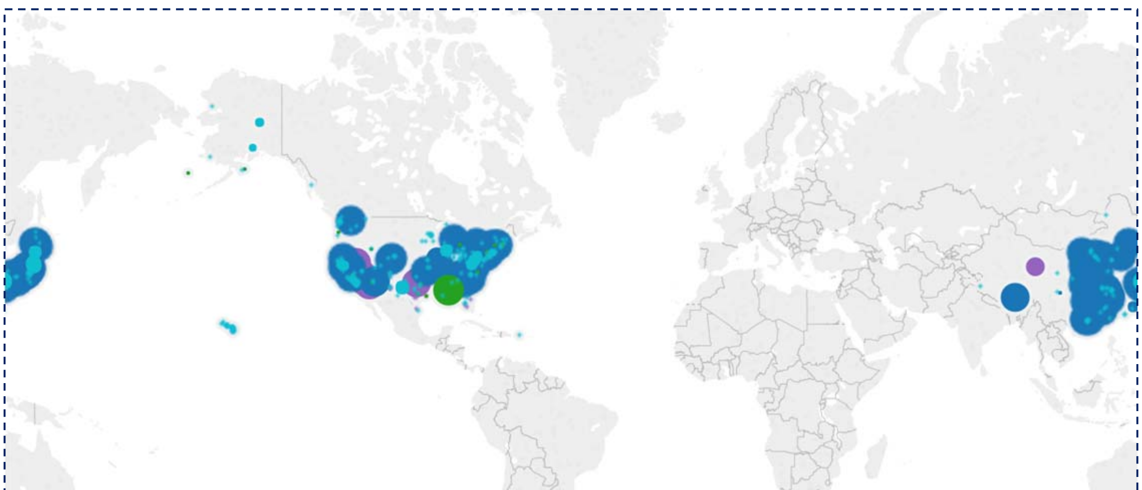


*Figure 6.15 Installed Energy Storage Capacity per top-three countries*

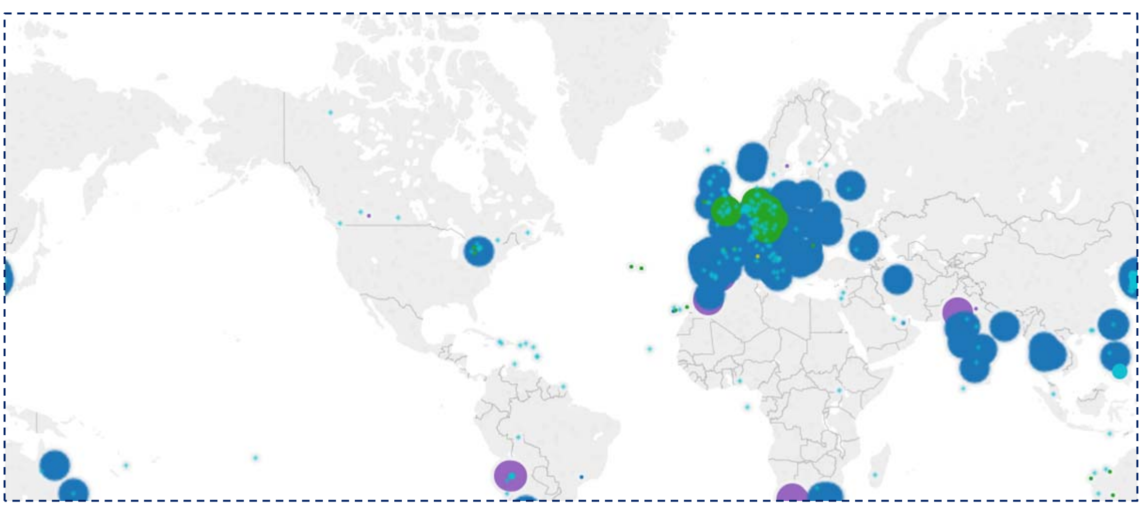


*Figure 6.16 Installed Energy Storage Capacity for the rest of the world*

Also, *Table 6.5* outlines some of the main participants or agents for the seven case studies previously discussed. What is relevant about this chart is that although there is no homogeneous active presence of utilities or technology providers among countries, governments are always involved in those situations where energy storage growth is relatively steady.

Table 6.5 Prominent players of the energy storage sector per country

| Country | Key energy storage agents |
|---|---|
| United States | • PJM, ERCOT, NYISO, CAISO<br>• Several other interconnectors<br>• Siemens<br>• GE<br>• Department of Energy (+GESDB)<br>• IEA |
| China | • IEA<br>• CNESA<br>• NEA<br>• Central Government |
| Japan | • IEA<br>• METI<br>• Solar Frontier |
| Germany | • ENTSO-E<br>• E.ON<br>• Bosch<br>• Siemens<br>• GE<br>• IEA<br>• Storage associations (BVES) |
| France | • ENTSO-E<br>• EDF<br>• Alstom<br>• GE<br>• IEA<br>• Storage associations |
| United Kingdom | • DECC<br>• E.ON<br>• Alstom<br>• GE<br>• IEA<br>• Storage associations |
| Australia | • AESC<br>• IEA |

| | |
|---|---|
| | • Storage associations (AESA)<br>• ZCell |

## 6.6 Expertise in ESTES and main challenges ahead

Within the ESTES context, expertise, and human resources main points can be broadly divided into three main categories. The first is comprised of the energy storage associations. Often a 'product' or an initiative from the private sector or international partnerships, energy storage associations are bodies of knowledge and cooperation that concentrate human talent and that constantly lobby on energy storage deployment and R&D funding.

Secondly, technology providers and academia work closely by investing in cutting edge technologies and promising research project around the globe. These joint works are majorly funded by private capital. Thus, it is very unlikely that any stage of the innovation process will be open to public scrutiny unless organizations are willing to pay a considerable fee.

The final point on human resources is not about human talent pools but it is about the necessity of creating incentives and training adequate candidates and researchers on energy storage for the future. Compliance with international standards and mobility across regions for more cooperative environments will be absolutely essential (IEA, 2014).

Table 6.6 Training roadmap (IEA, 2014)

| Actions recommended | Milestone |
|---|---|
| Develop improved workforce training programs with customized course content pertaining to energy storage technologies. | 2018 |
| Further develop international standards and testing programs to document safety and performance of energy storage technologies. | 2018 |
| Develop and implement programs to increase the utilization of distributed demand-side energy storage capacity (i.e. residential water heaters with timers and remote control capabilities to shift demand from peak to off-peak periods) | 2020 |

As an analogue of Section 1.3, IEA (2014) proposes actions to be taken when it comes to training and human resources. This is shown in *Table 12*. Finally, *Table 13* synthetizes the main challenges currently faced by each case of study as discussed in their own profile sections.

Table 6.6.1 Main challenges faced in ESTES deployment per country

| Country | Main challenges faced |
|---|---|
| United States | • Coordinated investment<br>• Lack of human talent<br>• Policy uncertainty<br>• Changing demand profiles |
| China | • Cost of large-scale deployments<br>• Lack of human talent<br>• Non-standardized growth<br>• Changing demand profiles |
| Japan | • Renewable's expansion dependency<br>• Cost of large-scale deployments<br>• Changing demand profiles |
| Germany | • Renewable's expansion dependency<br>• Energy efficiency (regional imbalances)<br>• Cost of large-scale deployments<br>• Deployment of other services |
| France | • Policy uncertainty<br>• Cost of large-scale deployments<br>• Deployment of other services |
| United Kingdom | • Policy uncertainty<br>• 'Revenue cannibalization risk'<br>• Disintegrated market structures |
| Australia | • Cost of large-scale deployments<br>• Deployment of other services |

Chapter 7

# PLAN OF ACTION

Chapter 7 : Plan of action

On aggregate, Energy Storage Technologies (ESTES) feasibility and deployment are continuously increasing. At a regional or national level, however, the specificity of certain solutions still requires that local policy makers, incumbent utilities and, certainly, customers meet a point where, broadly, clear financial mechanisms should be the norm. For instance, in the case of the SAARC region, not political stability nor policy framing but political will towards investment in ESTES is expected to be a key point for further development.

Internationally, it has been stated that U.S.A., China, and Japan remain as the global references in terms of both installed and under-construction energy storage capacity projects. Nevertheless, as seen in Chapter 6, this prevalence is not only related to a purely technical factor. What these three governments share, is that they have all experienced massive political support in the last 5 years.

In the case of the North American giant, the ‘Storage Technology for Renewable and Green Energy Act’ in 2013, for example, could be seen as the trigger of a subsequent set of directives -and even orders from the federal government- where the U.S. Senate, the DOE, and other entities have shown interest by introducing several tax credit and cost-sharing subsidies schemes and by creating incentives for more ancillary services. In this same line, China and Japan, supported by the *Central Government* and the *Ministry of Economy, Trade and Industry*, respectively, have recently decided to focus on flexibility (time-shift demand), time-of-use pricing mechanisms, and direct subsidies for storage batteries up to 50%.

On a complementary point, a strong and clear correlation with the total expenditure on Science and Technology can be noticed, since for these three cases as well as for the rest of the examples debriefed in Chapter 6, R&D figures are far above the world’s average.

## 7.1 Recognition of Potential Application Areas

Chapter 7 synthesizes all the technologies, concepts and, more importantly, the opportunities discussed in this document. In this regard, the authors also outline guidelines and recommendations for the deployment of energy storage technologies in the SAARC region. This, anchored in the most suitable courses of action studied and the '*sui generis*' projects currently being implemented in the World, but, of course, adapted to the technological context, the economic and financial viability, the mass awareness, and the policy ecosystem of South Asia as described in Chapter 4.

## 7.2 Important Prerequisites

The most important prerequisites for a successful deployment of energy storage technologies, that have eroded throughout the primary and secondary research conducted, are summarized in the section ahead. In order to create a multifactorial assessment for decision making support, these prerequisites are based on a combined exchange of the main points and challenges to overcome, from Chapter 2, Chapter 5 and Chapter 6.

### a. Political and Institutional Preconditions

In general, and as for many others economic and social developments, ESTES deployment is tied up to political and institutional stability. However, for regions where supranational entities are clearly defined and do have an influence on the regulation of individual members, the bargaining power for negotiations on ESTES deployment, seems to be left at the utilities, interconnectors and technology providers hands.

Governments in these contexts have adopted a role of pure coordinators and facilitators rather than central pivot points for energy storage penetration. This does not mean that political will is not key, it means that political will should be understood as the need to prevent the fall back of energy storage penetration achieved so far, as opposed to being a starting point for maturing the market.

The success of any endeavour as humongous and widespread as the deployment of energy storage depends very much on the support that it receives from the political level. This is even more important when the need is for a sustained campaign not only to bring in the most optimal resources over a period of time at the right places but also to try and ensure that the focus is not lost midway.

Some of the key drivers for political backing for the energy storage policy and implementation would be:

- The primary need to work towards energy security for the country in the medium term
- The criticality of reducing dependence on imported oil, even if prices stay low
- The massive push towards a renewables led electricity sector
- The continued pressures of climate change necessitating reduction of fossil fuel based energy
- Commitment to reach electricity for all
- Ensuring adequate support to the economy through reliable electricity supply
- Do all of the above within the limits of funding that are feasible over a reasonable period

The crux of any such gigantic effort to induct energy storage technologies on a large scale over the next several years is the resolution of a common political dilemma. If energy storage measures are introduced too quickly, the price of electricity will rise quickly and potentially trigger a backlash from consumers including industry. If energy storage measures are introduced too slowly, major renewable energy resources will either not become as reliable as fossil fuels or will risk becoming commercially too risky due to output curtailment.

Political establishments would also want to understand as to how much of the thrust for energy storage deployment needs to come through public investment and how much could be left to private funding albeit through strategic signals in the form of incentives and subsidies. This is where the role of think tanks and unbiased studies would prove handy in offering advice to support the political levels in setting the agenda for energy storage

Commercial requirements for energy storage systems need to keep in mind the future market needs, industry capability, and the best use of storage in as many situations as feasible.

The key outcomes expected from a storage facility include:

- Shifting of capacity from low demand periods to high demand
- Smoothing/firming out the output of intermittent generation resources
- Assisting with utilisation of surplus RE generation more effectively
- Adding MW capacity to the system
- Providing additional electricity ramp up and ramp down services
- Helping in managing transmission constraints
- Providing contingency response and energy reserves

Since storage is a relatively nascent technology when it comes to grid level applications, it would be important that the commercial mechanism provides a financial backstop to bridge any gap between market revenues and the total required costs. It would also be essential to incentivise the facility to operate when it is economic to do so, so that the facility is effectively integrated into the prevailing market. In a similar fashion, there should also be penalties for lower system availability.

## b. Legislation and Policy Regime

Different legislation structures and policy regimes converge on the type of the main ownership model that a given country has been using to grow in the realm of energy storage until today. In the case of the U.S.A., China, and Japan, again the global main players of the segment, these ownership models are often mixed, customer-oriented or third party oriented. This, of course, having several, idiosyncratic and historic reasons.

Even if the rest of the countries are also considered, it is hard to predict whether a specific scheme can be predominant beyond the basic guarantees that any investor or stakeholder should receive. However, it seems that for those countries that have rapidly grown energy storage capacity in recent years, agreements were always defined in the benefit of utilities; at least at the beginning. Legislation structures tend to then adapt to the technology providers and end customer's financial needs or expectations.

What is required to be done for the storage sector in the SAARC region involves recognition of storage systems as energy consumers as well as energy sources thereby enabling them to participate in the grid.

Subordinate legislation would also need to be brought in to ensure the setting of continually updated standards for design, manufacture, testing and operation of energy storage devices, besides safety standards.

While finalizing subordinate legislation in the form of storage regulations, electricity regulators need to assess the fit that the various storage technologies may have with the planned energy mix. Regulators also need to consider the policies that will enable and incentivise storage adoption within their jurisdiction.

Government support through financial contributions, tax credits, standard setting and market creation is important for effective technology development, innovation and deployment. Large public investments into technology innovation and infrastructure are not new. It is also known that today's electricity sector is the result of long years of policy support for conventional energy resources, building of transmission networks and control of retail tariff levels.

Government investments come in a variety of forms, from outright subsidization to contracting and procurement to various tax deductions, subsidies, and other mechanisms aimed at starting, financing and otherwise supporting industries deemed important either to the national economy, energy security, or both. Many successful new technologies cannot become commercially viable without public investment in the form of government procurement.

Many alternative approaches and strategies are possible for achieving an effective Energy Storage policy. There would, however, be some key guiding principles which we consider to be as follows:

- ESTES to be considered a resource of national and strategic importance
- Take a co-ordinated approach to power sector planning, including energy storage also as an integral component
- Reduce large tariff impacts for distribution companies between procurement from standalone RE resources and those combined with energy storage until storage requirements are better understood and their prices come down.
- Give small-scale/distributed Energy Storage close to end-users the same priority as large-scale/centralized storage

### c. Human Resource and Academia Involvement

Central considerations for developing expertise in ESTES and attracting talent for local initiatives, can be tackled by three main categories. First, energy storage associations must concentrate human talent and hopefully connect with governments for more R&D funding. The second channel is the collaboration between technology providers and Academia. The more of these joint works in applied research, primarily funded by private capital, the more changes that cutting-edge technologies will be indeed released to the market.

Adoption of storage technologies will necessitate significant skill development in some areas and partial re-skilling in others. A key challenge therefore will be the development of adequate trained human resources. While this will help in expansion of manufacturing as well as research and development, it would also create considerable value for the economy while supporting and sustaining a vibrant energy storage sector.

The availability of trained manpower, some of it specialist, attracting and retaining talent, training and capacity building for those in the sector, and the necessary expansion of energy storage curricula in universities to ensure the sustained supply of quality manpower would be very essential. The key skill areas include:

- In manufacturing of components
- Testing, standards and safety requirements
- Installation, Operation and maintenance
- Grid planning, particularly on matching technology with locational needs
- System operations
- Regulatory capacity

The availability of trained manpower, some of it specialist, attracting and retaining talent, training and capacity building for those in the sector, and the necessary expansion of energy storage curricula in universities to ensure the sustained supply of quality manpower would be very essential.

Universities, other research institutions and academia can contribute tremendously by getting involved in the energy storage debate. This would not only raise the level of the debate beyond purely commercial matters but would also help create an environment where young people who study or work at such institutions would get motivated to work on storage projects as researchers or innovators or business developers.

Collaborations between academia and industry offers advantages to both entities and is a means by which academic institutions and industry can address challenges to their mutual benefit. Academia-industry partnerships can facilitate research discoveries reaching the people who need them and serving the purposes for which they are required, at affordable prices.

Academia must also work with governments, scientific bodies, non-governmental and inter-governmental organisations to help realise a more sustainable energy future through unbiased advocacy of appropriate technologies and applications of energy storage systems. This will also help bring together the resources and players necessary to bring about a balanced and minimally wasteful deployment of storage.

Knowledge dissemination is the top purpose of universities whereas in industry, knowledge could be subordinated by its ability to provide competitive advantage. Members from academia typically bring insights and strategies from very different contexts. The cultures of academia and industry are quite different and it essential for that very reason that both must work and collaborate closely with each other and with government and other stakeholders to increase the complementary exchange of knowledge resources. Academia promotes intellectual contributions, technological skills and provides competent and well-educated employees for industry.

Some of the valuable contributions of academia involvement would include the following:

- Accelerate R&D efforts focused on optimising the integration of energy storage technologies in the energy system
- Work on efficiency and reliability of existing systems
- Push technologies beyond their current limits in order to bring down their costs and/or widen their potential applications
- Work on improving storage management systems through integration of academic research and feedback from industry
- Provide an overarching and non-partisan voice in industry debates without being bogged down by corporate loyalties or commercial gain.

Finally, adapting to international standards will enhance mobility and cooperation with global champions. Thus, spreading open innovation and accelerating the process of ESTES adoption. Complementary, an adaption of Table 6.6, Chapter 6, is shown next to highlight specific actions for more effective training of human resources.

Table 7.1 Training roadmap (IEA, 2014), adapted for SAARC

| Actions recommended | Milestone |
|---|---|
| Cooperate with Academia for the prioritization of updated and improved workforce training programs related to energy storage technologies. | 2018 |
| Adapt to international standards and testing programs to document safety and performance of energy storage technologies. | 2018 |

| | |
|---|---|
| Develop and implement programs to increase the utilization of distributed demand-side energy storage capacity. | 2020 |

## d. Infrastructure and Mass Awareness Requirements

Infrastructure requirements are diverse and dependent on many factors such as population, electricity consumption, and even climate and geographic conditions. As reviewed in Chapter 6, these conditions should be thoroughly studied before deciding on which technologies a country should invest in. Moreover, historic storage technologies per country -e.g. pumped hydro- are no longer a clear reference since environmental agreements require different solutions but, generally, more renewables used for electricity production.

The economics of energy storage is improving significantly with recent advancements in materials and manufacturing. Traditional storage technologies such as pumped hydro and compressed air seem to have limited applicability and appear to be losing market share to emerging battery technologies, many of which are leveraging experience in the transportation and consumer electronics sectors to compete in the power sector. Some storage technologies can provide power quickly while others may be able to deliver it over an extended period. Infrastructure requirements for storage could therefore vary widely.

A very different form of infrastructure would be required if Electric Vehicles adoption outpaces grid storage due to its other benefits especially on climate change parameters. In terms of aggregated volumes even in limited geographical areas, EVs could emerge as significant players in balancing the load-generation gap caused by the intermittency of renewables output.

Infrastructure requirements for ESTES would include:

- Manufacturing infrastructure
- Safe transportation methods, particularly for hazardous materials
- Ease of access not just for initial installation but also for operation and maintenance, including component replacements
- Charging stations and associated equipment and accessories, including meters and switching devices that respond to price signals and of course time-of-day record keeping
- Testing laboratories for certification and compliance validation of components and systems

- Training centres for skill development

Thus, and although diversification seems to be preferred at a political level, our assessment on the infrastructure and mass awareness per member state is somehow biased towards the deployment of renewables and cleaner energies. Depending on the nation, the most common necessities are investment in physical infrastructure for transmission and distribution lines. In more developed nations, further ESTES penetration barely requires physical infrastructure but it depends on better customer services and mass awareness of the several benefits of ESTES usage that should go beyond a ‘green’ consciousness.

As electric generation shifts away from central, thermal plants to more distributed and variable renewable sources, the ability to flexibly store energy will play an ever more critical role. While there is a certain degree of familiarity with behind-the-meter energy storage like batteries in SAARC Nations due to their use in homes and offices to deal with load shedding, there is little awareness of storage applications that are in-front-of-the-meter.

Energy storage companies and utilities would be keen to send out a clear message that storage products provide value to the grid even perhaps if it’s a value that the markets currently aren’t designed to compensate. The rules written before this technology came into its own would need to be amended for storage providers to recoup investments that yield tangible services to the grid and to its customers.

A well planned and sustained mass awareness campaign is therefore necessary to set out the benefits of energy storage systems before the people and also the elected representatives. It is necessary to get the storage story out to more people and help push the policy conversation in a direction that creates opportunities for storage to provide flexibility, reliability and renewables integration to the grid.

Besides awareness campaigns through print and electronic media and through the use of knowledge dissemination workshops as well as pilot demonstration projects, it would be essential in today’s age to effectively use social media. The use of mobile apps may also be very effective.

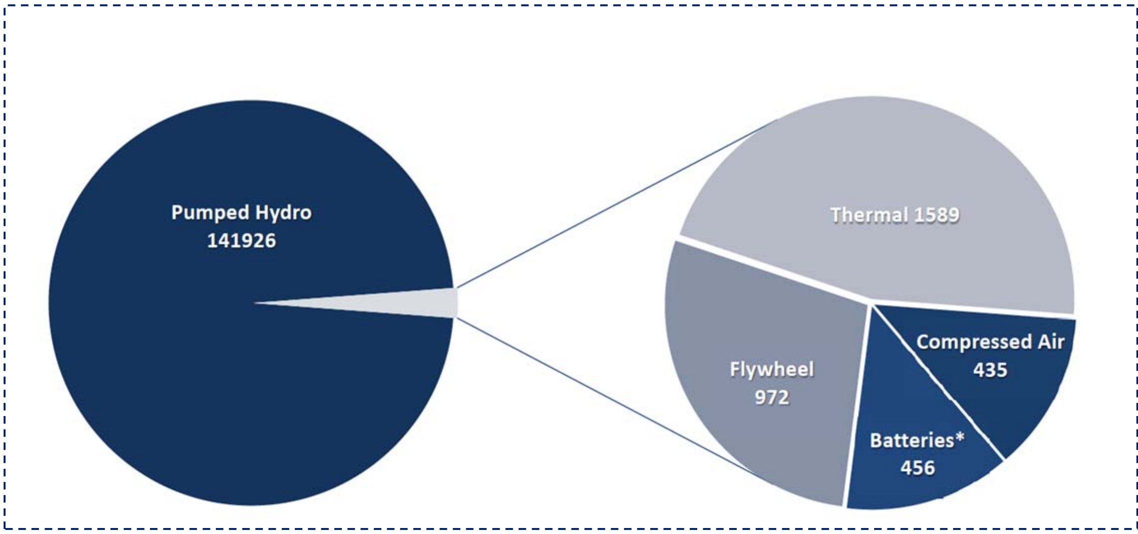
## Regional Cooperation, Institutional Partnership in capacity building and Recommendations based on Targets for the SAARC Region

Table 7.2. Political framing roadmap (IEA, 2014), adapted for SAARC

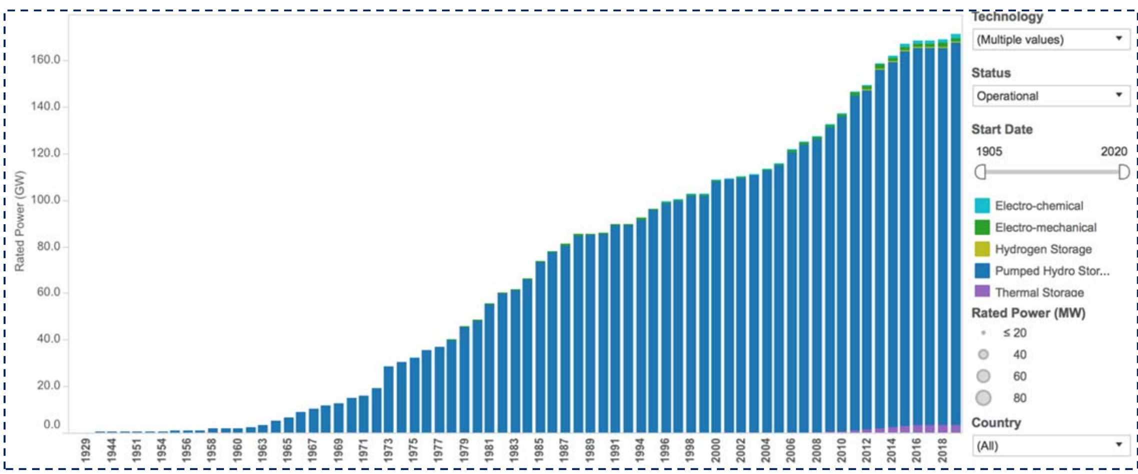
| Actions recommended | Milestone |
| --- | --- |

| | |
|---|---|
| Eliminate price distortions and increase price transparency for specific ESTES and for each Member State | 2020 |
| Government support of energy storage use in remote communities and members with lower ESTES current capacity | 2025 |
| Support of the rapid retrofit of existing energy storage facilities to increase efficiency and financial support for identified key utilities and technology providers | 2030 |
| Inclusion of energy storage technologies as options for supplying energy and power services, and support for their continued development through government-funded R&D programs | 2030 |

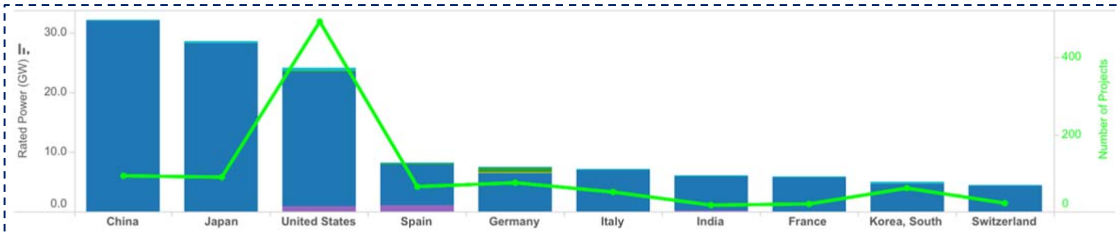
# APPENDIX




*Appendix 1. Energy storage capacity installed world-wide (Huff, 2014)*

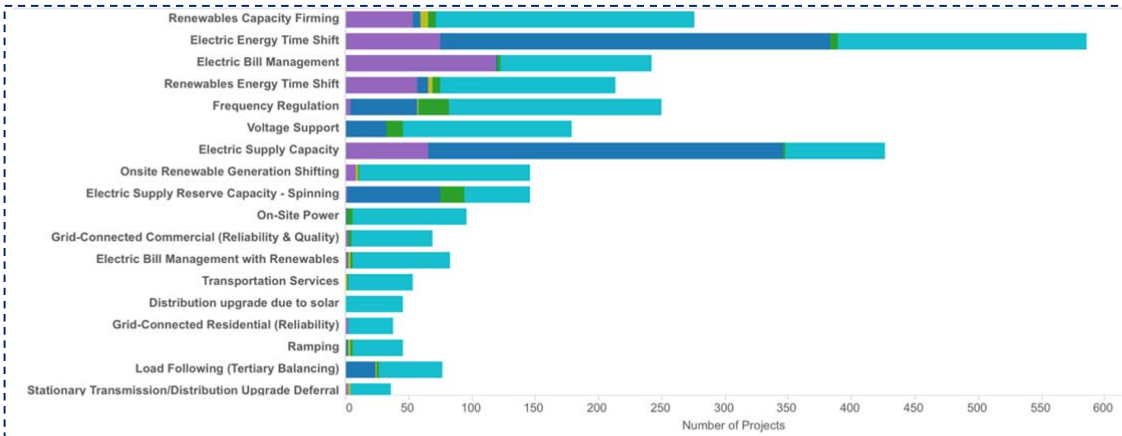



*Appendix 2. Energy storage capacity installed over time (Huff, 2014)*

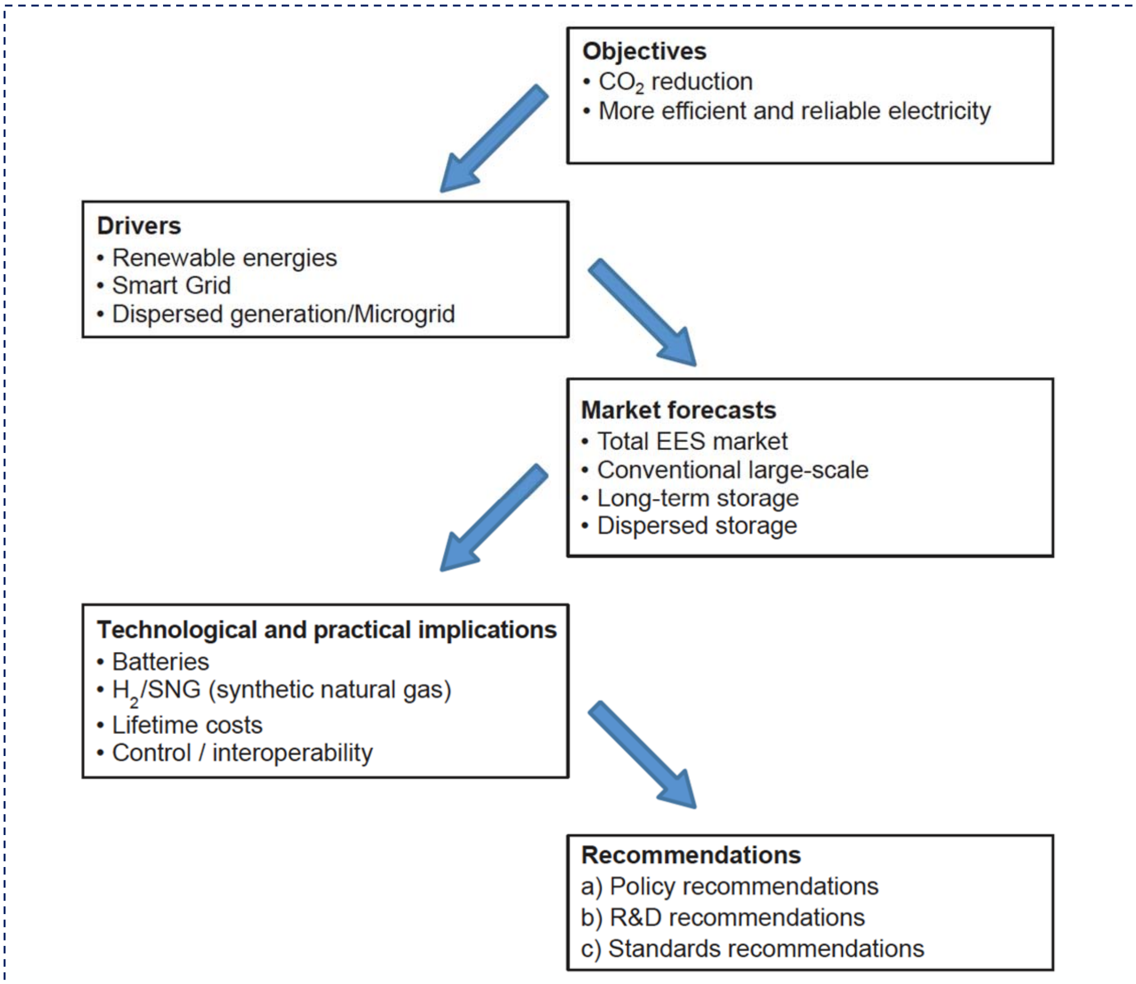



| Country | Number of Projects | Rated Power (kW) |
|---|---|---|
| China | 94 | 32,103,770 |
| Japan | 90 | 28,506,426 |
| United States | 494 | 24,123,397 |
| Spain | 66 | 8,121,066 |
| Germany | 76 | 7,567,264 |
| Italy | 52 | 7,133,197 |
| India | 18 | 6,013,290 |
| France | 21 | 5,834,192 |
| Korea, South | 62 | 4,991,408 |

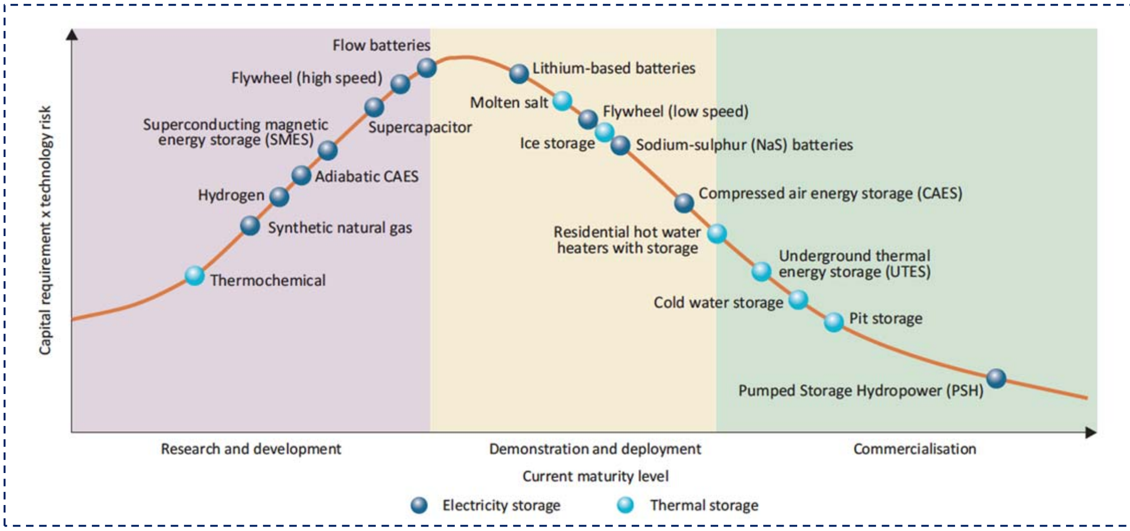
*Appendix 3. Top countries by installed capacity (Huff, 2014)*



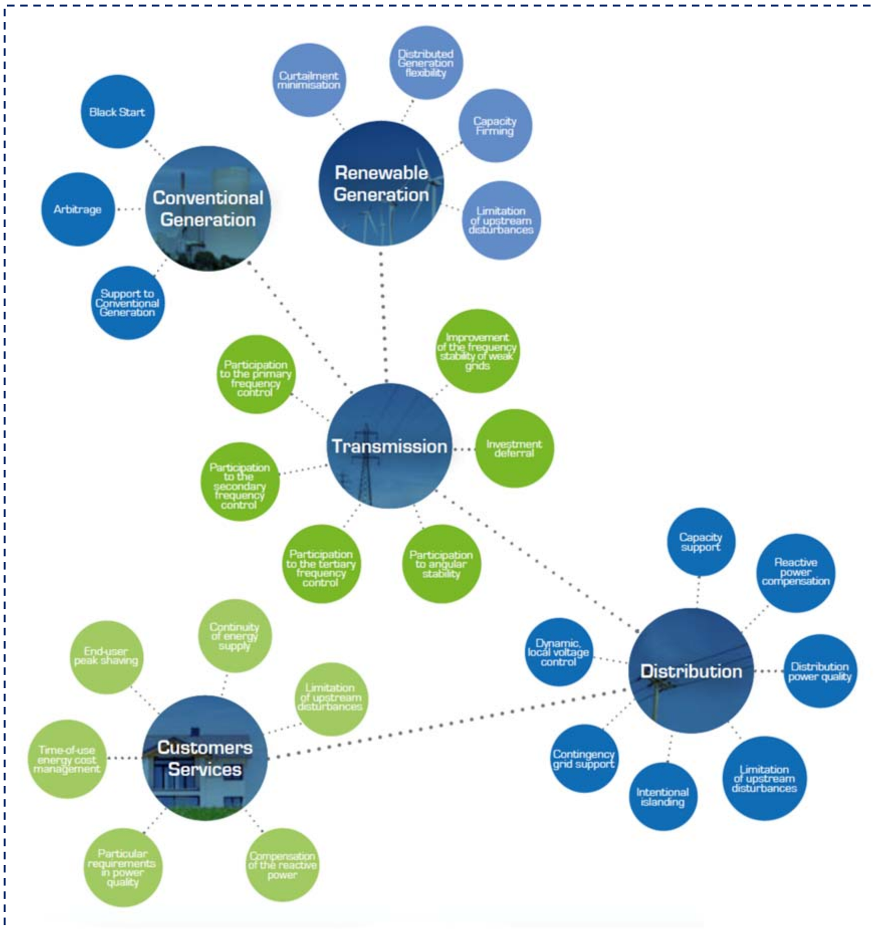

*Appendix 4. Top use cases and applications (Huff, 2014)*




*Appendix 5. Summary of action steps proposed by (IEC, 2014)*




*Appendix 6. Maturity of energy storage technologies (IEA, 2014)*




*Appendix 7. Energy storage applications (EASE, 2014)*

*Appendix 8. Table. Near term action for stakeholders (IEA, 2014)*

| Lead Stakeholder | Actions |
|---|---|
| Governments | • Create an accessible global dataset of energy storage technology project overviews, including information on system specifications, cost and performance. Establish international and national data co-operation to foster energy storage research, monitor progress, and assess the R&D bottlenecks<br>• Compile a comprehensive dataset of renewable generation production behaviour with high levels of granularity to allow for assessment across a wide range of energy storage technology applications through the year<br>• Support materials research and efficiency gains via mass production for battery systems to improve energy density and reduce costs<br>• Develop improved workforce training programs with customized course content pertaining to energy storage technologies<br>• Streamline the siting and permitting process for new energy storage projects<br>• Implement testing programs to document the safety and performance of energy storage technologies, based on published standards and protocols<br>• Eliminate price distortions and increase price transparency for power generation and heat production, including time-of-use pricing and pay-for-services models |
| Industry | • Quantify waste heat availability and opportunities, including details on waste heat quantity, quality and location for both resources and potential demand<br>• Quantify distributed energy storage potential in existing infrastructure<br>• Assess global energy storage potential by region for capital-intensive projects, including PSH, CAES and UTES<br>• Document and more effectively communicate the cost and performance of ice storage systems for cooling applications and best practices for installation and operation<br>• Improve battery assembly design to improve system reliability and performance<br>• Demonstrate energy storage system performance in the context of multiple applications and share results with stakeholder community<br>• Improve operation management of battery systems, both centralized and distributed<br>• Retrofit existing energy storage facilities to increase efficiency and flexibility |

| | |
|---|---|
| | • Explore new business models to overcome the barrier of high upfront costs of innovative and efficient energy storage solutions |
| Universities and other research institutions | • Accelerate R&D efforts focused on optimizing the integration of energy storage technologies in the energy system<br>• Improve thermal efficiency and reliability of UTES systems at elevated temperatures<br>• Develop molten salts (or similar thermal energy storage materials) with lower melting temperatures while maintaining their stability at higher temperatures<br>• Improve containment vessels and associated equipment used in PCM storage systems<br>• Improve the efficiency of supercapacitors and document technology performance through testing and demonstration |
| Financial institutions | • Streamline the financing process for new large-scale storage systems, with clear guidelines on documentation requirements<br>• Incentivize the co-financing of distributed electricity generation technologies with integrated storage after assessing the risks and benefits of this approach |
| NGOs | • Implement consumer awareness campaigns to increase utilization of distributed demand-side energy storage capacity (e.g. residential hot water heaters for peak demand reduction)<br>• Work with standard–setting organisations and governments to develop performance-based labelling of energy storage |

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