Council on Energy, Environment & Water

ENERGY STORAGE IN INDIA

Applications in the Renewable Energy Segment

NEERAJ KULDEEP, KARTHIK GANESAN, VAIBHAV GUPTA, ADITYA RAMJI, KANIKA CHAWLA AND MANU AGGARWAL

Energy Storage in India

Applications in the Renewable Energy Segment

NEERAJ KULDEEP, KARTHIK GANESAN, VAIBHAV GUPTA, ADITYA RAMJI,
KANIKA CHAWLA AND MANU AGGARWAL

CEEW Report

November 2016

ceew.in

An interim report on 'Energy Storage in India: Applications in Renewable Energy Segment'.

Editor: Dr Arunabha Ghosh

The Council on Energy, Environment and Water (http://ceew.in/) is one of India's (and South Asia's) leading think-tanks with a vast scope of research and publications. CEEW addresses pressing global challenges through an integrated and internationally focused approach. It does so by promoting dialogue and common understanding on energy, environment, and water issues in India and globally through high quality research, partnerships with public and private institutions, and engagement with and outreach to the wider public. Visit us at http://ceew.in/ and follow us on Twitter @CEEWIndia.

Council on Energy, Environment and Water

Thapar House, 124, Janpath, New Delhi 110001, India

About CEEW

The Council on Energy, Environment and Water (http://ceew.in/) is one of South Asia's leading not-for-profit policy research institutions. CEEW addresses pressing global challenges through an integrated and internationally focused approach. It prides itself on the independence of its high quality research, develops partnerships with public and private institutions, and engages with wider public.

In 2016, CEEW was ranked the best in South Asia in two categories three years running (Global Go To Think Tank Index); among the top 100 out of 6846 think-tanks in nine categories. This included CEEW being featured on a prestigious list of 'Best Managed Think Tanks' and 'Best Independent Think Tanks'. In 2016, CEEW was also ranked 2nd in India, 4th outside Europe and North America, and 20th globally out of 240 think tanks as per the ICCG Climate Think Tank's standardised rankings. In 2013 and 2014, CEEW was rated as India's top climate change think-tank as per the ICCG standardised rankings.

In six years of operations, CEEW has engaged in more than 130 research projects, published well over 70 peer-reviewed books, policy reports and papers, advised governments around the world over 260 times, engaged with industry to encourage investments in clean technologies and improve efficiency in resource use, promoted bilateral and multilateral initiatives between governments on more than 50 occasions, helped state governments with water and irrigation reforms, and organised more than 140 seminars and conferences.

CEEW's major projects on energy policy include India's largest energy access survey (ACCESS); the first independent assessment of India's solar mission; the Clean Energy Access Network (CLEAN) of hundreds of decentralised clean energy firms; India's green industrial policy; the $125 million India-U.S. Joint Clean Energy R&D Centers; developing the strategy for and supporting activities related to the International Solar Alliance; modelling long-term energy scenarios; energy subsidies reform; decentralised energy in India; energy storage technologies; India's 2030 renewable energy roadmap; solar roadmap for Indian Railways; clean energy subsidies (for the Rio+20 Summit); and renewable energy jobs, finance and skills.

CEEW's major projects on climate, environment and resource security include advising and contributing to climate negotiations (COP-21) in Paris; assessing global climate risks; assessing India's adaptation gap; low-carbon rural development; environmental clearances; modelling HFC emissions; business case for phasing down HFCs; assessing India's critical mineral resources; geoengineering governance; climate finance; nuclear power and low-carbon pathways; electric rail transport; monitoring air quality; business case for energy efficiency and emissions reductions; India's first report on global governance, submitted to the National Security Adviser; foreign policy implications for resource security; India's power sector reforms; resource nexus, and strategic industries and technologies for India's National Security Advisory Board; Maharashtra-Guangdong partnership on sustainability; and building Sustainable Cities.

CEEW's major projects on water governance and security include the 584-page National Water Resources Framework Study for India's 12th Five Year Plan; irrigation reform for Bihar; Swachh Bharat; supporting India's National Water Mission; collective action for water security; mapping India's traditional water bodies; modelling water-energy nexus; circular economy of water; and multi-stakeholder initiatives for urban water management.

About the Authors

Neeraj Kuldeep

Neeraj Kuldeep is a Research Analyst at the Council on Energy, Environment and Water (CEEW), India. His research interest includes renewable energy technologies, policy, finance, sustainability and smart cities. Prior to his association with CEEW, he has worked at Arup Group Ltd in Mumbai. At Arup, he has worked on projects related to township planning, renewable energy integration and building services.

He has been actively involved in renewable energy and sustainability activities. He was the founding member of Team Shunya, the first ever team from India to qualify for participation in the prestigious Solar Decathlon Europe, an international competition that challenges collegiate teams to design and build houses powered exclusively by the sun. He also initiated the Energy Club at IIT Bombay where he organised various events to raise awareness about sustainability and RE technologies.

Neeraj holds an M. Tech in Energy Systems and a B. Tech in Energy Science and Engineering from Indian Institute of Technology (IIT), Bombay.

Karthik Ganesan

Karthik Ganesan is a Research Fellow at the Council on Energy, Environment and Water (CEEW), India. As a member of the team at CEEW, his research focus includes the development of long-term energy scenarios for India (based on an in-house cost-optimisation model) and energy efficiency improvements in the industrial sector in India. Linked to his work in industrial efficiency is his role as the principal investigator in an effort to identify critical mineral resources required for India's manufacturing sector. In addition, he supports on-going work in the areas of energy access indicators for rural Indian households and has carried out a first-of-a-kind evaluation of the impact of industrial policies on the RE sector in India.

Prior to his association with CEEW, he has worked on an array of projects in collaboration with various international institutions, with a focus on low-carbon development and energy security. His published (and under review) works include Rethink India's Energy Strategy (Nature, Comment) the Co-location Opportunities for Renewable Energy and Agriculture in North-western India: Trade-offs and Synergies (American Geophysical Union), Valuation of Health Impact of Air Pollution from Thermal Power Plants (ADB), Technical Feasibility of Metropolitan Siting of Nuclear Power Plants (NUS), and Prospects for Carbon Capture and Storage in SE Asia (ADB). His role as a research assistant during his graduation focused on the linkages between electricity consumption and sectoral economic growth using a time-series approach.

Karthik has a Masters in Public Policy from the Lee Kuan Yew School of Public Policy at the National University of Singapore (NUS). He also has an M.Tech in Infrastructure Engineering and a B.Tech in Civil Engineering from the Indian Institute of Technology, Chennai.

Aditya Ramji

Aditya Ramji is a Programme Lead with the Council on Energy, Environment and Water (CEEW), India. He is an energy and development economist by training with a specialisation in environmental and resource economics. His key areas of research have been development policy, energy access and energy policy, programme implementation and impact evaluation. Prior to joining CEEW, he worked with The Energy and Resources Institute (TERI), New Delhi, as a Research Associate with the Green Growth and Development Division, dealing specifically with issues pertaining to green growth, sustainable development and energy security.

Most of his work has involved policy analysis with regard to energy and environment with a focus on quantitative modeling of energy-economy-environment linkages. He has extensive field experience across India. He has also published in leading academic journals including the Journal of Energy and Journal of Energy Policy (Elsevier Publications).

Kanika Chawla

Kanika Chawla is a Senior Programme Lead at the Council on Energy, Environment and Water (CEEW), India. Prior to her association with CEEW, she has worked at the Renewable Energy Policy Network for the 21st Century (REN21) Secretariat in Paris. She has worked extensively on distributed renewable energy in developing countries, urban energy policy and investment in sustainable energy. Kanika specializes in international cooperation and sustainable energy policy.

She has researched energy policy issues in developing countries around the world with a specific focus on renewable energy, energy efficiency and gender. She has previously also worked with GIZ on sustainability reporting.

Kanika holds an M.Sc in Economics and Development Economics from the University of Nottingham and an undergraduate honors degree in Economics from Miranda House, University of Delhi. She is fluent in English and Hindi and speaks basic French.

Vaibhav Gupta

Vaibhav Gupta is a Programme Lead at the Council on Energy, Environment and Water (CEEW), His research interests include energy and resource efficiency, industrial ecology, and collaborative environment management. His current research focuses on greenhouse gas emission estimates of India's manufacturing sector. He is also carrying out a study that identifies the most critical non-fuel mineral resources for the manufacturing sector of India. Some of his previous research work addresses vulnerabilities in India's energy infrastructure, identifies strategic industries and technologies for manufacturing in India and the state of environmental clearance procedures in India. Prior to joining CEEW, he worked with a prominent mining company of India in the roles and responsibilities of engineering, environment management (ISO 14000), project planning and liasoning with government departments.

Vaibhav holds a Masters degree in Environmental Science and Engineering from the Indian School of Mines (ISM), Dhanbad. He also holds a post graduate diploma in Environmental Law from National Law School of India University (NLSIU), Bangalore. He is affiliated as a life member with the Mining Engineers' Association of India (MEAI).

Manu Aggarwal

Manu Aggarwal is a Research Analyst at the Council on Energy, Environment and Water. His research interests lie on the intersection of development policy, finance and institutions, and he takes a keen interest in the primacy of global coordination and cooperation in bringing about national-level changes. Prior to CEEW, Manu worked with Mu-Sigma, where he advised clients on the design of marketing campaigns, and at Futures First, Bangalore, as a trader in international oil and gas markets. Manu has also worked with Seva Mandir, a grass-roots development organisation in Udaipur, where he coordinated the efforts of the natural resources management programme.

Manu has a B.E. in mechanical engineering from Thapar University, Patiala, and is currently pursuing his CFA charter from the CFA Institute, USA. Outside of work, he is a travel junkie and Floyd aficionado.

Contents

1. Introduction

Electricity generated from any source, whether traditional or renewable, needs to be consumed instantly. This limitation of electricity has led to the development of energy storage technologies. Energy storage has been part of the electric system for decades. Energy storage technologies provide flexibility in the use of electricity, for both centralised and decentralised supply provisions. Conventional use of storage systems by way of batteries (in electronic goods, vehicles) and accumulators (inverters and UPS as electricity backup solutions) have been driven by commercial and technology considerations (and requirements), with little policy directive to incentivise the use of these novel solutions.

In India, lead-acid batteries have been the primary storage solution for a range of stationary and portable applications. Increasingly, with the potential application of energy storage in hitherto unexplored areas such as large grid-connected systems for applications including peak shaving, ancillary services, grid stability etc. and novel applications in electrical vehicles, a lot of the research and development (and the resulting products) will find use in replacing conventional technologies in other existing applications. The demand from telecom, micro-grids, rooftop solar and diesel generator replacement markets are also going to intensify the demand for advance battery technologies and storage solutions. However, the expectations for the market must be tempered at this stage given the regulatory uncertainty and the economic case for alternative solutions in balancing the electricity grid. That electrochemical storage is not mainstream is made amply clear by the absence of any reference to storage (other than pumped hydro) in the draft note circulated by the CERC (on the introduction of ancillary services for the Indian electricity market). (1)

The Indian Energy Storage Alliance (IESA), in 2013, estimated that by 2020, the market potential in India for energy storage systems in renewable energy applications alone would be in the vicinity of 6000 MW. (2) The potential for energy storage has been revised to about 15 – 20 GW by 2020 after the ambitious renewable energy targets of 175GW of renewable energy capacity by 2022. Furthermore, India's international commitment made to the UNFCCC in October 2015, projects 40% of the electricity capacity in 2030 to be non-fossil. (3) The role of energy storage, in an energy mix that includes significant contributions from solar and wind power, cannot be emphasised enough.

In 2015, the Government of India (GOI), launched a massive programme to provide 24/7 electricity supply to all by 2019 and reducing the peak deficit in electricity (power) to 3.2%. (4) This is envisaged through a large addition of renewable energy capacities to the grid, which will create demand for batteries for large renewable integration into the grid and for integrating micro-grids in remote locations. Further, the Ministry of Power is also focusing on improving the transmission efficiencies and reducing losses by adding large storage capacities. The process has already been started for demonstration projects and Power Grid Corporation of India Limited (PGCIL) has announced that it will set up a 1 MWh of storage project based on NaNiCl2, alkaline and flow batteries. (5) Prior to this, the Ministry of New and Renewable Energy (MNRE) had already put out a call soliciting Expression of Interest (EOI) to demonstrate storage technologies for various renewable energy applications. (6)

The dynamics of battery market in India are changing rapidly, with the increasing demand for advance battery technologies and emerging application areas. It is thus important to study the emerging landscape of energy storage technologies and their applications in the renewable energy segment.

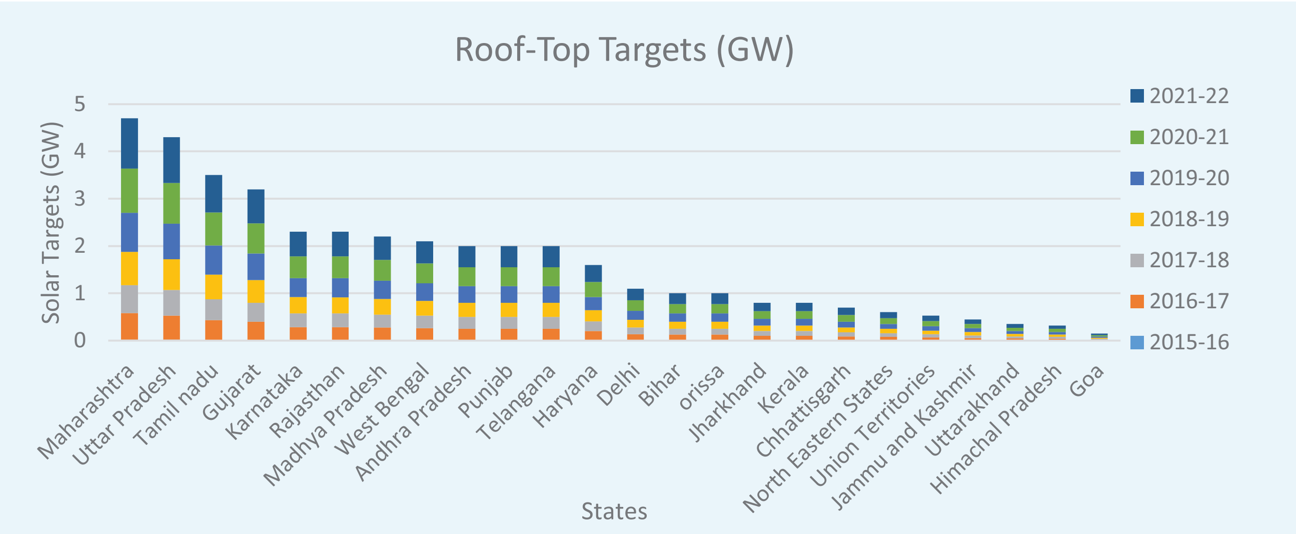
2. Indian power sector and need for storage

India has set an ambitious target of reaching a renewable generation capacity of 175 GW by 2022. In order to integrate such high penetration of renewables into the grid, effectively, several actions (inter alia) have to be taken such as bringing flexibility in the conventional generation, frequency control, maintaining generation reserves and introduction of ancillary services. Analyses show that additional investments in flexibility are required in the Indian grid, to ensure the reliability of the system at high shares of variable RE and the specific performance requirements are key for the identification of the most suitable technologies. (7) The technical aspects of electrochemical storage must be included in simulations that explore the different storage or balancing. Depending on the existing demand and energy mix, system flexibility can be increased through options that act on the supply side. While pumped storage is the main form of storage that is considered in most simulations, it must be reiterated that only 6 GW of pumped hydro storage has been identified in India. (8) In addition, after the nationwide power outage in July 2012, there are strict limits on movement of power between states that has not been scheduled. This limit could be as low as 150 MW. Given that pumped storage options (even the limited capacity) may not necessarily be in the same state as the one that is generating power from RE, storage options within the state become more important. Given the cost structures today and the lack of accurate modelling of the costs of electrochemical storage, there is no definitive evidence on the unsuitability of battery based storage and batteries for the provision of various ancillary support services. In August 2015, CERC announced the Ancillary Services Operation Regulations and made it mandatory to have generation reserves in place. (9) Though storage systems do not explicitly figure in the notification, as long as it is cost competitive, storage providers can participate in the bidding.

3. Application of batteries in rooftop solar segment

In 2015, the Government of India announced a target of 40GW of solar-power to be achieved through roof-top installations by the year 2022. The 40GW target is to be achieved through solar installations on rooftop space on residential, commercial, industrial, government, academic institute buildings. The target is further distributed among the various states as illustrated below (Fig 1). States including Maharashtra, Uttar Pradesh, Tamil Nadu and Gujarat are alone expected to install about 20 GW by 2020.

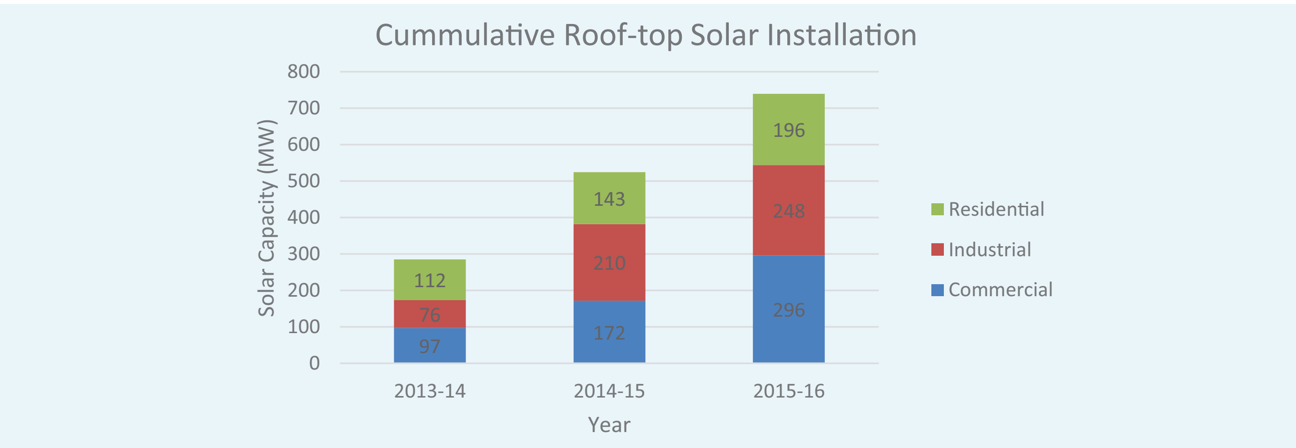
Fig. 1: Distribution of solar roof-top targets



Source: Ministry of New and Renewable Energy

The current roof-top solar installations stand at ~800 MW (as of early 2016). Commercial and industrial consumers are adopting roof-top solar aggressively due to the high tariff levels and the availability of unused roof space.

Fig. 2: Cumulative roof-top solar installations in India



Source: Compilation of annual roof-top solar installation data published by Bridge to India

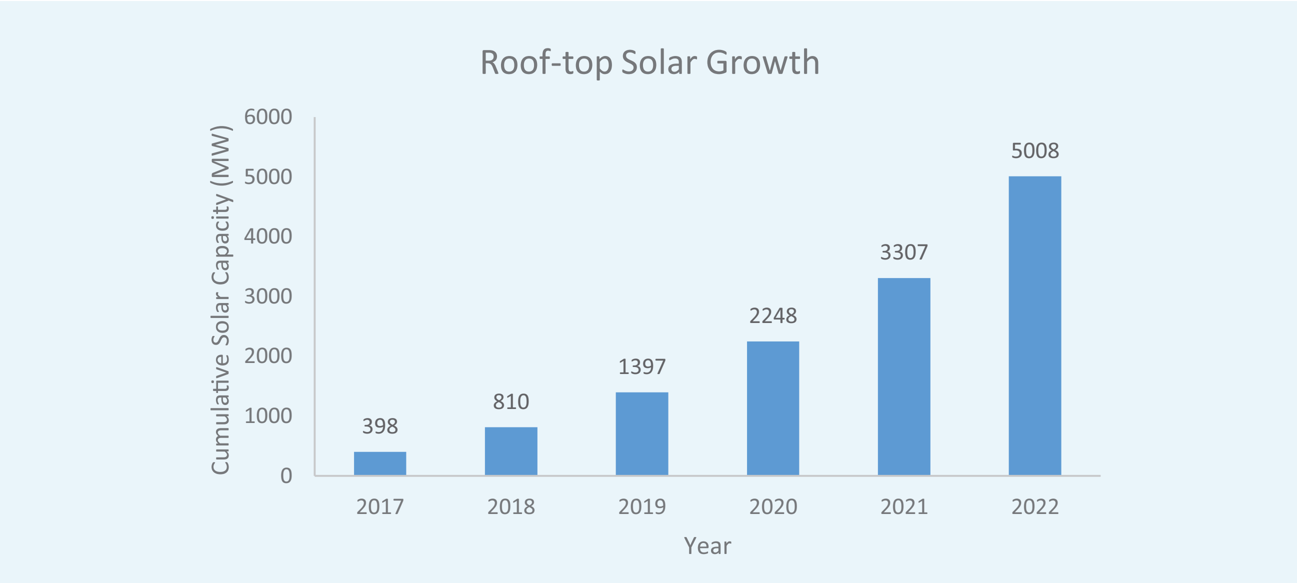
As mentioned earlier, the roof-top solar market can be segmented in three main consumer categories viz. residential, commercial and industrial. As part of this study we have interacted with companies catering to different segments and geographies including Rajasthan, Gujarat, Delhi, West Bengal and Tamil Nadu to understand key drivers of the adoption of solar roof-top across India. The following section highlights the characteristics of solar system and application of battery technologies for each consumer segment.

3.1 Residential segment

For residential consumers, depending on the connected load, solar systems of up to 5 kW capacity are installed. Solar systems of 1 kW and 2 kW capacities can meet the electricity demand of average households and are frequently encountered installed. Roof-top solar systems could be either grid-connected (with/without battery backup) or standalone (with battery backup). With the recent developments in solar inverters, hybrid systems have also been installed where inverter is integrated with grid and solar system with battery backup. In the residential segment we have received mix responses for battery backup systems. Choice of battery backup and extent of backup largely depends on the availability of power in the region. In states such as Uttar Pradesh, where long power-cuts are very frequent, 100% backup (of installed solar capacity) is provided whereas in the states with moderate power outages (1-2 hrs), 25-30% of installed solar capacity is provided as backup.

Based on our analysis, roof-top solar installations in the residential segment could reach ~5 GW (cumulative installations) by 2022. Fig. 3 provides the growth trend as evinced from our calculations.

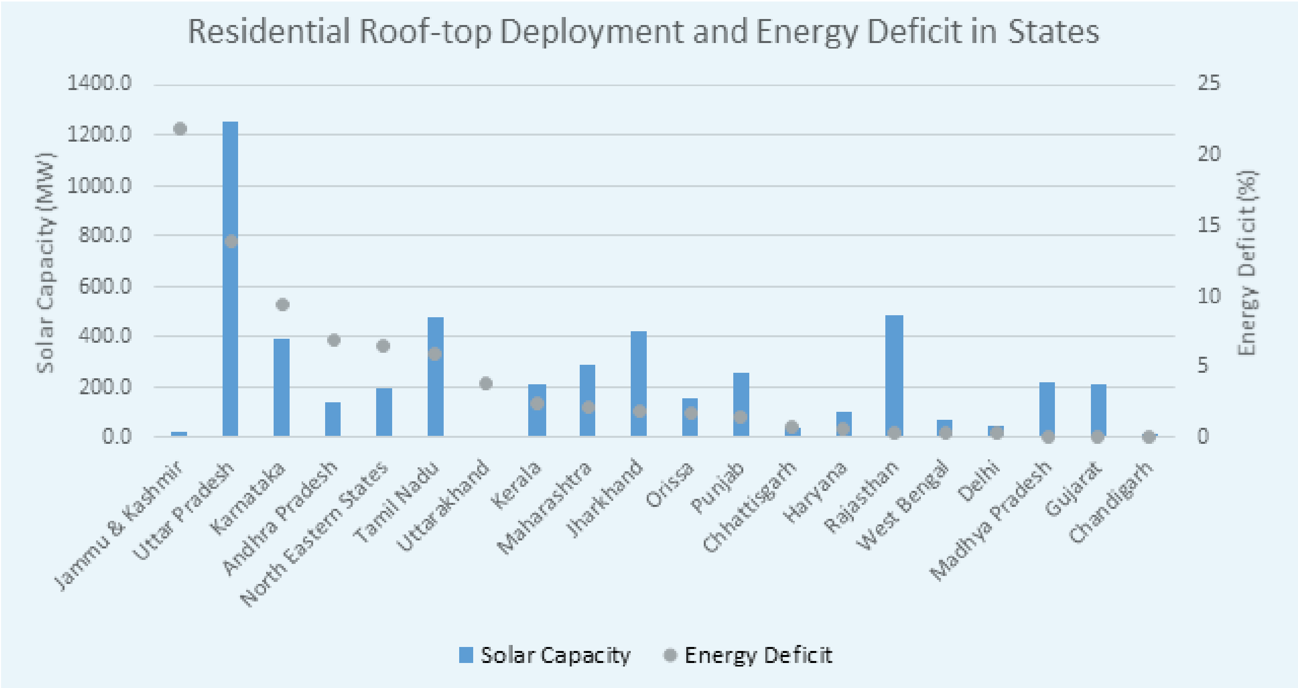
Fig. 3: Cumulative roof-top solar installations in India (till 2022)



Source: Based on CEEW analysis

Further, the projections were estimated for each state as depicted in Fig. 4. Some of the states with large roof-top potential are Uttar Pradesh, Karnataka, Tamil Nadu, Jharkhand, Maharashtra and Rajasthan. Bass Diffusion model is used to estimate the solar deployment in each state. The model evaluates the potential adoption of solar systems based on economic viability of solar roof-top installation. The economic viability is calculated based on domestic grid tariff and performance characteristics of solar PV systems (varying based on solar insolation) in each state.

Fig. 4: Residential roof-top solar deployment and energy deficit in states



Source: CEEW analysis based on Bass Diffusion Model. Primary and secondary data is used from multiple sources

Residential segment is dominated by tubular flooded lead acid batteries and a small fraction of households also use VRLA batteries. 12V batteries with 150Ah rating are predominantly used. For a 1 kW system 2 to 4 units of lead-acid batteries (12V&150Ah) are deployed as per backup requirements and depending on power availability from the grid.

For flooded tubular batteries, the design depth of discharge is kept between 50-70% of the rated capacity and in case of VRLA batteries, depth of discharge is kept at 40% of the rated capacity.

3.2 Industrial and commercial segment

This segment is dominated by industrial consumers where solar systems of up to a few Megawatt (1-3 MW) have been deployed on roof-tops which were otherwise unused. In this segment, size of solar system and selection and application of batteries varies across different consumers. Since the grid tariffs are higher than solar tariffs presently, deployment of solar for industrial and commercial consumers is purely based on economic benefits. The key characteristics of these two segments are described below.

3.2.1 INDUSTRIAL SEGMENT

Industrial units are large consumers of electricity and thus have potential for large scale solar systems from few hundred kilowatts to few megawatts. Solar companies prefer to install systems that are larger than 100kW. Solar systems installed for industrial consumers are grid-integrated and only minimal back-up is provided for critical system loads. Also, it has been communicated that the availability of grid power to industrial consumers is fairly reliable, across states Outages are scheduled and planned for, by the units.

Power generated through solar is instantaneously consumed through grid interactive inverter systems. In the industrial segment solar installation is limited to meet the base load only to fully utilise the power generated through solar system, since backup is not provided. The power generated through solar primarily caters to administrative, lighting and air-conditioning loads of the factory premises, whereas the larger inductive loads are fed through grid power.

3.2.2 COMMERCIAL SEGMENT

Commercial entities who are either highly dependent on diesel generators or lack the access to power are potential consumers for battery based back-up system. Telecom towers, petrol pumps, academic institutes, medical centres and rural banks are predominantly using solar systems with battery backup. We have observed diversity in adoption of battery backup system by commercial consumers. However, there is a marked preference for low/no maintenance batteries.

A. Petrol Pumps

A large number of petrol pumps are remotely located (or in sparsely populated areas) and are highly dependent on diesel generators for energy requirements due to lack of access to reliable power. At petrol pumps 1 HP and 1.5 HP pumps are installed (typically) for dispensing of fuel along with few kilowatts of lighting and cooling loads.

Solar systems with a capacity in the range of 10kW to 15 kW with battery backup of 96V and 150Ah are installed along with a 6.5 kVA inverter to cater to the entire station load in urban areas. At remote locations and on highways, solar PV systems of capacities of 6 kW and 3.3 kW are installed (as per the guidelines issued by oil companies). Both flooded tubular and VRLA batteries has been deployed for energy storage. Batteries are the most expensive component constituting almost 40-45% of the system cost. Depth of discharge for flooded tubular batteries is specified between 50-70% and for VRLA batteries it is limited to 40%. With this configuration, solar power at INR 13-14 per unit turns out to be a cheaper alternative to diesel generators which cost INR 17 per unit. Following table summarises the different sizes of solar PV system deployed and associated battery capacities at petrol pumps across India.

Table 1: Solar PV system and battery bank installed at petrol pumps

Sr. No.	Petrol Pump name and Location	System Parameters
1	IOCL filling Station in Chehal, Punjab	Solar: 2 kW Number of batteries: 16 Battery Model: 12V & 150 Ah
2	ESSAR petrol pump in Georai, Aurangabad, Maharashtra	Solar: 3 kW Number of batteries: 16 Battery Model: 12V & 180 Ah
3	IOCL petrol pump in Kodada, Andhra Pradesh	Solar: 3 kW Number of batteries: 8 Battery Model: 12V & 180 Ah
4	Indian Oil petrol pump in Panipat, Punjab	Solar: 3 kW Number of batteries: 15 Battery Model: 12V & 180 Ah
5	HP petrol pump in Panipat, Punjab	Solar: 6 kW Number of batteries: 16 Battery Model: 12V & 150 Ah
6	Indian Oil petrol pump in Kadapa, Andhra Pradesh	Solar: 3 kW Number of batteries: 10 Battery Model: 12V & 150 Ah

Source: CEEW Compilation

In India, currently there are 52,000 petrol-pumps in total. Indian Oil Corporation owns the largest share of petrol pumps (~24,000), followed by HPCL and BPCL with 12,900 and 12,200 petrol pumps respectively. Private players, RIL, Essar and Shell owns a small fraction of total petrol pumps with just ~3000 petrol pumps across India. Out of the total 52,000 petrol pumps, ~25000 are suitable for solar deployment.

IOCL is driving the market of solar powered petrol pumps. The company is targeting an installation of solar systems at ~10,000 retail outlets in the next 2-3 years. Currently, only ~2000 petrol pumps are solar powered. 1500 of these belong to IOCL. Based on the solar system characteristics and battery requirements for the needs of petrol pumps, the total market for batteries is estimated to be of the order of INR 2.6 billion.

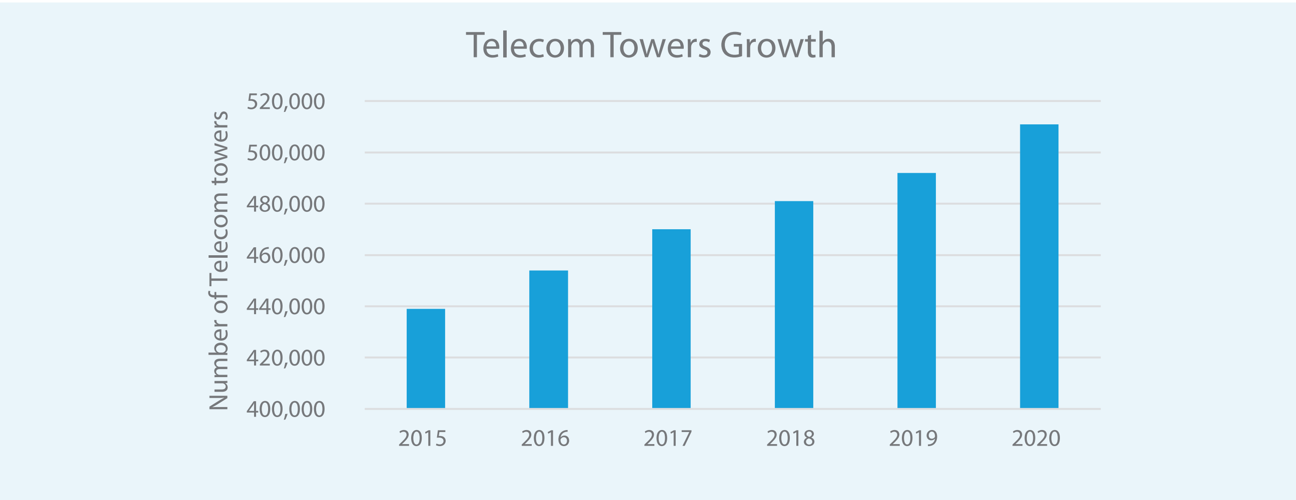
The solar petrol pump segment is further expected to witness a huge surge for solar installations, as Government of India is targeting to add another 35,600 petrol pumps in next 2 – 3 years to boost availability of oil products and particularly CNG on highways. (10)

B. Telecom Towers

India, is experiencing a sustained growth in wireless telecommunication sector, with an addition of 8 million mobile users every month. (11) Currently, there are about 456,500 telecom towers operating in urban and rural areas to cater 907 million active mobile users as on Nov-2015. (12)

As per the report published by GSMA, in collaboration with International Finance Corporation, the number of telecom towers is expected to grow at 3% CAGR and will have about 511,000 towers by the end of 2020. With the tower density in urban areas approaching a peak (of sorts), the focus has shifted to extending the telecom tower penetration in semi-urban and rural areas. Share of telecom towers in rural and semi-urban areas will increase to 45% of total installation from currently being 39%. This is also supported by increasing mobile user base in semi-urban and rural areas.

Fig 5: Expected growth in number of telecom towers in India



Source: Rajat Banerji, Anjlika Chopra, Abhishek, Anu Peisker, Sumit Satija, Rishabh Maheshwari, Laksh Maggoo, Jatin Gupta, Himanshu Rai (2015) Indian Tower Industry: The Future is Data, Deloitte, June, p. 28.

Growth in telecom towers, especially in rural and semi-urban parts of India will face the challenges associated with access to grid and reliable supply. In 2015, approximately ~16% of towers were operating off-grid and another 38% were exposed to unreliable grid.

Table 2: Number of telecom towers based on access to electricity

Grid Access	Telecom-towers		
		Electricity Source	**Telecom-towers**
Off-grid	71,500	Diesel Generator(DG) Only	643
		DG + Battery	56,842
		Renewables	14,015
On-grid	2,10,000		
		Grid Power Availability	**Telecom-towers**
Unreliable grid	1,75,000	6 – 10 Hours	49,350
		10 – 16 Hours	53,550
		> 16 Hours	72,100

Source: Groupe Speciale Mobile Association (2015) Energy for the Telecom Towers: India Market Sizing and Forecasting, International Finance Corporation, p. 4

Telecom towers without access to grid are primarily operating on diesel and battery based backup system and a handful of towers, about 14,000 are utilising renewable energies. Out of total 175,000 towers connected to unreliable grid, about 31% receive grid power for 10 – 16 hours per day and about same fraction of towers receive grid power for even lesser duration.

The demand for batteries in telecom segment is likely to witness a surge in coming years with increasing penetration of renewable energy for telecom towers and the directives from Telecom Regulatory Authority of India, which mandates telecom operators to migrate 75% and 33% of their cell towers in rural and urban areas to hybrid power respectively by December 2020. (13)

Telecom towers have an average load in the range of 1 – 4 kW, depending on installed Base Transceiver Station (BTS) equipment. However, towers shared by more than one operators could have power demand in the range of 5kW to 6kW as well. Following table 3 provides the power demand and backup system configuration for different telecom sites.

Table 3: Grid power availability and back-up requirement at multiple telecom sites

Parameters	Site – 1	Site – 2	Site – 3	Site – 4	Site – 5
Location	Vasod, Kerala	Hunasanahalli, Karnataka	Soldha (Bahadurgarh), Haryana	Kolar, Karnataka	Sundar ban, West Bengal
Operators	Reliance, Idea, Vodafone	Reliance, Vodafone, BSNL	Vodafone	Single operator	Reliance, BSNL, Vodafone
Electricity Source	Grid, Diesel, Battery	Diesel, Battery	Grid, Diesel, Solar, Battery	Grid, Solar, Battery	Grid, Solar, Wind, Diesel, Battery
Total load (kW)	2.23	2.07	1.2	1	3
Grid Supply	-	Not available	10 Hours	9 Hours	6 Hours
Diesel Generator (kVA)	20	20	15	N/A	20
Battery	48V & 1250Ah	48V & 1630Ah	48V & 600Ah	48V & 600Ah	48V & 3600Ah
Diesel Operation	24 X 7 days (at 10% load)	24 X 7 days (at 10% load)	Not used	Not used	2 Hours per day

Source: CEEW compilation

Telecom industry is also witnessing reduction in power requirements of telecom equipment (Base Transceiver Station). Power requirement of a BTS equipment are expected to reduce to 500 W by 2020. (14) Also, ultra-low power (50W-100W) requirement based communication technologies are penetrating in rural India. (15) Such innovations will further enable the off-grid operation of telecom sites and utilisation of renewable energies with battery backup.

C. Solar ATMs

A large share of India's total population does not have bank accounts. ATMs form a key channel for financial inclusion of a large part of Indian consumers. The potential for increasing the penetration of ATMs is high, as at present roughly there are 98 ATMs for every one million people in India, compared to 211 (China), 530 (Britain) and 1,390 (United States) in other parts of the world. A typical ATM set up requires approximately 750 Watt of power. Of this, roughly 60% is consumed in air-conditioning, which is necessary to maintain a controlled environment for better performance. This translates to an annual demand of 1.2 billion units of electricity by all the ATMs (193622, as on December 2015) installed in India[1]. High power requirement (on a 24 x 7 basis) is a crucial factor, and somehow acts as an impediment in expansion of ATM networks in India (especially in rural and semi-urban centres).

More recently, solar application has found its way into the ATM sector through the introduction of low power ATMs. The innovative solution has a rated power requirement of 50 Watts, as it can work efficiently without any air-conditioning. Storage batteries offer an excellent combination with low power ATMs for consistent and reliable banking solution, even in the remote areas of the country. If we consider only the rural and semi-urban areas for such ATMs, the current power demand could be reduced to 36 million units (approx.) against the current average of 550 million units, on an annual basis.

In 2015, ~44% of the ATMs were located in rural (33250) and semi-urban (51942) areas which are ideal candidate for solar installation with battery backup. Further the rural and semi-urban areas are witnessing the highest growth rates in terms of new ATMs being set up. In 2015, ATMs in rural areas grew by 16% and semi-urban areas witnessed 11% growth in ATMs. Based on our analysis, ATMs in rural and semi-urban areas offer an opportunity of INR ~2.4 billion to battery manufacturers.

D. Academic Institutes:

Solar systems with a capacity ranging from few kilowatts to few hundred kilowatts have been deployed for diverse consumer groups depending on the energy requirements. Battery backup in this segment is only preferred for critical loads instead of 100% backup. Battery bank of 12V and 600Ah capacity is installed for 1 kW system for academic institutes.

3.3 Micro-grids

In order to achieve the goal of universal access to electricity, Government of India has taken up the electrification of remaining (un-electrified) villages through a dedicated program. Only 10,000 villages remain un-electrified. However, the issue of access to electricity and reliable supply still remains the same. Though nearly 96% of the villages are electrified villages, 31% of the homes in these villages are un-electrified. As a result, nearly 290 million households still do not have any access to electricity. (16)

Given this vast opportunity in rural India, many entrepreneurs and NGOs has setup the micro and mini-grids to provide reliable electricity for basic needs of a rural household. There are currently more than 10 micro-grid companies in India that have installed 600 solar photovoltaic mini-grids, with a total capacity of 8.2MW. (17) Along with private companies (commercially motivated) and NGOs (grant supported), state nodal agencies are also actively deploying micro and mini-grids in the rural areas under Remote Village Electrification (RVE) program. Bihar, Jharkhand, Assam, Chhattisgarh, Odisha, West Bengal and Uttar Pradesh are some of the most prominent states where solar micro/mini-grid deployment is expected is a big way. UP has also come up with a draft policy for linking micro-grids with grid, as and when the grid does arrive in these villages.

1 Statistics from Reserve Bank of India, 2015

Solar micro/mini-grids are a promising alternative to grid to supply reliable and un-interrupted electricity. Acknowledging the importance of micro/mini-grids for providing electricity to rural households, Ministry of New and Renewable Energy (MNRE) has launched National Micro/mini-grid Policy in June 2016. MNRE targets to deploy at least 10,000 RE based micro and mini grids across the country with a minimum installed RE capacity of 500 MW in next 5 years (taking average size as 50 kW). (18) Since the electricity to rural households need to be supplied during evening hours primarily, micro/mini-grids require a large battery bank to store the entire energy generated from solar PV system during day hours. Installation of 10,000 mini grids will require more than 2.2 million batteries of 1kWh.[2] This will go a long way in accelerating the energy storage market.

Micro/mini-grids are installed in the range of few Watts to 100 kW, depending on number of households served and duration of supply. Micro/mini-grids power few lights, mobile phone charging and 1-2 fans per household for a duration of 5 – 6 hours per day. Following table summarises these characteristics for state nodal agencies and private companies.

Table 4: Comparative assessment of different micro/mini-grid solutions provided by state nodal agencies and private companies

Parameter	WBREDA	CREDA	Mera Gao Power	Gram Oorja	Desi Power
Area of Operations	West Bengal	Chhattisgarh	Uttar Pradesh	Maharashtra	Bihar
Establishment	1996	2004	2011	2008	1996
Average size of plant	1 – 100kW	1 – 6 kW	120 – 800 W	1 – 10 kW	0.5 – 5 kW
Energy provisions	2 – 5 lighting points and a fan point	2 lighting points	2 lighting points and a mobile charging point	Lighting, fan, tv, computer, fridge	Lighting, fan and mobile charging
Supply duration	5 – 6 Hours	5 – 6 Hours	7 Hours	5 – 6 Hours	5-6 Hours

Source: Debajit Palit and Gopal K Sarangi (2014) Renewable energy-based rural electrification, TERI, p. 15. And CEEW compilation

Batteries are a critical component of micro/mini-grid systems. In absence of commercial consumers that could act as anchor loads for these micro/mini-grids, 100% of the total energy generated from solar PV is stored in batteries to supply the power during evening and night hours to rural consumers. The following table provide a glimpse of battery backup installed for different micro/mini-grid capacities.

Table 5: Solar micro/mini-grids and corresponding storage capacities

Name of the plant	PV capacity (kW)	Inverter capacity (kVA)	Battery capacity (Ah)	Battery voltage (Volts)	Connected load (kW)	Number of households
Dound-II, Chattisgargh	1	1.5	200	48	0.3	25
Latdadar, Chattisgargh	2	3	400	48	0.7	30
Chatal, Chattisgargh	3	5	400	48	0.7	24
Gudagarh, Chattisgargh	4	5	800	48	1.2	60
Sura, Udaipur, Rajasthan	17.25	15	1200	120	5.0	50
Nurda village, Jharkhand	28	20	1200	120	9.5	350
Anandgarh, Bikaner, Rajasthan.	34.5	2 X 15	2 X 1200	120	10	50

Source: http://mapunity.org/projects/gvep and Rajasthan Renewable Energy Corporation (RREC)

2 CEEW Analysis

Case Studies (Micro/mini-grids): three different case studies are presented here to better understand the system characteristics of a micro/mini-grid setup.

Table 6: Micro-grid case study 1

Mini-grid size	9.36 kW
Battery bank size	48V & 600 Ah, VRLA Batteries
Inverter size	10 kW
Households and Population	39 Households, 220 people
Electric load	10 TV sets, 2 computers, 2 water pumps and 1 flour mill in operation apart from basic home and street lighting
Grid characteristics	230 V, 50 Hz, 17 poles, grid length ~1.5 km
Year established	Jul-2012
Location	Darewadi, Ahmednagar, Maharashtra
Mini grid company	Gram Oorja

Source: CEEW compilation

Table 7: Micro-grid case study 2

Mini-grid size	5.04 kW
Battery bank size	220V & 100 Ah, Tubular Batteries
Inverter size	5 kVA
Households and Population	22 Households, 90 people
Electric load	Primarily for domestic and street lighting, mobile charging and a few appliances.
Grid characteristics	230 V, 50 Hz, 7 Poles, grid length 350 m
Year established	March-2014
Location	Viral Village, Supa, Karnataka
Mini grid company	Gram Oorja

Source: CEEW compilation

Table 8: Micro-grid case study 3

Mini-grid size	2 kW
Battery bank size	48V & 300 Ah, Tubular Batteries
Duration of Supply	5 Hours
Households and Population	40 Households, 206 people
Electric load	Two 9W CFLs for each household and eight 11W street lights. Occasionally for a tv set for community
Year established	2014
Location	Salepada Village, Nuapada, Odisha
Mini grid company	Odisha Renewable Energy Development Agency (OREDA)

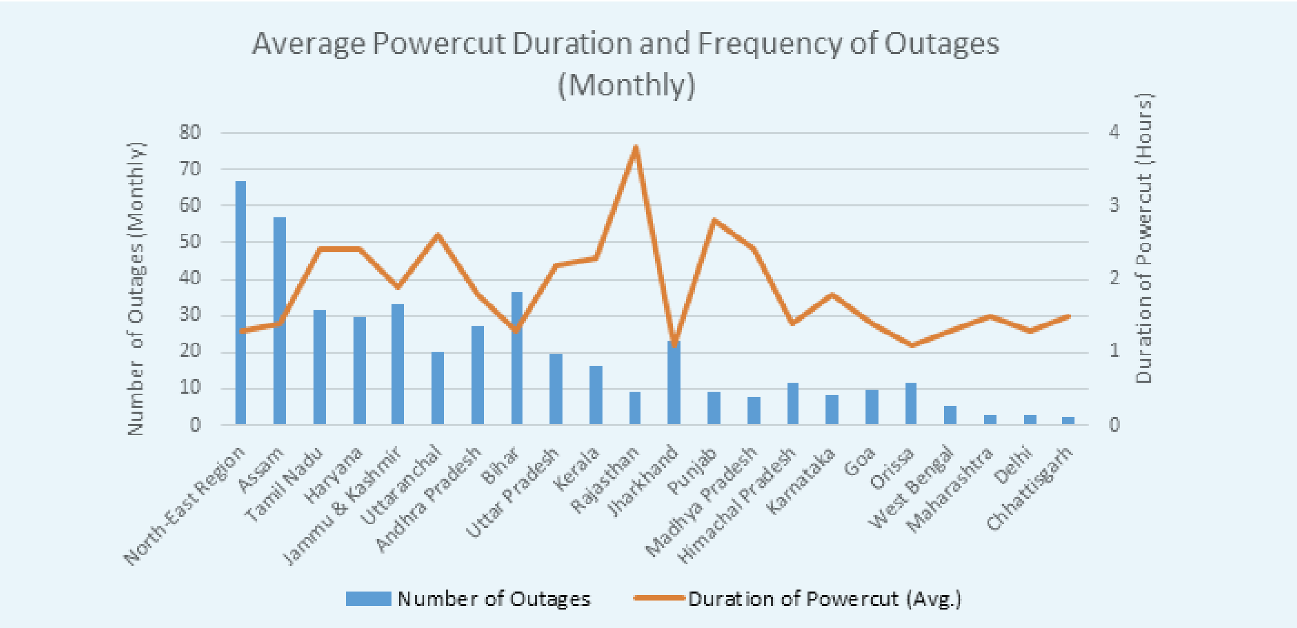
Source: Compilation from: Ashden India Renewable Energy Collective (2014) RE-Engineering Odisha: An Assessment of Renewable Energy Policies, Challenges and opportunities, Climate Parliament, October, p. 32.

4. Key industry drivers for battery adoption

4.1 Power outages

Availability of grid electricity and power-cut durations has been key driver for adoption of battery based backup systems in residential segment. Most of the Indian states still suffer from prolonged electric outages, particularly during summer months (Fig. 6). The reliability of grid has improved over the time but it is still a long way before we start getting un-interrupted grid electricity.

Fig 6: Total average monthly outages and average power-cut duration in states



Source: CEEW analysis of data collected from world bank enterprise survey dataset

4.2 Cost of grid vs. solar

Grid electricity for the residential sector is highly subsidised and cost much lower than solar power. Grid tariff for average consumers range between INR 1.8 to INR 6.5 per unit depending on monthly consumption and state. Grid tariffs are even higher (up to INR 12/unit) for domestic consumers (at certain consumption slabs) in some of the states. Tariff for solar system without battery backup is at-least INR 6-7 per unit and with battery backup system this could go up to INR 14 per unit. The large difference between grid and solar tariff is hindering the penetration of solar and battery backup system in residential segment. However, the two are converging fast. Grid tariffs are continuously rising at an average rate 6% per annum. Along with this, the cost of solar system is also decreasing at a rate of 5% annually. With these rates, by 2020, solar systems could be cost competitive with the grid for residential consumers as well.

For commercial and industrial consumers, cost of power from solar is already cheaper than grid tariff. Further, increasing grid tariffs will make already cost competitive solar system more economically viable alternative in future. As per CEEW's analysis, given the current trends of decrease in solar price and increasing grid tariff, it is expected that the grid tariff will surpass the tariffs from solar plus battery systems by 2020. This will further increase the demand for batteries to utilise maximum available roof area to provide solar electricity during evening and night hours at lower rates than grid tariff.

4.3 'Time of Day' tariff

Time-of-day tariff- higher electricity tariff during peak consumption periods of the day is employed on grid connected consumers to curtail the peak power demand. In the time-of-day regime, consumers tend to install battery backup to supplement their energy demand from batteries during peak hours. In India, 'time-of-day' tariffs are currently applicable to HT consumers only and that too only in a handful of states. However, government is considering the introduction of time-of-day tariff to residential and commercial consumers as well. NITI Aayog is tasked with conducting a detailed analysis to evaluate the applicability of time-of -day tariff for residential and commercial consumers. Addition of time-of-day charges in electricity bill will result in increased demand for batteries.

4.4 Access to electricity

Stand-alone systems like solar home systems, micro/mini-grids will play an important role in solving energy problems in rural India. Micro-grids can operate independently, in island mode, or be connected to the utility power grid. They can meet the growing power demand of consumers whether it is connected through grid or operating in islanded mode. Micro-grids along with storage will allow for fast installation of electricity supply without the need for expensive transmission infrastructure investments and the lengthy development approval and construction process. Solar micro/mini-grid system, since energy is need to be supplied during evening and night hours to rural households, depends solely on batteries to store the energy.

As stated earlier, MNRE's initiative to deploy at least 10,000 RE based micro and mini grids across the country with a minimum installed RE capacity of 500 MW in next 5 years will alone create an opportunity for more than 2.2 million batteries of 1kWh each. Private companies operating in micro/mini-grid segment have also set aggressive targets which will further fuel the demand for batteries.

4.5 Grid scale storage

With increasing share of renewable energies in national grid, will provide opportunities for advance battery technologies for hitherto unexplored areas such as ancillary services, peak shaving, grid stability, renewable integration to the grid and forecasting. Foreseeing the necessity of grid scale storage, Ministry of New and Renewable Energy has launched multiple pilot projects recently.

Most promising of these pilots is the recently floated tender by NTPC, inviting bids for 625 MW of Solar PV with storage, in Andhra Pradesh. This tender has a storage component of 100 MWh. This will be the first utility scale storage tender in India. SECI also floated a tender for 2.5 MW of hybrid solar and wind project with 1Mwh of storage. (19) The private sector too is testing energy storage options and transitioning to batteries (away from diesel generators) for a more secure and sustainable energy system. Panasonic India and AES India Private Limited announced an agreement to construct a 10 MW energy storage array at Panasonic's Technopark manufacturing facility in Haryana. (20) These initiatives will certainly help in ushering in new energy storage technologies in India.

5. Barriers to the proliferation of storage for RE applications

5.1 Cost of battery technologies

Consumers and solar installers in solar photovoltaic segment are highly cost sensitive. The back-up system (batteries) could increase the upfront cost of solar system by up to 50% along with additional maintenance and replacement cost associated with batteries. This makes the system less viable economically. This also leads to under designed battery backup systems.

5.2 Maintenance requirements and performance of battery system

Solar system can run without or minimum maintenance for the entire life of project. However, when batteries are introduced in the system, they require regular maintenance and replacement of batteries every few years. Reoccurring cost of battery replacement works against the notion of "free power for 25 years" by investing only once. Also, battery performance is very unreliable and largely depends on usages. Shortfall in battery performance is directly blamed on solar companies. To avoid such situation, companies prefer to install grid-integrated solar systems without battery backup.

5.3 Net-metering policy

As the focus on grid connected solar rooftop grows, there is wide spread adoption of net-metering policies in states around the country. Due to the nature of net metering policies, solar rooftops are unlikely to drive up demand for energy storage solutions, in case the grid is reliable and offers nearly 24 x 7 power supply. Net metering effectively converts the local grid into a battery. Excess power generated at household level is immediately fed into the grid, leaving no need for any additional storage solution to be deployed. However, in regions where there are many power outages or too many scheduled/unscheduled power cuts, rooftop owners are likely to adopt energy storage solutions, to store the solar power generated on site almost like a captive solar unit.

Also, there are differences among net metering policies of various states. One such difference that can affect energy storage market is on what basis do states charge customers post net metering. Implementation of net-metering will reduce the grid based energy consumption of these customers and help them fall into the lower tariff slabs but there are states such as West Bengal which don't recognise this and still charge these customers at higher slabs. (21) States like Delhi, Gujarat allow customers to fall into lower slabs and enjoy the benefits. (22) Customers will tend to consume all the generated power onsite instead of feeding it to grid in case of West Bengal than in Delhi. Hence this policy arbitrage can still lead to a thriving energy storage market even with adoption of net metering in states like West Bengal.

5.4 Improving power availability scenarios

One of the important challenges to improving the penetration of battery technologies is the improving power availability scenario in existing markets. While data to back this is limited, at-least national statistics seem to suggest that the overall deficit in electricity supply is seeing a significant drop.

Anecdotal evidence suggests that this is the case in Tier-1 cities while the situation in newly electrified areas and smaller towns could still be as poor. It is unlikely that the government will hit their target of 24x7 electricity supply and the demand for backup systems will still remain robust in newly electrified areas. As a result, the important transition would be in the shift of the markets away from traditional centres (in large cities) to smaller cities and towns and even rural areas. While the net-metering policy (seemingly) is against the interest of battery manufacturers, it is a distorting incentive which is not likely to be a permanent fixture or a successful one given the state of utility finances. Eventually, a situation with high grid tariffs could incentivise autonomous consumption from roof-top of local generation and this would then drive up demand for efficient storage technologies.

5.5 Limitation of the business model adopted by developers

Solar developers that are catering to industrial consumers are acting as an independent power producer who uses the roof space on lease, for solar installation, and sells power to industrial consumer itself. In order to maximise the profit by selling the entire generated power to the consumer, limit the solar system capacity such that it only meets base load. Further, there is no incentive for a solar company to sell power at INR 14 units (the cost of electricity when backup is considered) where grid power is available at lower rates.

6. Indian battery market and associated challenges

For solar applications in India tubular flooded lead acid batteries and VRLA batteries are predominantly used along with Ni-Cd and Li-ion batteries for a very few specific applications. Batteries are preferred to be connected in series to achieve higher voltages. In case of large number of batteries, series and parallel combinations are configured. Also, parallel combination is limited(preferably) to two strings only.

- **Flooded Tubular Batteries**
  It has been observed that on average tubular flooded batteries achieve desired cycle life and in some cases outperforms the expected cycle life. These batteries are designed at 50-70% of depth of discharge. Cycle life of a battery largely depends on usage patterns which has been discussed in following section. Flooded batteries are able to achieve about 600 – 900 cycles for different depth of discharge levels, based on our interaction with companies catering to different geographies (climatic and local environment conditions).

  Tubular flooded batteries require regular maintenance. Distilled water needs to be refilled on interval of 6 months and terminals also need to be cleaned to avoid corrosion. Tubular batteries also exhibit higher tolerance to temperature variations and harsh environments as compared to VRLA batteries.

- **VRLA Batteries**
  Depth of discharge in VRLA batteries is limited to 40% of total battery. VRLA batteries very sensitive to temperature. VRLA batteries have not been able to meet the desired cycle life and constantly underperformed for solar applications. Observations shows that VRLA batteries only last for 400-600 cycle life with 3 years of overall life.

  For both VRLA and Flooded batteries, 12V modules are preferred for solar applications.

6.1 Technical challenges

6.1.1 BATTERY CHARGING PATTERN

Different battery manufacturers and technologies offers different charging patterns to improve the overall charging duration and life of battery. Inverters are needed to be configured accordingly which pose a limitation. This has been faced particularly with Li-ion battery technologies where up to 7 different charging steps are followed based on different state of charge in the battery. Specific chagrining pattern also restrict the choice of inverters and in some cases, force to purchase the inverter from an international company which further add to the cost of system.

6.1.2 MEMORY EFFECT

Lead-acid batteries need to be charged and discharged to rated capacities once every 4 months to avoid the memory effect. Lack of maintenance could significantly reduce the energy capacity of battery.

6.1.3 SURGE CURRENT

In the hybrid systems when load is switched from grid to battery, an instantaneous high current is drawn from batteries which reduces the capacity of a battery in longer term.

6.1.4 BOOST CHARGE

Solar systems also cater to consumers in remote locations where grid in not available. Batteries when discharged beyond the designed cut-off, require high boost charge to start the recharging process. Power generated from solar is not able to provide the required boost charge. This requires transporting either batteries to charging stations or charging through diesel generator which again need to be transported to solar site. VRLA batteries are more prone to this issue.

6.1.5 HIGH DISCHARGE RATE

Consumers add additional loads to the existing system which put additional load on the batteries and the entire system becomes under-designed. The high rate of discharge again reduces the capacity and life of the battery.

6.1.6 C-RATE

Batteries are rated at C-10 and C-20 discharge rate whereas in solar applications, desired discharge rate is C-5 to sustain high discharge current.

6.1.7 LOW MAINTENANCE DEEP-DISCHARGE BATTERIES

Deep discharge batteries are not recommended for solar applications in areas where grid is not available due to requirement of high charge to re-charge the battery.

6.1.8 BATTERY MANAGEMENT SYSTEM

Due to intermittent power generation nature of solar system, a battery management system is required to charge the battery at specified voltage and current levels. Battery management system is also important to configure battery with inverter system and during battery discharge, to manage appropriate depth of discharge and avoid surge currents.

6.1.9 INDUCTIVE LOAD

Lead acid batteries are not suitable for large inductive loads in an industrial setup. Solar companies are exploring batteries which can cater to inductive loads as well.

6.1.10 UNDER-DESIGNED BACKUP SYSTEM

Some of the solar players themselves under-design the battery backup to keep the system cost on lower side. This results in deep-discharge of batteries which again reduces the life span significantly.

6.2 Operational challenges

6.2.1 HIGH DEPTH OF DISCHARGE

In case of under-designed backup systems or longer power outages, consumers tend to use batteries beyond specified depth of discharge. Options to over-ride design depth-of-discharge must be kept limited and less to the discretion of the consumers.

6.2.2 HEAVY LOADS

In urban areas consumers run heavy loads such as ACs directly from batteries and in rural areas consumers run electrical machineries by batteries which drain the battery faster and reduces the overall life.

6.2.3 DISTILLED WATER REQUIREMENT

In remote locations where distil water is not available, an additional solar distillation plant is deployed to generate distil water. This additional system increases to cost of overall system and reduces economic viability. This opens up opportunities for maintenance free batteries.

6.2.4 DISTILLED WATER REFILL FREQUENCY

Similar to previous point, it desired to have minimum refill frequency. Currently, in flooded tubular batteries, distil water need to be refilled every 6-month's interval.

6.2.5 ACID SPILLAGE

Due to high operating temperatures, acid spillage has been reported. This is also linked to poor design of batteries from local manufacturers.

6.2.6 TRANSPORTATION

Transporting lead-acid batteries has been again a challenge for micro-grid players who are operating remote areas. There have been cases of damage to batteries and acid spillage. Along with this, due to high weight and volume, the transportation costs are also significant.

6.2.7 REPLACEMENT

Frequent replacement of batteries is not desired specially in-case of remote locations where frequent replacement over long distances increases operational expenditure significantly.

6.2.8 DIRECTLY CONNECTED LOADS

It has also been observed both in urban and rural areas that consumers sometime directly connect the loads to the battery which then results in deep-discharge of the battery.

6.2.9 HOME INVERTER FOR SOLAR APPLICATIONS

Consumers sometime use the home inverter for solar system. Since the availability of power from solar is different than grid, it hampers the charging and discharging of the battery.

6.3 Commercial challenges

6.3.1 CAPITAL COST

Roof-top solar market is highly cost sensitive and batteries add significant cost to solar system. 1 kW roof-top solar system with battery backup is almost 40% costlier than grid-tied solar system.

6.3.2 HIGH MAINTENANCE COST

Due to shorter cycle life of lead-acid batteries, they need to be replaced every 4-5 years which increases operational cost of solar system significantly.

6.3.3 AFTER SALE SERVICES

After sale services are highly valued by solar companies. After sale services are required for technical support, replacement of batteries etc.

Customer support from battery manufacturers varies from location to location. Exide batteries has stronghold in eastern India whereas in Rajasthan they are not able to provide effective after sale services.

6.4 Commercial challenges (advance battery technologies)

6.4.1 HIGH DEPENDENCE ON BATTERY MANUFACTURER

Adoption of advanced battery technologies is likely to be driven by manufacturers rather than a demand pull from consumers. Due to a lack of technical understanding the retail consumers rely on manufacturers and contractors to arrive at the right solution.

6.4.2 HIGH LEAD TIME

Companies providing advance battery technologies in India have a high lead time to import batteries from their factory in home country, since these companies are not manufacturing batteries locally. Lead time for Trojan batteries in India is about 30-40 days.

6.4.3 CUSTOM DUTIES

Custom duties could be as high as 35% of cost of battery which will increase the cost of battery significantly. Increase in cost could surpasses the performance benefit which an advance could offer.

6.4.4 UPFRONT PAYMENTS

Requirement of upfront payment and high lead time make the offer non attractive.

6.4.5 AFTER SALE SERVICES

Due to low quantum of sales in local market, advance battery companies are not able to scale-up their network and are not able to meet after sale service requirements.

7. Analysis of battery and diesel generator for power backup

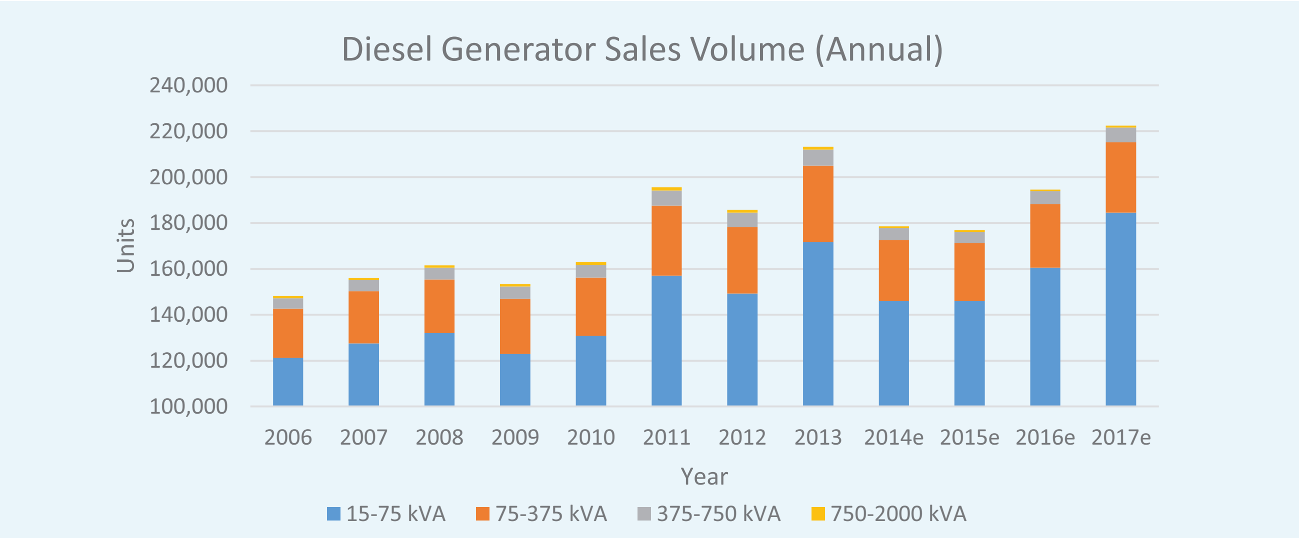
India has an installed power generation capacity of 303 GW as of May 2016, and yet reliable and uninterrupted power is still a distant dream in most parts of India. The outages force industrial and commercial consumers to switch to diesel generators as a reliable source of power. As per the Central Advisory Committee (CAC) of CERC, it is estimated that, in 2014 approximately 90,000 MW power is generated through diesel generators during power cuts. It is further estimated to grow by 5,000 to 8,000 MW every year.

Diesel gensets of different sizes ranging from 0.45 kVA to 3000 kVA are used across different consumer segments. Depending on connected load of a consumer, diesel genset users can be divided into two categories. First, residential and small scale retailer/commercial consumers who uses small size gensets of capacities below 10kVA and consumers with large electric loads such as residential complexes, malls, hotels, hospital and industries are placed in second category (above 10 kVA).

Small size gensets (below 10kVA) are primarily used in households and retail shops. The small size gensets variants are available for all different combustion fuels such as kerosene, petrol, LPG and diesel. Gensets with kerosene as fuel are prominent in this category due to low cost of fuel (INR 14.96/litre). Large genset with capacities above 10kVA uses diesel as fuel predominantly.

As per an analysis conducted by ICF, about 0.22 million number of diesel gensets with a combined capacity of 17,000 MW were sold in 2015. The analysis further indicates an annual market growth rate of 7.2%.

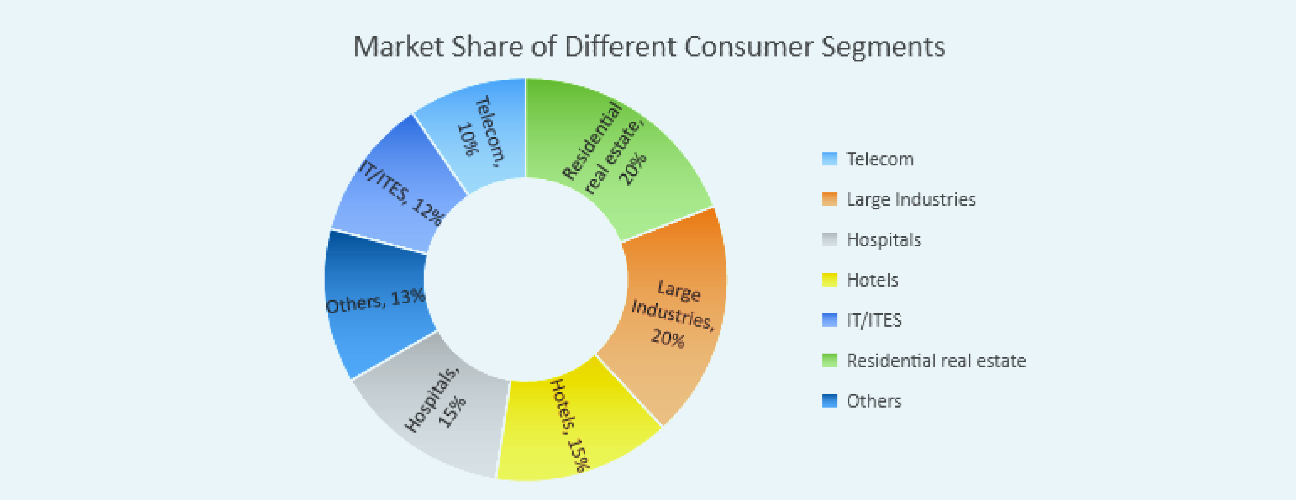
Fig 7: Annual sale of diesel generators



Source: Bhatnagar, Vineet (2014) "Diesel Gensets: In a sweet spot" Ground Zero, 15 July, p. 9

Small scale generators in the range of 15 – 75 kVA, dominate the market with 80% of total sales volume. These gensets are primarily used in telecom, residential and retail segment. Demand for diesel generators in telecom, residential and retail segment contributes to 45% of total sales volume.

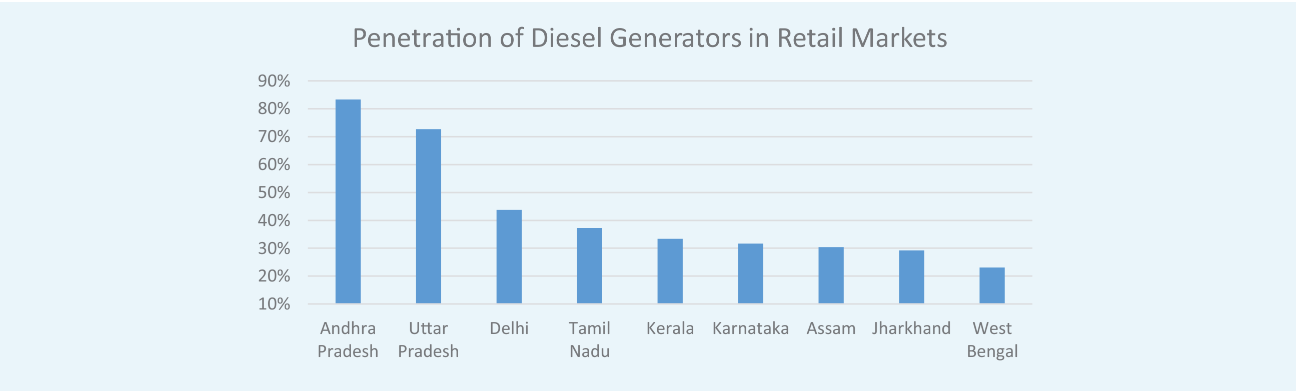
Fig 8: Market share of different consumer segment



Source: Bhatnagar, Vineet (2014) "Diesel Gensets: In a sweet spot" Ground Zero, 15 July, p. 10

Use of diesel generators by consumers in retail segment suggests that Andhra Pradesh, Uttar Pradesh and Delhi are large markets where 40 – 80 % of total consumers were using generators for power backup.

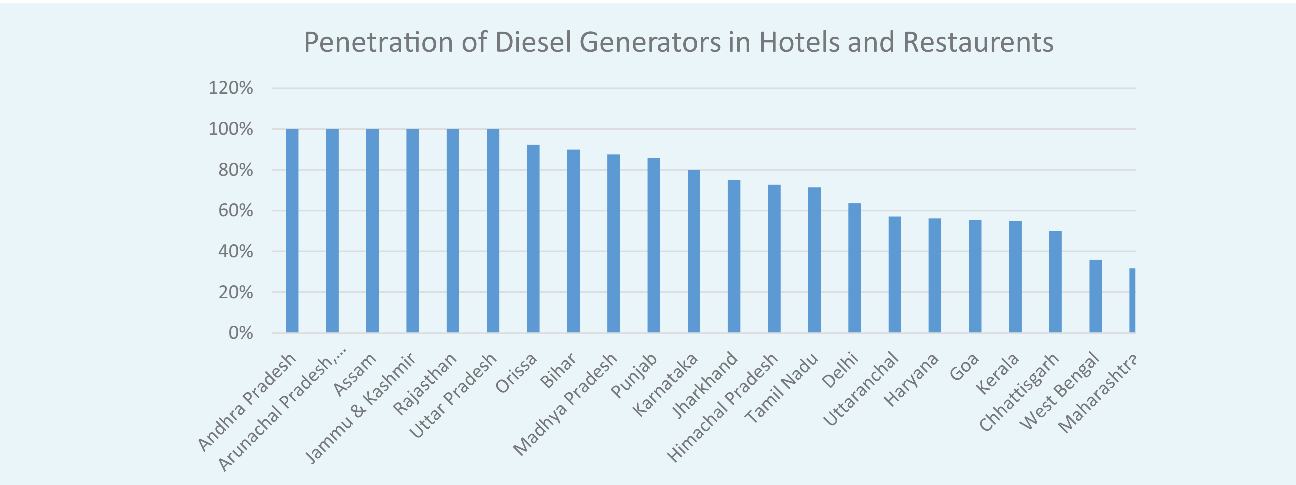
Fig 9: Penetration of diesel generators in retail markets



Source: CEEW analysis of data collected from world bank enterprise survey dataset

Penetration of diesel generators in hotel and restaurant segment is more uniform across most of the states.

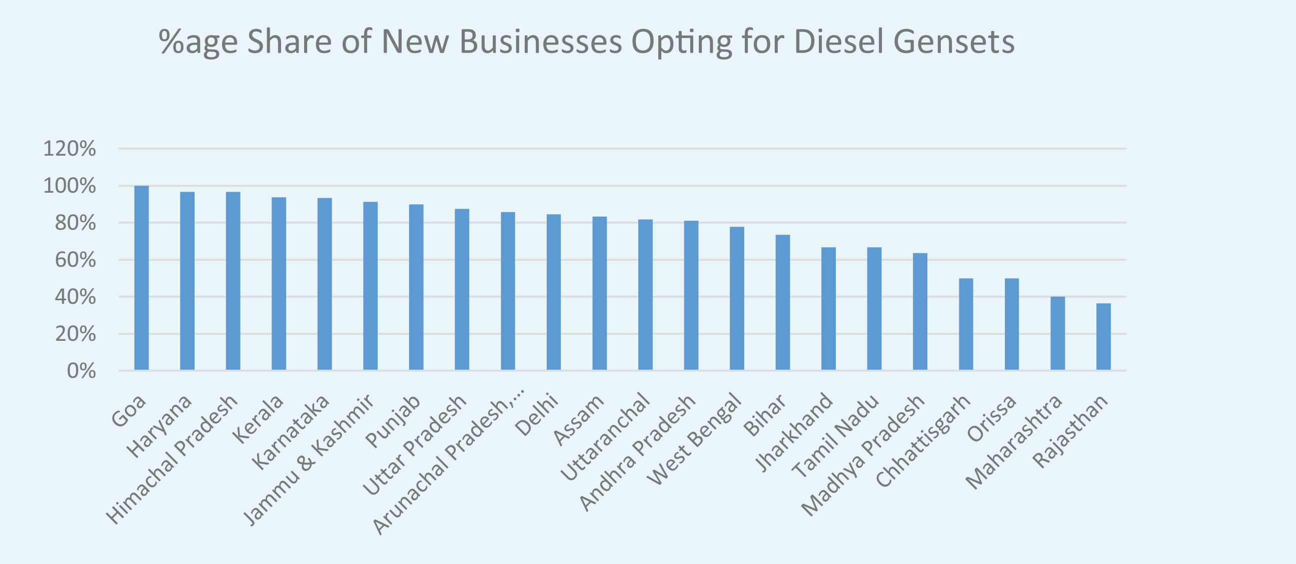
Fig 10: Penetration of diesel generators in hotel and restaurants segment



Source: CEEW analysis of data collected from world bank enterprise survey dataset

Additionally, we found a similar trend when we considered adoption of diesel generators by new business entities.

Fig 11: Percentage share of new business opting for diesel gensets



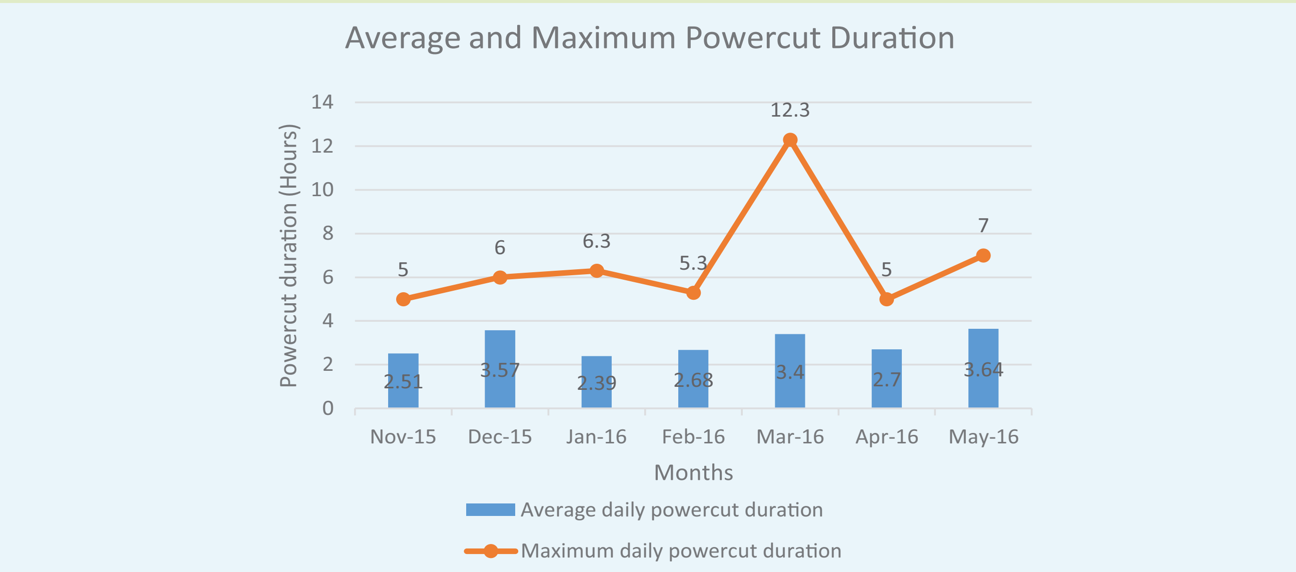
Source: CEEW analysis of data collected from world bank enterprise survey dataset

Table 9: Case study on application of diesel generator in a housing society

Case Study	Diesel Generator usages pattern
Location	Oil India Society, Noida (Sector-15A)
Households	40 apartments
DGSet Capacity	160 kVA

The Oil India Society in Noida has installed 160kVA diesel generator for power backup. Maintenance staff has been maintaining daily record of generator operating hours and electric load on generator. As shown in the Fig. 12, on average the power-cuts are for a duration of 2.5 – 3.5 hours. However, actual outages could be for as long as 12 hours.

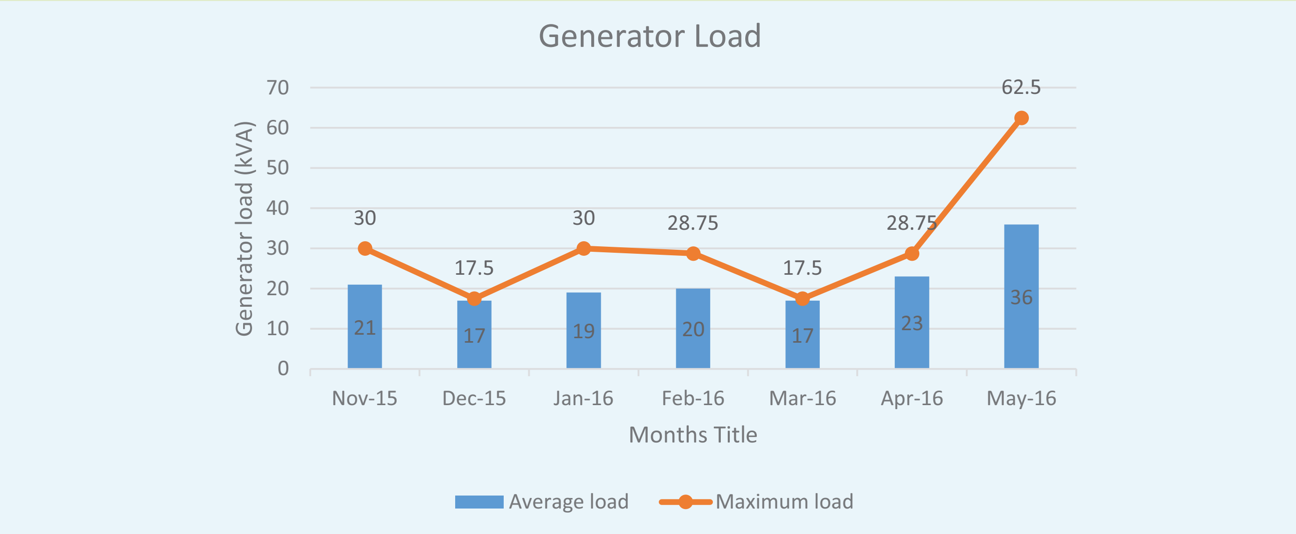
Fig 12: Average and maximum power-cut duration



Source: CEEW analysis of primary data

Further it is observed that the diesel generator had been running on load factor less than 25% for entire duration. There are only a few instances when generator is utilised above 25% load and the maximum load employed is 40% of generator capacity (Fig. 13). This results in higher inefficiencies and increased cost of electricity generation which will make batteries more competitive to diesel generators as an alternative for power backup.

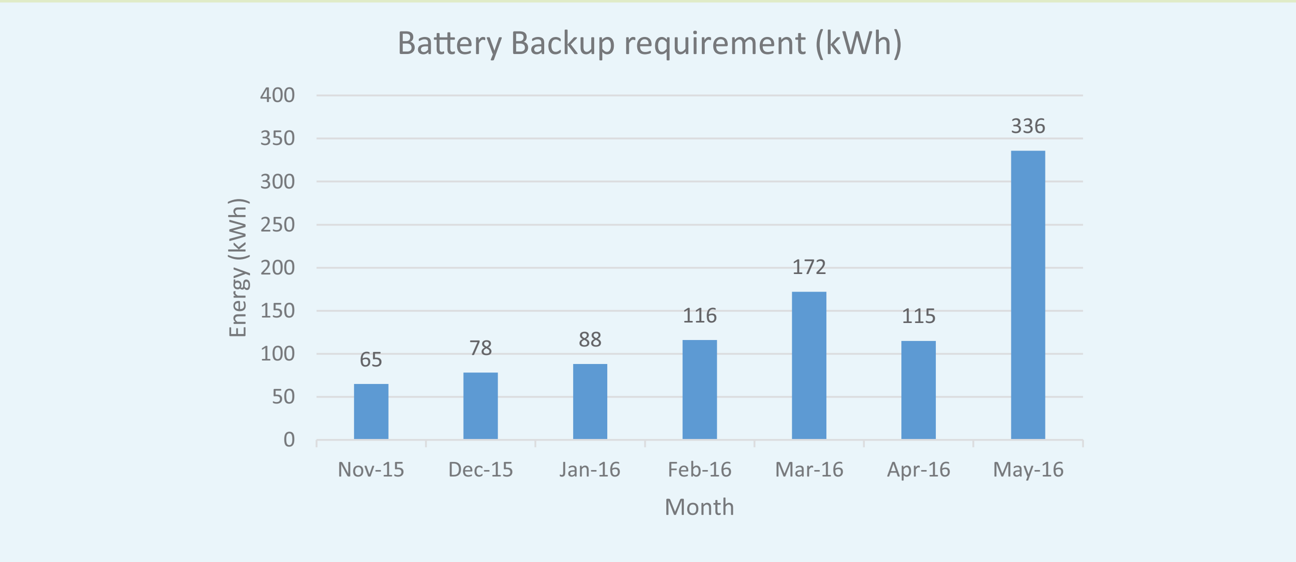
Fig 13: Average and maximum power-cut duration



Source: CEEW analysis of primary data

Considering the battery as an alternative to diesel generator will require to provide backup equivalent to the energy generated from diesel generator. As it is show in Fig. 14 below, a battery bank of capacity of 336 kWh, corresponding to maximum energy generated, will be required to replace diesel generator.

Fig 14: Battery backup requirement (kWh)



Source: CEEW analysis of primary data

Source: CEEW analysis

It was observed, based on interactions with multiple consumers in the residential and commercial segment, that there are concerns over reliability of battery based backup system. The concerns are particularly because of short duration of discharge of batteries and long recharge duration required to replenish the battery.

Frequent replacement of batteries due to short life and regular maintenance requirement also hinders the adoption of battery based backup system in retail stores.

We have compared gensets of different capacities, available in market with batteries based on Life Cycle Cost (LCC) framework. The comparison is for required back-up capacity for different time durations. Following table summarises the cost of generation (INR/kWh) from gensets, using different fuels and batteries.

Small size gensets, running on kerosene cost lowest for generating a unit of electricity (14 – 20 INR/kWh) followed by diesel and petrol. It is observed that running the gensets for one to three hours is most economical with cost of generation being lowest for all three different fuels. Batteries in this segment turns out to be the most economical solution for power backup.

Table 10: Cost of Generation (INR/kWh) for Connected load < 10 kVA

Back-up Hours	Kerosene	Battery	Petrol	Diesel
0 – 1 Hour	20	16	34	29
1 – 3 Hour	14	12	30	24
3 – 10 Hour	18	12	40	27
>10 Hours	20	11	44	28

Source: CEEW Analysis

For consumers with large electric loads, above 50kVA diesel generators are more viable and cost INR 12 – 14 per unit of electricity generated. Batteries are also competitive, to some extent with diesel generators for longer duration power cuts.

Table 11: Cost of Generation (INR/kWh) for Connected load > 10 kVA

Back-up Hours	Battery	Petrol	Diesel	
			10 – 50 kVA	>50 kVA
0 – 1 Hour	19	21	17	12
1 – 3 Hour	15	19	15	12
3 – 10 Hour	14	25	17	14
>10 Hours	14	28	18	14

Source: CEEW Analysis

8. Application of batteries in Indian Railways

The Indian Railways consumes about 1.8% of the country's total power generation for its traction and non-traction applications in 2013-14 (REMCL). Fuel expenditure in the railways constitutes a major portion of the Working Expenditure of the Indian Railways. The total expenditure on fuel during 2013-14 is estimated around 22.26% of the total Ordinary Working Expenses (O.W.E.), as compared to about 18.49% in 2010-11. (23) Electricity accounted for about 22% of the railways' total working expenses.

In view of rising energy demand and uncertainty in power tariffs, the Indian Railways identified the need for an aggressive push towards alternate fuels in the Indian Railways (24) as well as identify potential opportunities for energy savings and realise a cost-effective energy system with least environmental impact. (25)

Given the large scale of operations and coverage of the Indian Railways, even sourcing a small percentage of its power requirements from renewable energy sources would have a substantial impact. The Union Rail Budget 2015-16 stressed the need for harnessing solar energy and identified railway stations as one of the largest potentials for the same.

Identifying critical areas for ensuring a comprehensive environmental management plan, the Union Rail Minister in the 2015-16 budget speech announced expanding and expediting the Solar Mission of the Railways with an additional capacity of 1000 MW to be set up by developers on railway or private land and on rooftops of railway buildings at their own cost with subsidy/Viability Gap Funding (VGF) support from Ministry of New and Renewable Energy over the next five years.

The Indian Railways has one of the world's largest railway network comprising over 64,000 route kilometres and about 8000 railway stations. Of this, only about half is electrified and the remaining are still un-electrified, which are plied by diesel locomotives. Large un-electrified routes and technical non-compliance of overhead electric supply for non-traction electric applications requires the installation of batteries in coaches and for signalling applications. As a result, the Indian Railways, currently, is the largest consumer of lead-acid batteries in the Indian market. (26) The battery market in 2015 for Indian Railways, including replacement demand, stands at INR ~5.3 billion (USD 80 million) which constitutes ~3.6% of overall market. The demand for batteries is primarily for coach and signalling & telecommunication applications (~90%), locomotive applications are only a small fraction.

Batteries for the Indian Railways are primarily used for the following applications:

- Traction Applications
    - Train lighting and air-conditioning
    - Locomotive Starting
    - Signalling and telecommunication
- Renewable Applications for non-traction applications
    - Renewable energy installations (particularly, solar, as per the Indian Railways' Solar Mission)

The Research Design and Standards Organisation (RDSO) defines the battery parameters and the performance standards of batteries for the Indian Railways. Previously, flooded lead-acid batteries were used and these are now being replaced by VRLA batteries primarily due to maintenance free operations.

8.1 Renewable energy installations for non-traction applications

The Indian Railways is now harnessing solar energy at a significant scale and has also announced in the Rail Budget 2015-16 to setup 1 GW of solar power by 2018-19. (27) These will be mostly located at railway stations, factories and workshops. (28) Currently, the Railways consume 2.5% of the total electricity consumption in India. With increasing renewable share, batteries will be required for reliability of the system.

For the purposes of this analysis, we have included diesel locomotive sheds, railway workshops, railway stations, railway offices, level crossing gates, car and loco sheds. Across its sixteen zones, the Indian Railways has close to 50 diesel sheds, 40 railway workshops, and over 8000 stations.

The total solar PV potential for the Indian Railways across its various non-traction operations was calculated in the report “Greening the tracks: Achieving the 1 GW solar PV target”. (28) The battery storage potential has accordingly been calculated assuming the use 12V batteries. Depending on the use of different batteries, the number of batteries required may change.

The analysis indicates that about 261 million AH is the battery storage potential for solar PV installations across the IR. The table below provides the details of the same. The annexure provides the zonal distribution of storage potential across the Indian Railways.

Table 12: Storage potential across various railway operations with solar PV installations

Application	Solar PV Potential (MW)	12 V Battery potential (million AH)
Diesel Loco Sheds	26.338	9.481
Railway Workshops		
Rooftop PV	175.091	63.032
Workshop land	67.531	24.311
Production Units		
Rooftop PV	131.474	47.330
PU Land	87.27	31.417
Car Sheds	157.828	56.818
Electric Loco Sheds	24.442	8.799
Railway Stations		
Already proposed (REMCL)	5.25	1.890
Additional potential	41.58	14.968
Level Crossing Gates (LCGs)	6.1	2.196
Street Lights	0.22	0.079
Railway Offices (Proposed by Ministry of Railways)	0.76	0.273
Total	723.884	260.596

Source: CEEW analysis

8.2 Traction application

Traction applications comprise locomotive starting, electric need of coaches (including lighting, fan, charging etc.), air-conditioning of AC coaches and signalling and telecommunication along the tracks. Batteries used for traction applications need to be robust and reliable to withstand outer atmosphere, vibrations, varying temperatures, continuous discharge and low maintenance.

8.2.1 TRAIN COACHES

The Indian Railways uses different types of coaches primarily categorised as air-conditioned and non-air-conditioned coaches. Currently, there are close to 50,000 coaches, of which 10,000 are air-conditioned (1st Class, 2nd AC, 3rd AC, AC chair car etc.) and 40,000 are non-air-conditioned (sleeper, 2nd sitting, general coaches etc.). The Indian Railways owned coach manufacturing companies - Rail Coach Factory at Kapurthala and Integral Coach Factory at Perambur produce approximately 3,200 coaches every year.

As per RDSO standards, power is supplied at 110V DC current from batteries in both AC and non-AC coaches. For air-conditioned coaches, higher capacity batteries (1100Ah) are used due to air-conditioning load while in non-AC coaches lower capacity batteries (120Ah) are used. (29) More variants of different battery models used in coaches are provided in previous section. The standard replacement cycle for batteries has been defined at four years by RDSO.

Batteries are a primary source of electricity in self-generating (SG) coaches while in the case of End-ON Generation (EOG) coaches batteries are only for backup and emergency power. End-ON Generation mechanism is primarily used in fully air-conditioned trains such as Rajdhani, GaribRath, Duranto etc.

RDSO and IRIEEN (Indian Railway Institute of Electrical Engineering) are also developing Head-ON generation (HOG), which will directly supply electricity from overhead electrical cables to coach applications apart from traction. Although, it has not been deployed yet, this could reduce the requirement of batteries in coaches.

8.2.2 LOCOMOTIVE STARTING

The Indian Railways currently has 5,633 diesel locomotives for non-electrified routes and 4,823 electric locomotives for electrified routes. A total of 250 electric and 320 diesel locomotives were produced in 2015 by the Chittaranjan Locomotive Works and Diesel Locomotive Works respectively.

Batteries are used to provide power to perform several pre-start functions of diesel engines such as powering up hydraulic pumps, air compressors and brake systems, which are mandatorily required for smooth starting of the engine without any damage to its components.

The Electric Multiple Units (EMUs) requires batteries to lift and connect the pantograph to the overhead electric line to start the operations from a disconnected situation. Batteries are also used for emergency backup power and breaking. With increasing electrification of India Railways, the demand from this segment is expected to grow steadily.

8.2.3 SIGNALLING AND TELECOMMUNICATION

Batteries are provided for backup power in signalling infrastructure to maintain fool proof communication in case of any interruption in main power for safety of railway operations. Batteries used for this have low self-discharge and should be maintenance free.

9. Conclusion

Battery market in India for renewable applications has been growing steadily with increasing renewable penetration across different segments. Deployment of renewables will further accelerate with the implementation of various national level policy initiatives such as micro/mini-grid policy, policy for domestic manufacturing of advance battery technologies and state level solar policies. Currently, lead-acid batteries are primarily catering to these demands. However, due to limited depth of discharge, cycle life and other technical challenges of lead-acid batteries, demand for batteries is shifting towards advance battery chemistries with longer cycle life and higher depth of discharge.

Adoption of batteries in solar segment is largely restricted due high cost of generation of power from solar plus battery system. As the grid tariff surpasses cost of generation from solar plus battery system, consumers tend to be captive user of solar electricity with battery backup instead of feeding the excess power to grid. This shift is expected to begin in as early as 2020. Industries and commercial consumers will be early adopters of batteries under this shift. These early adopter of batteries in industrial segment will be from Maharashtra, Odisha, Delhi, West Bengal, Tamil Nadu, Uttar Pradesh and Karnataka states. While the adoption of batteries, in residential segment will be primarily in Uttar Pradesh, Karnataka, Tamil Nadu, Andhra Pradesh, Maharashtra, Jharkhand and Kerala.

Micro/mini-grid developers, being reliant on batteries to store and supply electricity to rural households during evening and night hours, could be targeted as early adopters of advance battery technologies with superior performance and low cost. Micro/mini-grids deployment is prominent in Uttar Pradesh, West Bengal, Bihar, Odisha, Chhattisgarh, Jharkhand and Andhra Pradesh states. Similar trends of micro/mini-grid deployment are expected to follow in the coming years as well which will offer opportunities to battery market as well.

Similar to micro/mini-grids, commercial setups such as petrol pumps, telecom towers, bank branches, healthcare centres and govt. offices established in remote location where reliable grid is not available will also be adopting batteries along with solar PV system for a reliable access to power. Petrol pumps and rural ATMs alone offer a market opportunity of INR ~5 billion (in current value term) in India.

Though the solar segment offers a huge market opportunity for advance battery technologies, manufacturers (and researchers alike) have some ground to cover in addressing technical limitations of batteries such as charging characteristics of a battery, thermal performance and requirement of boost current to charge deep cycle batteries. Also since solar companies directly procure batteries from manufacturers and require after sale services and technical support, battery companies should have wider presence to address these expectations.

References

1. Commission, Central Electricity Regulation. *Introduction of Ancillary Services in Indian Electricity market*. Delhi : Central Electricity Regulation Commission, 2013.

2. Energy Storage in India: Market Overview. Indian Energy Storage Alliance. [Online] Indian Energy Storage Alliance, 2016. [Cited: 15 February 2016.] http://indiaesa.info/index.php/news-details?newsid=21.

3. India's Intended Nationally Determined Contribution: Working Towards Climate Justice. *Ministry of Environment, Forest and Climate Change*. [Online] 2015. [Cited: 15 February 2016.] http://www.moef.gov.in/content/press-statement-india%E2%80%99s-intended-nationally-determined-contribution-indc-02-10-2015-0.

4. Power, Ministry of. Comprehensive State Specific Action Plans for 24x7 Power. [Online] Ministry of Power, 2015. [Cited: 15 February 2016.] http://pib.nic.in/newsite/PrintRelease.aspx?relid=133631.

5. Technical Specification for Sodium Nickel Chloride / Alkaline/ Flow Battery Energy Storage System (BESS). *Power Grid Corporation of India*. [Online] 2015. [Cited: 15 February 2016.] http://files.ctctcdn.com/9eafabef201/c8645577-99be-4722-b393-582c48f3a50f.pdf.

6. Expression of Interest (EOI) for Energy Storage Projects for Supporting Renewable Generation. *Ministry of New and Renewable Energy*. [Online] 2015. [Cited: 15 february 2016.] http://mnre.gov.in/file-manager/advertisement/EOI-for-Energy-Storage-05082015.pdf.

7. Technical Committee. *Large Scale Integration of Renewable Energy, Need for Balancing, Deviation Settlement Mechanism (DSM) and associated issues*. Delhi : Government of India, 2016.

8. Amol Phadke, Nikit Abhyankar, Ranjit Deshmukh, Susheel Soonee, Sushanta K Chatterjee. *Can India Integrate its Renewable Energy Targets into the Grid? Investment and Operational Insights from Grid Planning and Dispatch Analysis*. s.l. : Lawrence Berkeley National Laboratory, 2015.

9. COMMISSION, CENTRAL ELECTRICITY REGULATORY. *Draft CERC Ancillary Services Operations Regulations*. Delhi : CENTRAL ELECTRICITY REGULATORY COMMISSION, 2015.

10. Oil retailers to open 35,600 new outlets in next three years. *Firstpost*. [Online] 2015. [Cited: 3 July 2016.] http://www.firstpost.com/business/oil-retailers-open-35600-new-outlets-next-three-years-2056043.html.

11. Wikipedia. Telecommunications statistics in India. Wikipedia. [Online] 2016. [Cited: 1 July 2016.] https://en.wikipedia.org/wiki/Telecommunications_statistics_in_India#cite_note-telecomtalk.info-4.

12. Telecom Regulatory Authority of India. Telecom Statistics. [Online] 2016. [Cited: 30 Jun 2016.] http://trai.gov.in/WriteReadData/PressRealease/Document/PR-TSD-Nov-15.pdf.

13. Economic Times. Trai to review rules on green energy-driven mobile towers. [Online] 2016. [Cited: 30 Jun 2016.] http://articles.economictimes.indiatimes.com/2016-03-10/news/71382536_1_trai-green-telecom-policy-hybrid-power.

14. Venu Gopal, Mrinmoy Chattaraj. *Enabling Clean Talking*. Delhi : Greenpeace,, 2012.

15. Vanu Rural Technical Innovation. *Venu Technical Innovation*. [Online] 2016. [Cited: 3 July 2016.] http://www.vanu.com/solutions/rural.

16. Sudeshna Ghosh Banerjee, Douglas Barnes, Bipul Singh, Kristy Mayer, and Hussain Samad. *Power for All: Electricity Access Challenges in India.* s.l. : World Bank, 2014.

17. Schnitzer, *D. Micro-grids for electrification: A critical review of best practices based on seven case studies.* s.l. : UN Foundation, 2014.

18. National Policy for Renewable Energy Based Micro and Mini Grids. *Ministry of New and Renewable Energy.* [Online] 2016. [Cited: 3 July 2016.] http://mnre.gov.in/file-manager/UserFiles/draft-national-Mini_Micro-Grid-Policy.pdf.

19. NIT for 2.5 MW Solar Wind hybrid Project at Rangreek, HP: Extension of Deadline for Bid Submission. *Solar Energy Corporation of India.* [Online] 2016. [Cited: 4 July 2016.] http://www.seci.gov.in/content/news_update/nit-for-25-mw-solar-wind-hybrid-project-at-rangreek--hp-extension-of-deadline-for-bid-submission.php.

20. Panasonic and AES announces India's first large scale battery based energy storage project. *AES Energy Storage.* [Online] 2016. [Cited: 4 July 2016.] http://aesenergystorage.com/2016/04/18/panasonic-and-aes-announce-indias-first-large-scale-battery-based-energy-storage-project/.

21. Policy on Co-generation and Generation of Electricity from Renewable Sources of Energy. *Ministry of New and Renewable Energy.* [Online] 2012. [Cited: 2 July 2016.] http://mnre.gov.in/file-manager/UserFiles/Grid-Connected-Solar-Rooftop-policy/West_Bengal_Solar_Policy_2012.pdf.

22. Delhi Solar Energy Policy, 2015. *The Government of Delhi.* [Online] 2016. [Cited: 2 July 2016.] http://delhi.gov.in/wps/wcm/connect/224a890049cda85ca0aae8124fa22605/Delhi_Solar_Policy_Draft_150910.pdf?MOD=AJPERES&lmod=-1181892927&CACHEID=224a890049cda85ca0aae8124fa22605F.

23. Railways, Ministry of. Railway Statistics. s.l. : Ministry of Railways, Government of India, 2015.

24. *White Paper - Indian Railways: Lifeline of the Nation.* s.l. : Ministry of Railways, Government of India, 2015.

25. Committee, Public Accounts. *Environment Management in the Indian Railways – Stations, Trains and Tracks, Third Report of the Public Accounts Committee.* s.l. : Sixteenth Lok Sabha, Government of India, 2015.

26. Board, Indian Railways. *Statistical Summary – Indian Railways.* s.l. : Ministry of Railways, Government of India, 2015.

27 *Solar Policy of Procuring 1000 MW Solar Power.* s.l. : Ministry of Railways, Government of India, 2015.

28. Ramji, Aditya. *Greening the tracks: achieving the 1 GW solar PV target of the Indian Railways.* s.l. : Council on Energy, Environment and Water, 2015.

29. Board, Indian Railways. *Lead-acid batteries for coaches – Indian Railways.* s.l. : Ministry of Railways, Government of India, 2010.

Appendices

Annexure 1: Cost of Power for Different Fuels

Fuel	Kerosene	Kerosene	Petrol	Kerosene	Kerosene	Petrol	Kerosene	Petrol
Daily Running Hours /load (kW)	0.4	0.5	0.6	0.8	1.12	1.4	1.68	2.24
0.25	31	27	43	27	22	50	21	41
0.5	21	18	35	20	15	41	15	35
0.75	18	16	32	17	13	37	13	33
1	16	14	30	16	12	36	12	32
2	14	13	29	14	11	35	11	32
3	17	15	34	17	13	41	13	37
4	18	16	37	19	14	44	14	41
5	19	17	39	20	15	47	14	43
6	20	18	41	20	16	48	15	45
7	20	19	42	21	16	49	15	46
8	21	19	43	21	17	50	16	47
9	21	19	43	22	17	51	16	47
10	21	20	44	22	17	52	16	48
11	22	20	44	22	17	52	16	48
12	22	20	45	23	18	53	17	49
13	22	20	45	23	18	53	17	49
14	22	20	45	23	18	54	17	50
15	22	20	45	23	18	54	17	50
16	22	20	46	23	18	54	17	50
17	22	21	46	23	18	54	17	50
18	23	21	46	23	18	55	17	50
19	23	21	46	23	18	55	17	51
20	23	21	46	24	18	55	17	51
21	23	21	46	24	18	55	17	51
22	23	21	47	24	18	55	17	51
23	23	21	47	24	18	55	17	51
24	23	21	47	24	19	55	17	51

Fuel	Diesel	Petrol	Petrol	Diesel	Petrol	Diesel	Diesel	Diesel	Diesel	Diesel
Daily Running Hours /load (kW)	2.6	4.4	4.4	6	10.4	8	12	16	20	24
0.25	46	45	41	33	24	26	21	19	19	18
0.5	35	38	32	27	20	21	17	16	16	16
0.75	32	35	30	25	19	19	16	15	15	15
1	30	34	28	24	18	18	16	15	15	15
2	28	34	27	23	18	17	15	14	14	14
3	31	40	32	25	21	19	16	15	15	16
4	32	43	35	26	23	19	17	16	16	16
5	33	46	37	27	24	20	17	17	17	17
6	33	47	38	27	25	20	18	17	17	17
7	34	48	39	28	26	21	18	17	17	17
8	34	49	40	28	26	21	18	17	17	17
9	34	50	40	28	27	21	18	17	17	18
10	34	51	41	28	27	21	18	17	17	18
11	35	51	41	28	27	21	19	18	18	18
12	35	52	41	29	28	21	19	18	18	18
13	35	52	42	29	28	21	19	18	18	18
14	35	52	42	29	28	21	19	18	18	18
15	35	53	42	29	28	21	19	18	18	18
16	35	53	42	29	28	21	19	18	18	18
17	35	53	43	29	28	21	19	18	18	18
18	35	53	43	29	28	22	19	18	18	18
19	35	54	43	29	29	22	19	18	18	18
20	35	54	43	29	29	22	19	18	18	18
21	35	54	43	29	29	22	19	18	18	18
22	35	54	43	29	29	22	19	18	18	18
23	35	54	43	29	29	22	19	18	18	18
24	35	54	43	29	29	22	19	18	18	18

Fuel	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel
Daily Running Hours /load (kW)	32	40	50	80	100	128	144	160	200	256	400
0.25	16	16	14	14	13	14	13	13	13	13	14
0.5	14	14	13	12	12	13	12	12	11	11	12
0.75	13	13	12	12	11	13	11	11	11	11	12
1	13	13	12	12	11	12	11	11	11	11	12
2	13	13	12	12	11	12	11	11	11	11	12
3	14	14	13	13	12	13	12	12	12	12	13
4	14	14	13	13	13	14	13	13	12	12	13
5	15	15	14	14	13	14	13	13	13	13	14
6	15	15	14	14	13	15	13	13	13	13	14
7	15	15	14	14	13	15	14	14	13	13	14
8	15	15	14	14	13	15	14	14	13	13	14
9	16	15	14	14	14	15	14	14	13	13	14
10	16	15	15	14	14	15	14	14	13	13	15
11	16	16	15	14	14	15	14	14	13	13	15
12	16	16	15	14	14	15	14	14	13	14	15
13	16	16	15	14	14	15	14	14	13	14	15
14	16	16	15	14	14	16	14	14	13	14	15
15	16	16	15	15	14	16	14	14	14	14	15
16	16	16	15	15	14	16	14	14	14	14	15
17	16	16	15	15	14	16	14	14	14	14	15
18	16	16	15	15	14	16	14	14	14	14	15
19	16	16	15	15	14	16	14	14	14	14	15
20	16	16	15	15	14	16	14	14	14	14	15
21	16	16	15	15	14	16	14	14	14	14	15
22	16	16	15	15	14	16	14	14	14	14	15
23	16	16	15	15	14	16	14	14	14	14	15
24	16	16	15	15	14	16	14	14	14	14	15

Table : Cost of electricity from battery backup

Daily usage Hours /load (kW)	0.4	0.5	0.6	0.8	1.12	1.4	1.68	2.24	2.6	3.3	4.4	Above 10 kW
0.25	21	19	19	18	17	17	19	19	19	20	20	22
0.5	16	15	15	15	14	14	15	15	15	16	16	18
0.75	14	14	14	14	13	13	14	14	14	14	14	17
1	14	13	13	13	13	13	13	13	13	13	13	16
2	12	12	12	12	12	12	12	12	12	12	12	15
3	12	12	12	12	12	12	12	12	12	12	12	14
4	12	12	12	12	12	12	12	12	12	12	12	14
5	12	12	12	12	12	12	12	12	12	12	12	14
6	12	12	12	12	12	12	12	12	12	12	12	14
7	12	12	12	12	12	12	12	12	12	12	12	14
8	12	12	12	12	11	11	12	12	12	12	12	14
9	12	12	12	11	11	11	12	12	12	12	12	14
10	12	11	11	11	11	11	12	11	11	12	12	14
11	12	11	11	11	11	11	11	11	11	12	12	14
12	12	11	11	11	11	11	11	11	11	11	11	14
13	11	11	11	11	11	11	11	11	11	11	11	14
14	11	11	11	11	11	11	11	11	11	11	11	14
15	11	11	11	11	11	11	11	11	11	11	11	14
16	11	11	11	11	11	11	11	11	11	11	11	14
17	11	11	11	11	11	11	11	11	11	11	11	14
18	11	11	11	11	11	11	11	11	11	11	11	14
19	11	11	11	11	11	11	11	11	11	11	11	14
20	11	11	11	11	11	11	11	11	11	11	11	14
21	11	11	11	11	11	11	11	11	11	11	11	14
22	11	11	11	11	11	11	11	11	11	11	11	14
23	11	11	11	11	11	11	11	11	11	11	11	14
24	11	11	11	11	11	11	11	11	11	11	11	14

Annexure 2: Analysis of power outages duration and outages frequency (Prayas Data)

Methodology: Multiple cities across different states are evaluated based on electricity availability data. An analytical approach has been employed on data to identify potential cities for storage deployment. Cities are ranked based on multiple parameters such as availability of power, frequency of outages etc. All parameters are explained in analysis section.

Data: The data have been collected from the "Electricity Supply Monitoring Initiative" portal, developed by Prayas Energy – Pune. The portal monitors multiple parameters for every one-hour inverter from different cities as mentioned below. For the analysis, 3 months of data starting from 1 December 2015 to 29 February 2016 (91 days in total) were collected for 30 cities. For each city, multiple data points were considered to represent the geographic diversity of a particular city. This results in a total of 52 data points for 30 cities.

State	City	State	City
Andhra Pradesh/Telangana	Hyderabad	Karnataka	Udupi
Chandigarh (UT)	Chandigarh		Bengaluru
Delhi	Delhi		Belgaum
Goa	Goa	Odisha	Kendujhar
Haryana	Gurgaon		Bhubaneswar
	Kurukshetra	Punjab	Mohali
Madhya Pradesh	Barwani	Rajasthan	Jaipur
	Bhopal	Tamil Nadu	Kancheepuram
Maharashtra	Nagpur	Telangana	Chennai
	Pune		Warangal
	Nashik	Uttar Pradesh	Mughal-Sarai
	Dhule		Varanasi
	Thane		Lucknow
	Akola		Kanpur
	Mumbai		Ghaziabad

Assumptions and limitations:

Assumptions	• Only domestic connection points are considered
	• Two data points from central and peripheral part of each city are considered to better represent electricity supply in the city.
	• Status of power supply is assumed to be similar for days when data are not available
Limitations	• Availability of data for longer durations
	• Missing data points
	• Lack of data points for domestic connections for cities

Analysis: The ranking of cities is based on evaluation of different parameters which influences the requirement of storage batteries. The parameters considered are as follow:

- Total duration of power outages in sample period
- Extent of power outages (Short, medium and long)
- Frequency of outages
- Daily average duration of power outages
- Number of days with/without power interruptions

1. Analysis of frequency and duration of power-cuts:

This analysis takes into account the frequency of power-cuts and total duration of unavailability of power for each individual city. Duration of power-cuts are classified into short (0 - 15 min), medium (15 - 30 min) and long (30 - 60 min). Since the duration of power-cuts influences the choice to opt for storage, different weightage is assigned to short (0.1), medium (0.3) and long (0.6) power-cuts. The final rank is prepared based on following formula

$$Rank\ Coefficient = \frac{\sum_{i=1}^{3} x_i n_i}{N} \times \frac{\sum_{i=1}^{3} t_i}{T}$$

Represents impact of average outages frequencies

Represents impact of average duration of power-cuts

Here,

x_i denotes weightage (0.6, 0.3 and 0.1)

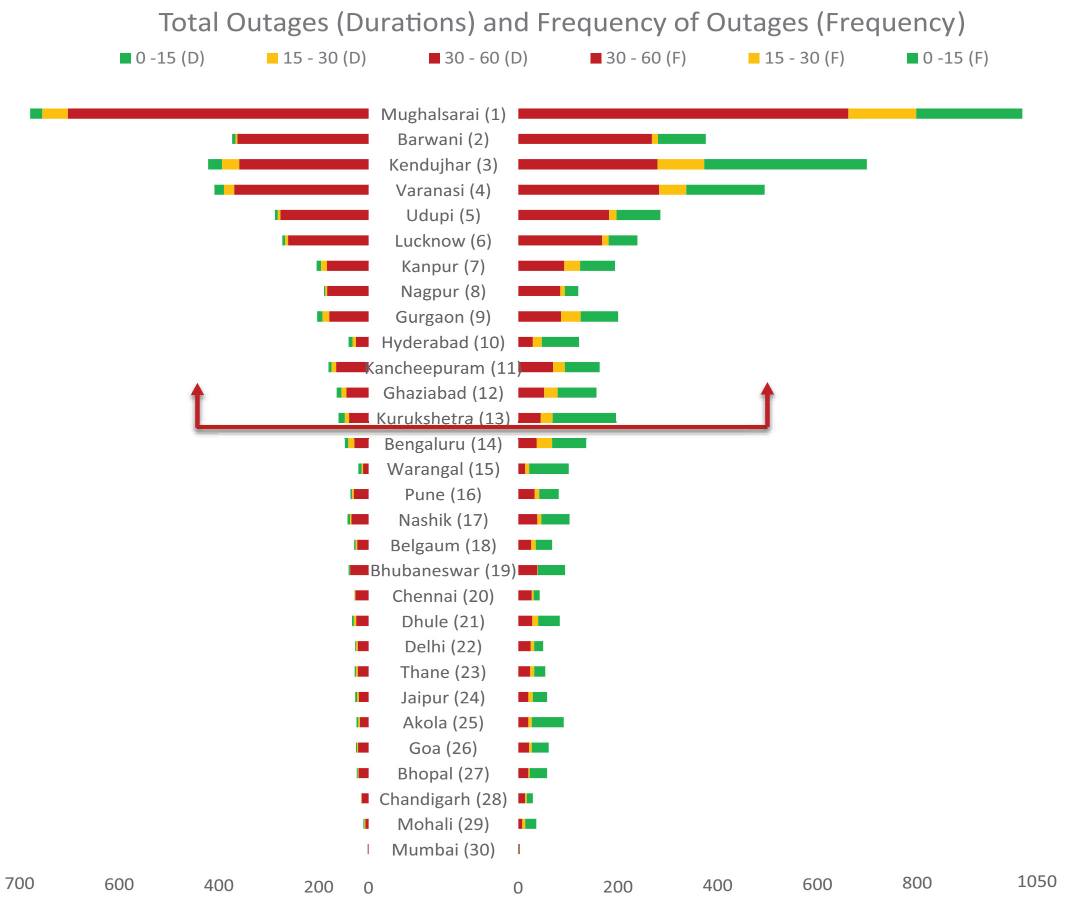
n_i denotes frequency of power-cuts for short, medium and long durations

N denotes total available data points between Dec-15 to Feb-16

t_i represents total duration of power outages in minutes

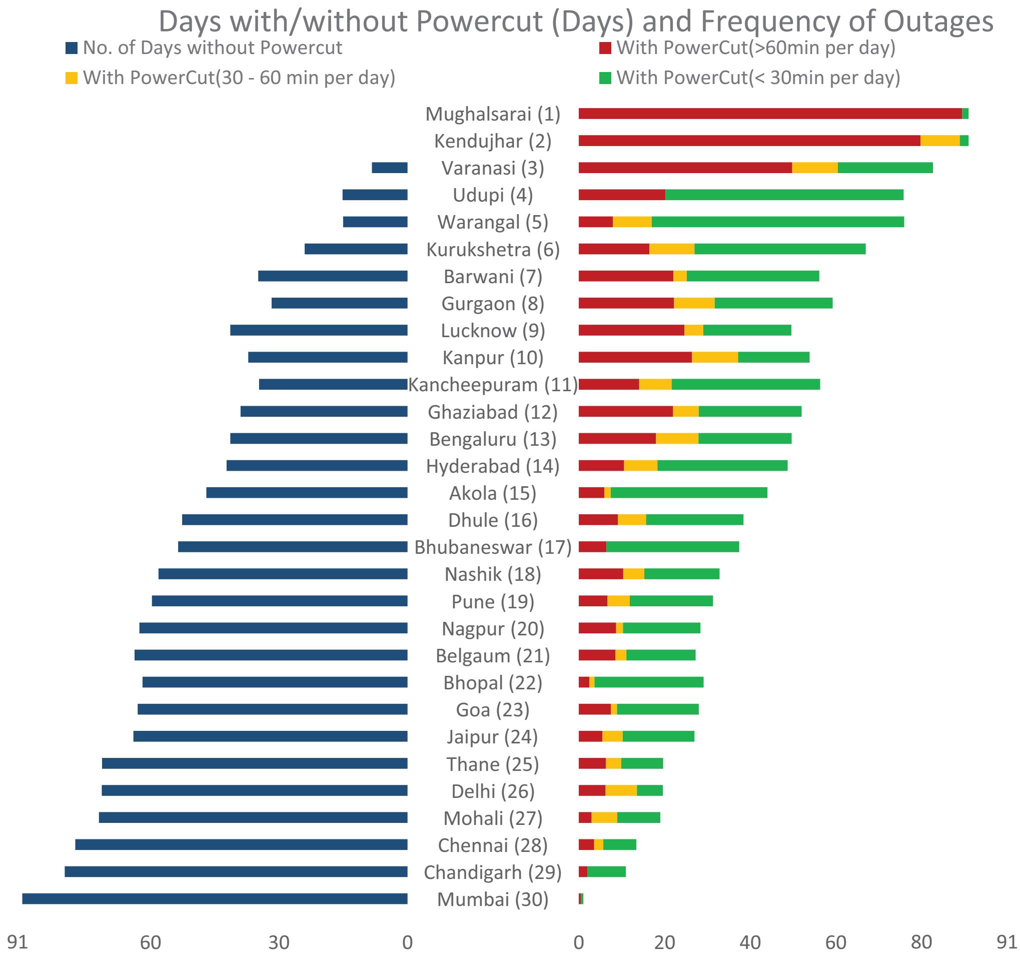
T represents total duration of recorded data in minutes

The following graph represents, total hours of outages and frequency of outages for all cities for the Dec-15 to Feb-16 (91 days). The rank of each city is mentioned next to the city names in brackets. Duration of outages is divided in three groups, 0 – 15 mins, 15 – 30 mins and 30 – 60 mins. The left side of the graph represents total duration of outages (in hours) occurred during the sample period. The right side of the graph represents frequency of outages in each of three groups for the sample period. Cities mentioned above red line are best suited for battery market.



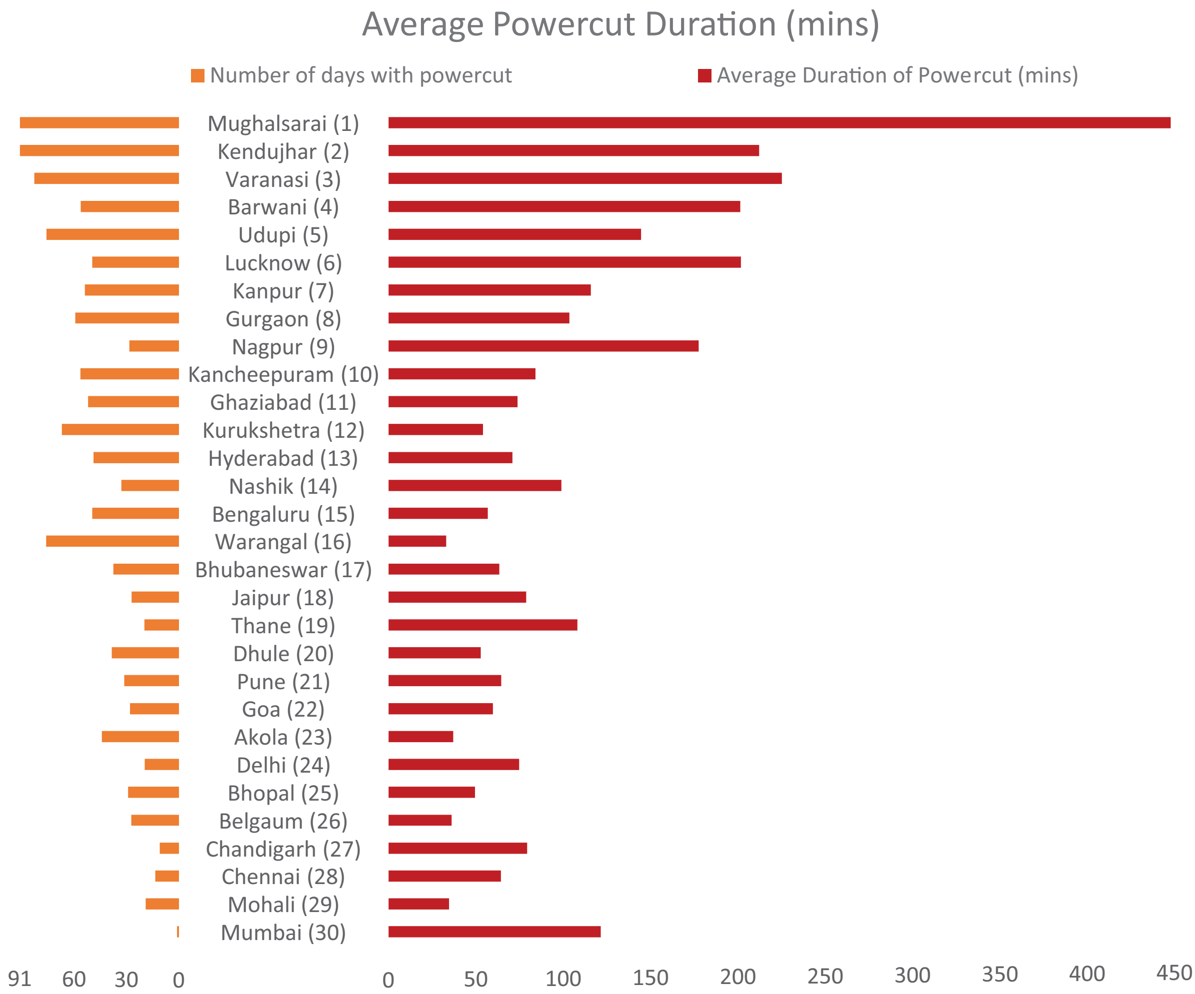
2. Power-outages and Outages intensity:

The analysis considers days with and without uninterrupted power and duration of power cuts on each day in all 30 cities. Based on the analysis, the following graph represents number of days without power-cuts on left side and the right side represents the number of days when power-cuts happened. The total number of days with power interruption has been further broken down into three categories depending on duration of outages. Outages categories are defined for duration between 0 – 30 mins, 30 – 60 mins and greater than 60 mins.



3. Average outages per day:

The analysis compares cities based on average duration of power outages per day and total number of days with power interruption. Duration of average power outages is calculated by considering only those days when there was any power interruption. Cities with more than 45 days of interrupted power and daily average outages more than 100 mins could be ideal for battery market.



Council on Energy, Environment and Water,
Thapar House, 124, Janpath, New Delhi 110001, India

Tel: +91 407 333 00 | Fax: +91 407 333 99

OUR WEB RESOURCES

- ceew.in/publications
- ceew.in/blog
- ceew.in/news
- ceew.in/events
- ceew.in/videos
- ceew.in/images
- ceew.in/annualreport

OUR SOCIAL MEDIA RESOURCES

CEEWIndia

@CEEWIndia

company/council-on-energy-environment-and-water

CEEWIndia