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Economics of stationary energy storage systems: Driving faster adoption for behind-the-meter applications in India

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ABSTRACT

Managing the transition to a low carbon economy is a complex challenge that needs both early wins and a longer-term alternate technologies leapfrog, to better supplement existing public policies. Relative to the significant investment and policy focus on renewable energy generation and Electric Vehicles (EV) - both globally and in India - Stationary Energy Storage systems (ESS) have received far lower investment and policy attention.

This is an important issue to redress for two key reasons. Firstly, ESS is a key rate limiting constraint to achieve the desired benefits of further increasing the share of renewables in the energy generation mix, in India's case from the current 20–25% to a target 40%+ range by 2030. Secondly, several ESS applications are already/very nearly economically viable.

Although the dominant discourse focuses on EVs, our analysis in this paper shows that there is a bigger near term opportunity in India for Stationary Battery Energy Storage Systems (BESS) to replace diesel gensets for power backup. Interestingly India offers a meaningful level of scale for power-backup applications, for adoption directly by end-users. BESS as an alternative to Diesel Generator (DG) for power backup is economically viable in the Telecom sector and for roof-top solar installations; further non-subsidy levers e.g. differential tariffs and an annual cess on DG use, can drive economic viability in large campuses e.g. residential, schools and commercial buildings. These applications could offer a BESS demand ranging from 40 to 145 GWh over the next three years – which is more than the BESS demand estimates for EV segment of 40 GWh.

Our study is verified and supported by experiential insights derived through primary research, personal interviews and hosting round-table discussions with relevant private and public policy experts.

The conclusions from this paper raise the interesting public policy and business strategy implications,[1] of given the economic viability and significant demand why has the adoption up to this potential not yet taken off, and what will it take to achieve this potential?[1]

1. Introduction

1.1. Energy storage system overview

Relative to the significant investment and policy focus on renewable energy generation and Electric Vehicle (EV) mobility - both globally and in India - Stationary Energy Storage systems (ESS) have received far lower investment and policy attention. This is an important issue to redress, as ESS is a key rate limiting constraint to achieve the desired benefits of further increasing the share of renewables in our energy generation mix, in India's case from the current 20–25% to a target 40%+ range by 2030 (INDC, UNFCCC, 2015). ESS have various applications both 'front of the meter i.e. at utility scale throughout the electricity value chain, as well as 'behind the meter' (BTM) applications for differing end-use segments.

There is an observed transition in the ESS technologies worldwide. Global operational installed capacity of energy storage technology is 177 GW out of which the dominant majority 96.4% is pumped hydro storage (PHS) technology, 1.6% of installed capacity is Thermal Energy Storage and Electrochemical technology comprises 1.3% (Table 1). Although pumped hydro storage historically dominates total electricity storage capacity, it has become a mature technology with high site-

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specific costs, significant environmental and geographical constraints driving the limited growth in further adoption of this technology. There is an increasing trend of utilizing various techniques to optimize ESS, especially in terms of capacity sizing and nodal siting (Mohamad et al., 2018).

1.2. Rise of battery energy storage system (BESS)

While, 'advanced chemistry'[2] Electrochemical Storage (BESS) installed capacity is currently very small, at 2 GW (1.3% of total ESS mix), it is the fastest growing and projected to grow significantly with increasing economic viability (Symeonidou et al., 2021). While a few alternative chemistry/technology options are emerging and the race for innovations in battery storage systems remains in high flux with potential for disruptive breakthroughs in performance levels (Fig. 1). However, thus far Lithium technology batteries (both Lithium Ion and Lithium metal chemistries) are leading the pack, with the highest share (73%) of installed and an even higher (85%) share of 'contracted in progress' capacities.

The lead of Lithium ion battery storage has been aided by dramatic cost reductions, nearly 85% over 2010–2019 and large shaping investment bets in manufacturing capacity of 9 GW (17 GWh) (Gupta, 2019) by a select few Chinese, Korean, Japanese and USA players. Further as the costs of battery storage technologies continues to fall further (IRENA, 2017), the range of economically viable applications for BESS will only increase. Improvements in advanced chemistry BESS performance and reliability is further driving BESS adoption.

Decreasing capital costs of Li-Ion BESS (Fig. 2) and its negligibly low operating costs have been major drivers in making it an attractive prospect for energy storage. Apart from their cost decline, the ability of Li-Ion technologies to provide high power or energy services in limited space and weight settings is one of the principal reasons behind their wide implementation in portable applications and their use in the electro mobility market. Li-ion technologies can also provide services at higher efficiencies than other battery technologies. This is supported by the data point that the current share of electrochemical technology in contracted or under construction projects is 46.5% and that of pumped hydro is 33.6% (Table 1).

The economics of providing grid services for electricity and stationary energy storage is more challenging today for batteries than other mechanical systems for electricity. Relatively high costs and often low-cost alternative flexibility options like PHS, Diesel fuel-based systems mean that current economics are very market-specific. Massive imports that accompany rapid growth are to be balanced with exports as an urgent focus area (Manthri et al., *2015*).

Several countries have attractive economics for battery energy storage in 'behind the meter' applications. The residential and small-commercial battery storage market have achieved meaningful scale, in Germany, Italy and Australia reaching its breakeven threshold with financial incentives provided by the governments to encourage battery storage (Rubel et al., 2017).

When we look at the advanced energy storage markets like US, China and Japan (Table 2), the adoption of battery systems is being actively driven by policy and regulatory landscape. According to data from China Energy Storage Alliance (CNESA, 2017), between 2016 and June 2017, over 1.35 GW of electrochemical energy storage projects were completed or under construction in China.

In some cases, it is observed that the battery demand can increase even before the breakeven point owing to consumer's desire to avoid power price increases, to disconnect from the grid power, or to adopt green-energy alternatives and smart-home technologies.

Thus the focus of this report is to provide a roadmap for adoption of battery technologies in India. We examine how India can develop competitive advantage and help businesses gain scale to achieve the breakeven threshold through fiscal incentives. For that we begin our assessment with the study of prevailing energy storage market in India.

2. Literature review

2.1. Energy storage landscape in India

The India landscape for ESS shows a much smaller 2.6 GW installed capacity of PHS, and while Central Electricity Authority (CEA) estimates (2018) a significant potential for 96 GW but this does not appear to be a policy focus area, due to implementation constraints and potentially adverse environmental effects of green-field projects for this. However, exploring alternate gravity storage (Husseini, 2019) technologies and evaluating the feasibility of environmentally benign brown field retro-fits for PHS and/or micro level schemes are areas worth further investigation as they offer fundamentally lower costs than most leading BESS technologies.

India's Energy Storage policy push currently is focusing on boosting demand for BESS and encouraging localized manufacturing of advanced chemistry battery manufacturing, as India is well behind in the Lithium/and other advanced chemistries battery race. Policies for boosting Electric Vehicles and Battery Storage have been announced and revised, example Faster Adoption and Manufacturing of Hybrid and Electric Vehicle (FAME I and II) targeting 30% EV penetration by 2030 (Table 3 summarizes several related initiatives).

India Energy Storage Alliance (IESA) estimates the total BESS Potential in India for the period 2019–2022 as 178 GWh and by 2032 a total potential of 2706 GWh (ISGF, 2019). Which implies significant growth in storage capacity, relative to the above-mentioned existing total capacity of PHS and BESS – both in India and globally. However, the analyses in this IESA report also imply that most applications are not yet economically viable, but are projected to be viable over the next 3–5

Table 1
Global Energy Storage Mix (in MW), data from DOE Global Energy Storage.

Technology Type	State of Project					
	Sum of rated power type			% Basis		
	Operational	Contracted or Under Construction	Announced	Operational	Contracted or Under Construction	Announced
Electrochemical	2220	1349	705	1.3%	46.5%	5.0%
Electro-mechanical	1338	75	620	0.8%	2.6%	4.4%
Hydrogen Storage	18	4	–	0.0%	0.1%	0.0%
Liquid Air Energy Storage	0	5	–	0.0%	0.2%	0.0%
Pumped Hydro Storage	170,479	974	12,335	96.4%	33.6%	88.3%
Thermal Storage	2855	495	306	1.6%	17.1%	2.2%
Grand Total	176,910	2902	13,966	100.0%	100.0%	100.0%

[2] 'Advanced chemistry' refers to the next generation of advanced energy storage technologies that can store electric energy either as chemical or as electrochemical energy and convert it back to electric energy as and when required (Energy.gov, 2014).

[3] The figures are rounded off.

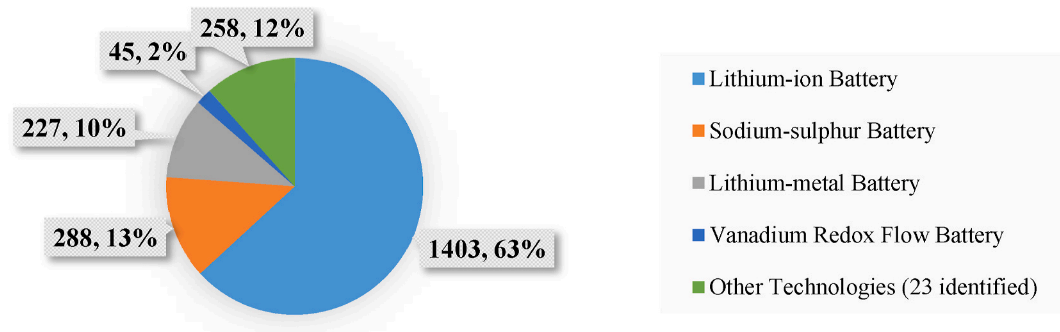

Fig. 1. Share of top 5 'advanced chemistry' battery technologies[3] in installed electrochemical storage capacity (sum rated Power in MW, % share), data from DOE Global Energy Database.
Note: Lithium Ion Battery Chemistries include Lithium Cobalt Oxide (LCO), Lithium Manganese Oxide (LMO), Lithium Nickel Manganese Cobalt Oxide (NMC), Lithium Nickel Cobalt Aluminum Oxide (NCA); Li-Metal Battery Chemistries include Lithium Iron Phosphate (LFP), Lithium Titanate (LTO).

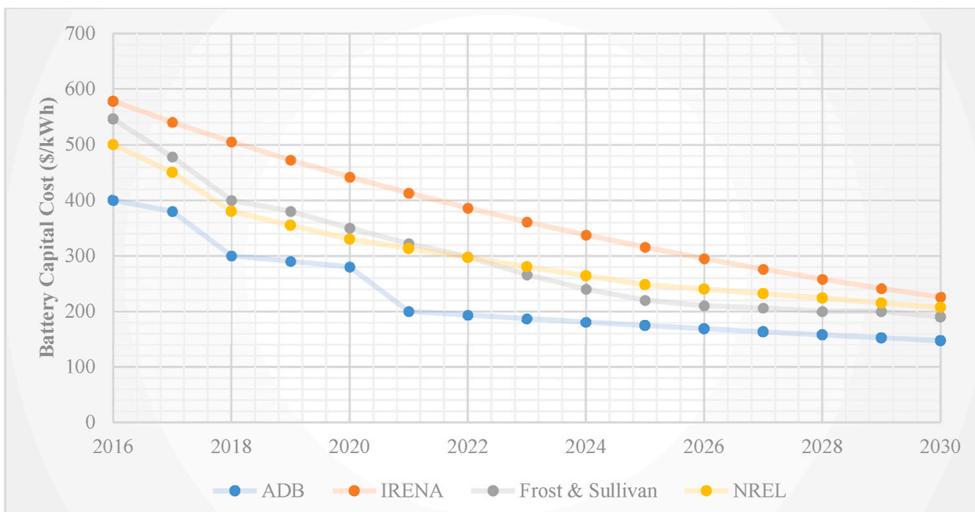

Fig. 2. Expected Drop in Li-Ion BESS prices over the next few years ($/kWh), data from (ADB, 2018; Frost and Sullivan, 2019; IRENA, 2017; Wesley and Frazier, 2019)
Note: Price decline shown for NCM and LPA battery chemistry, as they are widely used with high market share due to extensive commercialization when compared to other battery chemistries.

Table 2
Market Share of Installed Capacity of Electrochemical Storage, country-wise (as of 30th September 2018), data from DOE Global Energy Database.

Country	Sum of rated power (in MW)	% Basis
United States	764	34.4%
Germany	320	14.4%
Japan	244	11.0%
Australia	229	10.3%
South Korea	188	8.5%
United Arab Emirates	109	4.9%
United Kingdom	70	3.2%
Italy	56	2.5%
China	53	2.4%
Canada	37	1.7%
Chile	32	1.4%
Kazakhstan	25	1.1%
Netherlands	21	0.9%
India	0	0.0%
Others	71	3.2%

years as BESS capital costs continue to reduce further per popular forecasts. While EV and other BESS demand is indeed growing, but thus far is far slower than most projections.

2.2. Stationary energy storage applications

Per FAME policy, the total energy storage market by 2022 in India is expected to go up to 70 GW (Walawalkar, 2017). Per IESA's estimates, power backup is major application of energy storage (Fig. 3). Diesel generator sets, are majorly used for provision of power backup in India and across the world.

It is important to understand the current Diesel generator market, to estimate how BESS can become a greener alternative to provide the power backup solution.

2.3. Diesel generators leading market for power backup solutions

Diesel generator sets (DG sets) are the most preferred power backup solution and accounted for more than 80% of the global generators market. Even in Indian market 85–90% of DG market is for power backup, while less than 15% is for prime power (Sharma and Shah, 2017). The Indian DG market assumes great importance as preferred power back-up in prominent sectors like agriculture, construction, industry, households, and other commercial applications as they are easy to install and operate, require low space and available easily in the market.

The Indian DG market currently is at an estimated value of $1 billion

Table 3
Summary of India's energy storage policies and initiatives.

Energy Storage Policies & Initiatives	Details
India's INDC targets (INDC, UNFCCC, 2015)	• Lower the emissions intensity of GDP by 33%–35% by 2030 below 2005 levels • To increase the share of non-fossil based power generation capacity to 40% of installed electric power capacity by 2030 (equivalent to 26–30% of generation in 2030) • To create an additional (cumulative) carbon sink of 2.5–3 $GtCO_2e$ through additional forest and tree cover by 2030
National Energy Storage Mission (NITI Aayog and RMI, 2017)	• Three-staged 'Make-in-India' approach to strive for leadership in energy storage sector by: o creating an environment for battery manufacturing growth; o scaling supply chain strategies; o scaling of battery cell manufacturing
National Electric Mobility Mission Plan, 2020 (NEMMP, 2020)	• encourage faster adoption of electric vehicle (hybrid and electric vehicles) • Helping India to emerge as leader in EV (Two-wheeler and Four-Wheeler) market in the world by 2020, with total 6–7 million sales
FAME India Scheme (PIB, 2019)	• Phase I and II of FAME Scheme to encourage EVs fitted with Li-Ion battery and other new advanced technologies • Achieve 30% EV penetration by 2030 • Outlay of Rs.10,000 crore from 2019–22 to support 10 Lakhs e−2W, 5 Lakhs e−3W, 55000 4Ws and 7000 Buses
National Smart Grid Mission (NSGM, 2015)	• Quality Power on Demand for All by 2027
National Mission for Energy Access (PIB, 2017)	• Providing 24 × 7 energy access to every citizen
National Solar and Wind Mission (Jethani, 2016)	• MNRE has set target of 100 GW Solar and 60 GW wind deployment by 2022 • Include over 20 Ultra Mega Solar parks of 1 GW + capacity
Taxation Benefits	• GST lowered from 12% to 5% for EV (PIB, 2019) • Additional income tax deduction of INR 150,000 (US$2185) on the interest paid on loans taken to purchase EVs (Union Budget of India, 2019–20)
Other Initiatives	• Reducing crude oil imports by 10% by 2022 (Saraswat and Bansal, 2016) • National Policy on Biofuels (MNRE, 2018)

in 2018, and volume of DG sales is around 1.3 Lakh, which is approximately 4 GW of installed potential. The DG market is projected to grow at CAGR 6.5% to reach $1.5 billion by 2024 (GlobalData, 2018). This shows a growing demand for power backup, and greater energy storage capacity requirements in future.

On the basis of power rating, 5–75 kVA holds the largest share with 56% of the Indian diesel generator set market in 2018 (Fig. 4). The high share can be attributed to wide application, among different segments like telecom, commercial complex, hospitality, small restaurants. Demand from Telecom industry drives the DG market for low range power rating (Fig. 5), and low capex investment in Telecom in 2015–16 led to fall in DG demand, which has reverted in recent years.

The next highest share in DG sales, is in the power range of 75–375 kVA (Fig. 6), with nearly 35% of the market share in 2018. The ease of availability and low cost of DG sets makes it prominent among sectors such as in real estate, small industries, healthcare, hospitality and infrastructure.

The higher range of 375–750 kVA and >750 kVA range have limited demand. These products are offered at premium price for critical power back for example, in data centers, large industries, roads, metros rail and other such niche applications.

In the recent years, the drivers of economics of DG market are faulting. The increasing fuel costs is increasing the cost of operations of the DG sets for the end consumer. This will further add to the current account deficit which is already impacted with the crude oil imports to fuel the DG sets. On the production front, there is a sharp rise pig iron prices over the recent years, pig Iron Wholesale Price index in Feb 2017 is 135.5, increase of 10% in Q2 -2017 (EAI, 2017), which constitute 50% of raw material cost of DG which is affecting the price points of the DG sets across different nodes (kVA ranges).

Apart from the economic constraints, there are also negative environmental impacts of DG sets. Under new proposed Bharat Stage VI (BS-VI) emission standards to be rolled out in 2020, DG sets are expected to comply with the smoke limit and other criteria laid out for particulate matter (PM) and gaseous emissions (ICCT, 2016). Amidst increasing levels of urban air pollution (e.g. in many cities in the norther India), the authorities have banned the use of diesel generator, and users are being forced to explore alternative sources of power.

In this scenario we evaluate the economic viability in India context of BESS technology, as an alternative source for power backup. Assuming the battery costs follow the price decline trajectory, and the widespread adoption of technology at the commercial level will start to get more push as we go closer the intersection with rising prices of conventional sources such as coal and diesel.

3. Methodology

3.1. Scenario for replacement of DG sets with Li-Ion BESS in telecom sector

Currently 461,000 telecom towers are operational, mounted with around 18 Lakh base tower stations (BTSs), as of July 2019 and are consuming over 12 billion kWh annually (Economics Research Unit, 2019). National Telecom Policy (TRAI, 2019) mentions that India needs 100,000 additional telecom towers to cater to the rising data demand in next five years (Fig. 7), which will create an additional demand of nearly 3 billion kWh by 2023.

The Telecom industry is major consumer of DG sets for power backup, and this segment alone constitutes one-third of the sales of the diesel generator sets (44,600 units sold in FY 2017). We do the economic assessment of a scenario of replacement of a DG set with a Li-Ion BESS system.

3.1.1. Storage modeling

Under prevailing conditions, on average, 70% of the mobile towers in India face average electrical grid outages in range of 8 h a day (Fig. 9). To provide a power backup of 8 h of power, a 10 kVA rated DG Set with a landed cost of Rs.2,00,000 can be used, with a fuel consumption of 3 L per hour.

Sizing & calculations for Li-Ion BESS Capacity –

$$\boldsymbol{Storage\ Capacity\ of\ BESS}\ (in\ KWh) = \left(\frac{1}{Round-trip\ Efficiency}\right)x\left(\frac{1}{Depth\ of\ Discharge}\right)x\left(\frac{1}{Parasitic\ Losses}\right)x(Average\ Power\ Demand)x(\#hours)$$

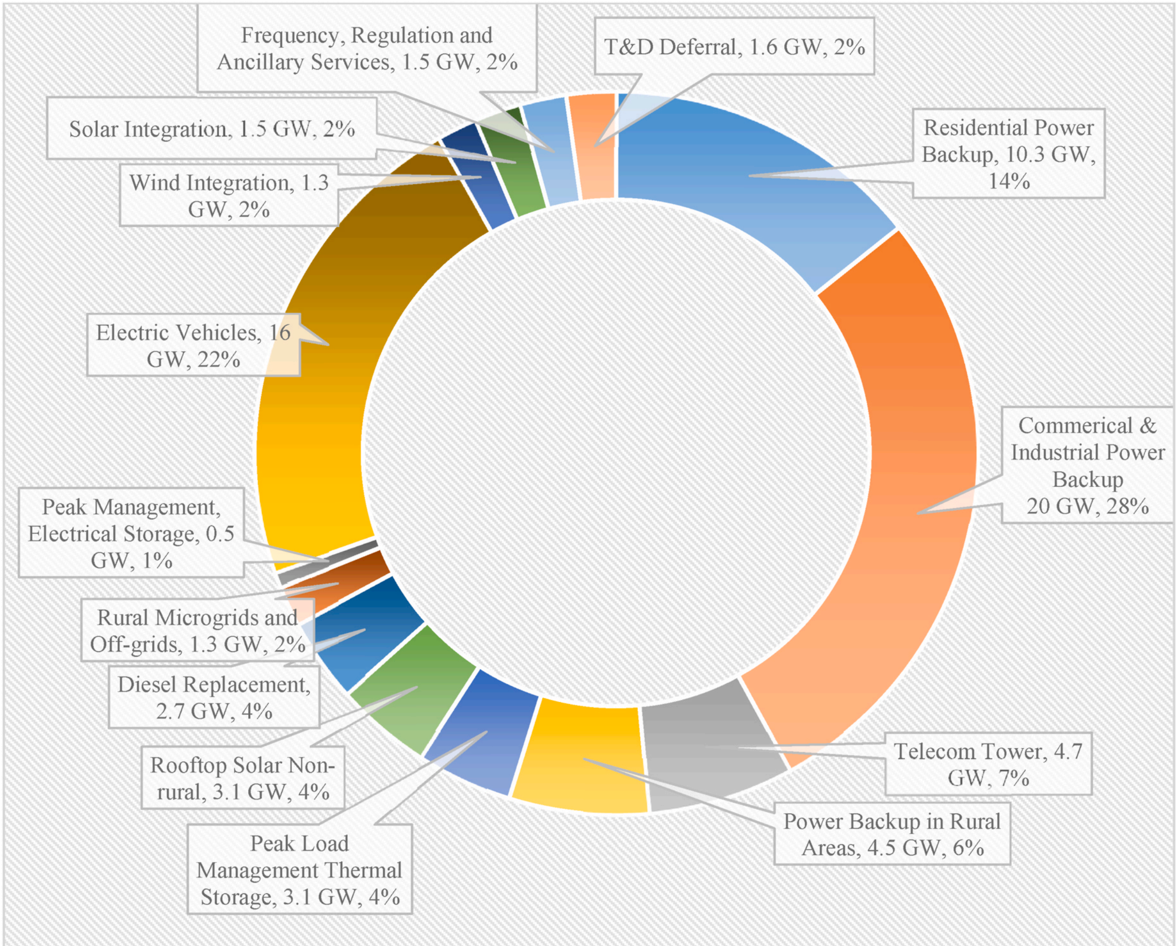

Fig. 3. Energy Storage Potential by Segments by 2022, data from IESA.

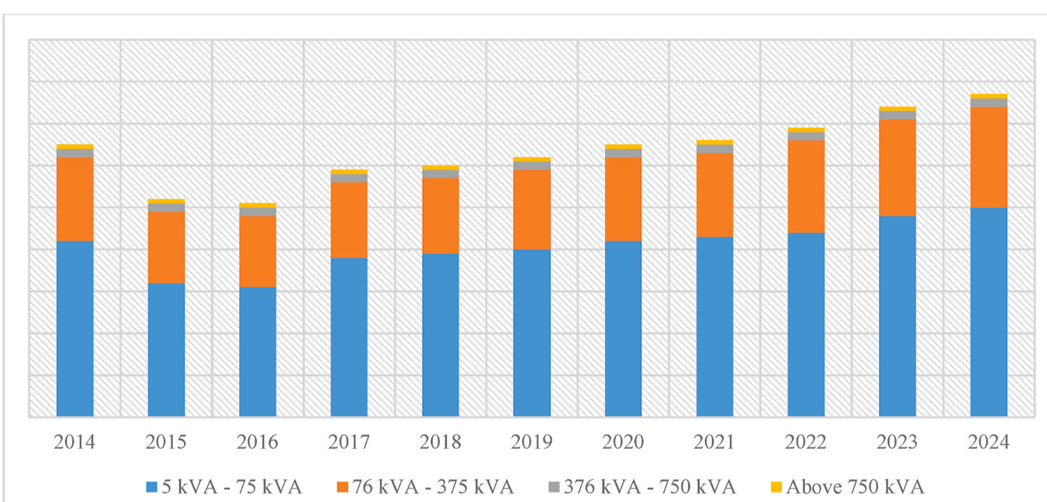

Fig. 4. Share of Indian Diesel Genset Market, by Power Rating, Units (2014–2024), data from (P&S Intelligence, 2018).

$$\textit{\textbf{Storage Capacity of BESS}}\ (in\ KWh) = \left(\frac{1}{0.90}\right)x\left(\frac{1}{0.80}\right)x\left(\frac{1}{0.99}\right)x(10\ kVA\ x\ 0.8)x(8\ hours) = \ 90\ kWh$$

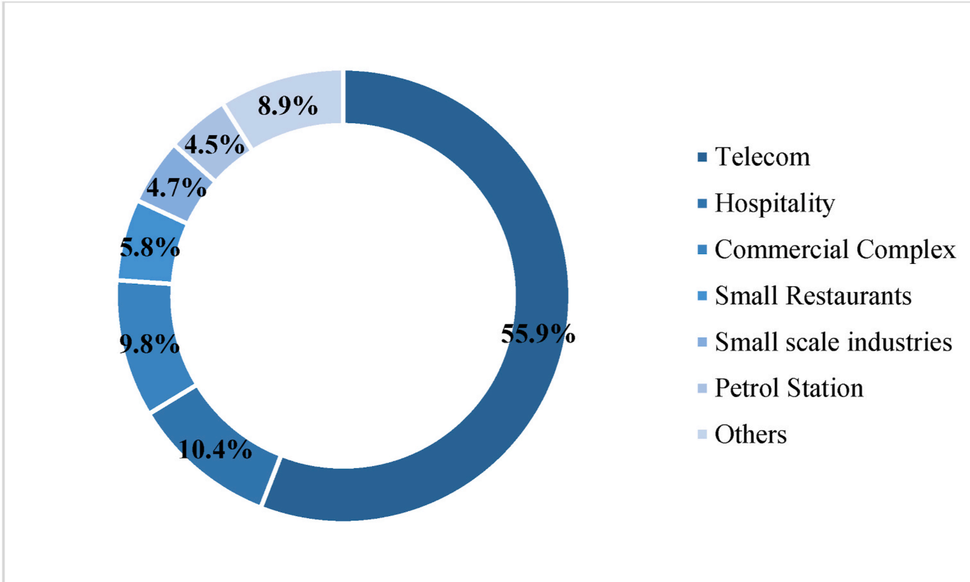

Fig. 5. Key end market segments for 15-75kVA DG sets and their share in DG sales, by Power Rating, data sourced from (Sharma and Shah, 2017).

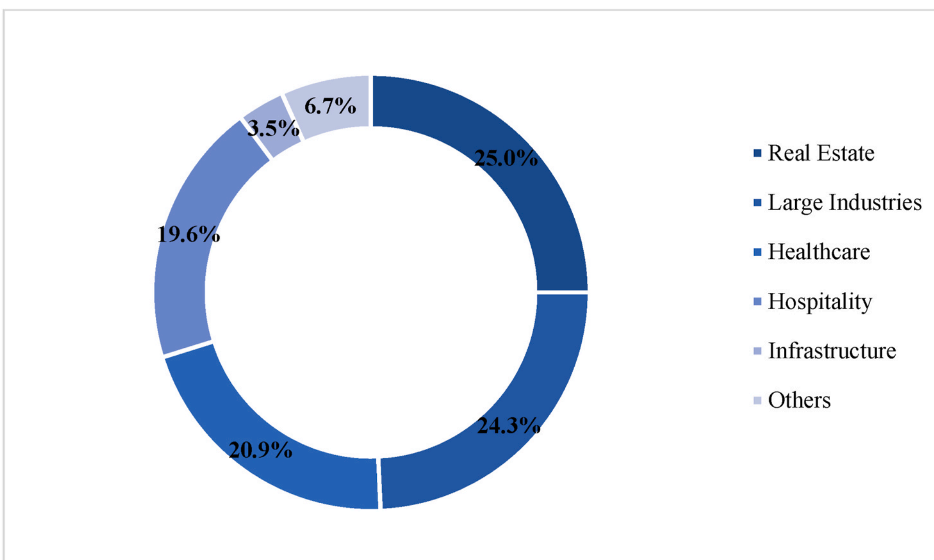

Fig. 6. Key end market segments for 75 - 375kVA DG sets and their share in DG sales (as %), by Power Rating, data sourced from (Sharma and Shah, 2017).

3.1.2. Model analysis

Note: 8 h power backup scenario used for modelling; Average Power Backup assumption of 3–14 h; Assuming Diesel Genset of rating 10kVA provides for the power backup and the Landed Cost of 10kVA DG set is INR.2 Lakh.

The Site requires 8 h or 64 kWh/day equivalent of back-up power. To meet the back-up power requirement, 90 kWh capacity of Li-Ion BESS is required for the installation. At current price levels of Li-Ion BESS at $350/kWh, the additional Capital Expenditure (CAPEX) of installation of BESS per unit is INR 28,791/kWh ($443/kWh). Additional CAPEX of BESS is in range of INR 5.7 Lakh – 33.7 Lakh ($8708 to $51,917) to provide power backup for 3–14 h, and an additional CAPEX of INR 18.4 Lakh ($28,348) to provide power backup for 8 h with Li-Ion BESS (See Fig. 8).

The annual Operational Expense (OPEX) savings for a DG replacement scenario is in the range of INR 2–7 Lakh ($2775 to $10,696) (assuming power backup for 3–14 h). For the 8 h power backup scenario, the annual OPEX savings over DG set by shifting to Li-ion BESS is INR 4.1 Lakh (or $6376) annually (See Fig. 8), which translates into per unit savings of INR 6451/kWh (or $99/kWh).

The payback periods is in the range of 3–5 years, and is 4.5 years (for 8 h backup). The project has an Internal Rate of Return (IRR) of 18% which make the replacement of DG set with BESS economically viable at current price levels of Li-Ion Battery technologies. Assuming that for such a BESS installation project, an IRR of greater than 15% is sufficiently above the cost of capital to be attractive to a storage facility developer/owner (Table 4).

In a retrofitting scenario, where BESS is installed in addition to the existing DG set incurs an additional capital cost of INR 2 lakhs but still proves to be economically viable for the Telecom sector, with a project IRR of 15% and a payback period of 5 years.

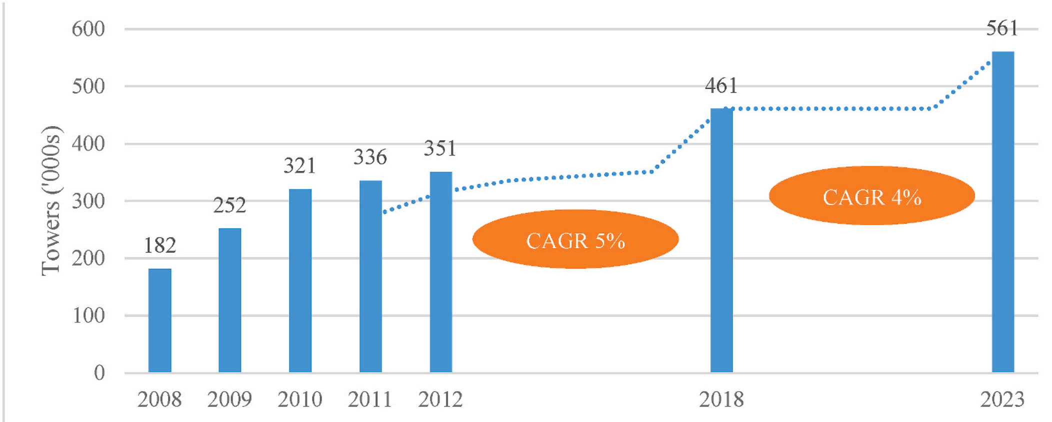

Fig. 7. Estimates of growing Telecom Tower demand in next three years, data from (Economics Research Unit, 2019).

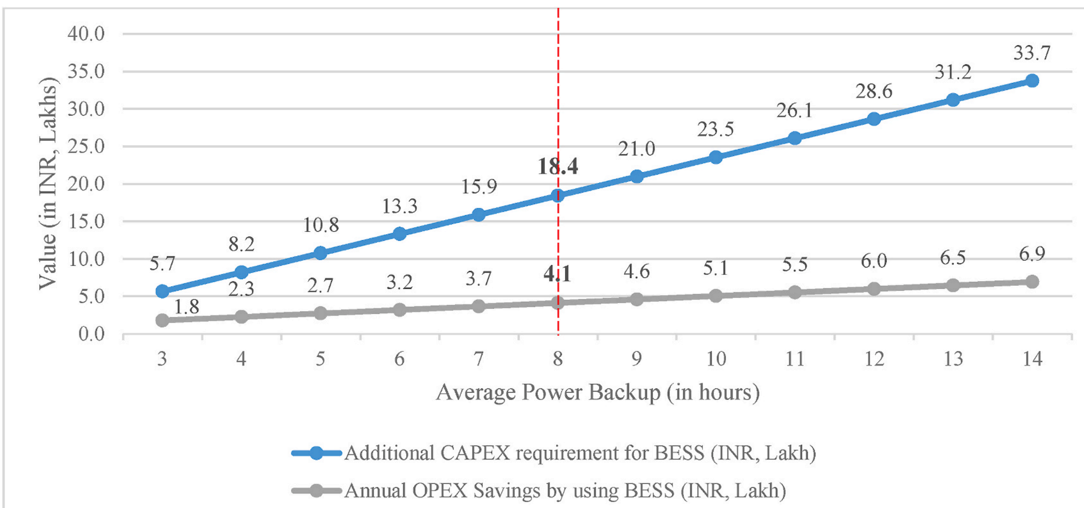

Fig. 8. Sensitivity Chart of Additional CAPEX requirement to replace DG sets with BESS, and Annual OPEX savings for the given scenario.

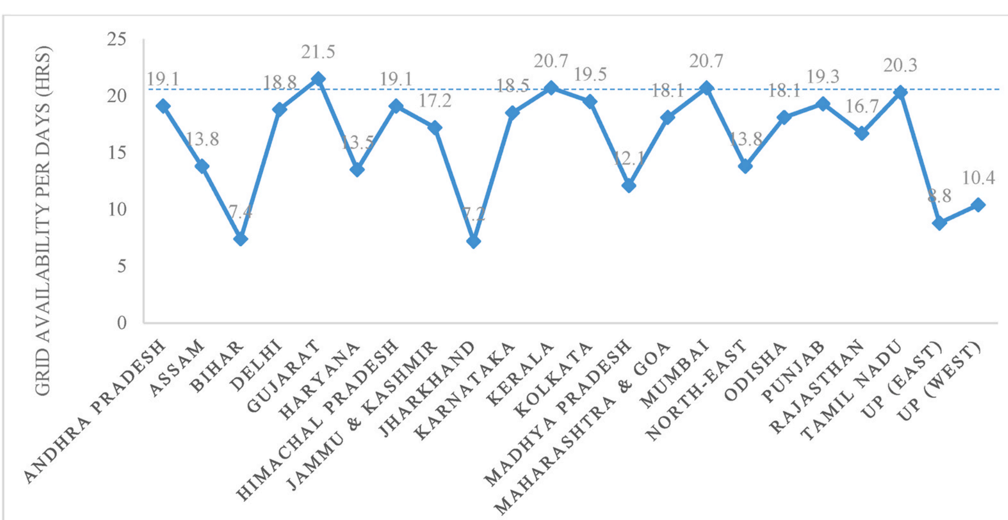

Fig. 9. Average Per Day Grid Availability by Region in India, 2018), data from (CEA, Ministry of Power).

Table 4
Calculations Table for 8 h' power backup, and replacement scenario of DG sets with BESS.

Example Calculations Table (for 8 h Power backup scenario)		
Financial Metrics	Units	Value
Average Power Backup	*hours*	8
Initial Additional CAPEX	*INR, Lakhs*	18.4
Annual OPEX Savings	*INR, Lakhs*	4.1
IRR (over 10 years)	*%*	18%
Payback Period	*years*	4.5
NPV (over 10 years, assuming rate of return as 10%)	*INR, Lakhs*	6.3

3.1.3. Implications

The cost of setting up a Telecom tower is around INR 30–40 Lakh (Moneycontrol, 2012), and additional CAPEX of INR 18.4 Lakh ($28, 348) for a 8 h power backup. This will increase the capital costs by 35–50% for the already stressed Telecom segment and may seem like an unattractive proposition at the offset. However, this scenario needs to be assessed from the perspective of cost of operations.

Currently 60% of operations of the Telecom towers are energy costs, accounting for fuel and power. The diesel fuel cost is nearly 40% of the total operations (GSMA, 2013). This provides for an OPEX savings of 25% from the shift to BESS, per tower (as per above calculations). It is expected that deregulation of diesel prices, if continued with current regulatory fees, tax structure and marketing margin, would result in an increase in diesel price further in upcoming days (GSMA, 2013). In other words, energy costs could constitute more than 90% of the cost of operating telecom towers, everything else being constant.

For the remote regions of India, operational costs are further aggravated due to transportation difficulties additional to the fact of rising diesel costs, which have already risen 100% since 2015 (PPAC, 2020). The growing power backup requirement have also lead to concerns over rising greenhouse emissions which causes a need to focus on better power management methods. With TRAI guidelines (2019) of 40% reductions of carbon emissions by 2022–23, it is an imperative for the telecom infrastructure companies to evaluate alternative options such as battery technologies so as to curb the power reliability issues and reduce carbon footprint.

3.2. Scenario for replacement of DG sets for residential and commercial & industrial (C&I) segments

At consumer end, the commercial and industrial segments include the retail, hotels, commercial complexes, healthcare, shops, hospitals, while the residential segment includes homes and small offices. Although, the battery storage system market in residential and C&I segment has been performing well in markets like the US and Germany, there is a need to push the development of these markets in India, as these segments currently use a backup system which is primarily powered by diesel.

3.2.1. Storage modeling

For Residential and C&I segment we do the assessment of DG replacement across two power ranges, providing a median power backup for 6 h:

- 15–75 kVA
- 75–375 kVA

The 15–75 kVA range can be further divided based on several key nodes for power requirement. The 15–45 kVA segment finds application in almost all end-user segments due to the need for basic lighting and electricity requirements in cases of grid power failures, with the key nodes in 15–45 kVA range are 15kVA, 25 kVA, and 30kVA. The 45–75 kVA segment primarily finds prominence in applications with higher load requirements apart from the basic lighting and power needs, and include key end-user segments such as infrastructure, hospitality (hotels and inns), government institutions, and nursing homes which prefer higher kVA nodes like 62.5 kVA, 75 kVA.

In the range of 75–375 kVA, real estate, healthcare, and hospitality industries are the key end-user segments. In the range, the prominent generator set nodes across the various end-user segments are 82.5, 100 kVA (real estate and healthcare), 125, 250 kVA (hospitality and industrial), and 320 kVA (large hotels and hospitals).

3.2.2. Model analysis

BESS installation in 15–45 kVA range is economically viable, for the end-user segments such as housing complexes, small commercial complexes, restaurants. The IRR of the DG replacement scenario for the 45 kVA range is 7% (for median power backup of 6 h), and is in the range of 9%–5% (to provide backup of 3–14 h). For the above case, the payback periods is in range of 6–8 years, with 7 years median payback for a scenario providing 6 h of power backup (Table 5).

The economics become more favorable, when the number of hours of power backup requirement reduces, which hints at possibility of early adoption in urban areas where there are less power outages. Negative IRR, for applications with power demand in range of 45–75 kVA and 75–375 kVA making the project seem prima facie unattractive at prevailing BESS capex. The current premium levels are in the range of 15–55% for providing backup for 3–14 h, and with approximately 31% premium to be paid for median power backup of 6 h. Note that, this is calculated for the additional annualized costs of depreciation and interest for the higher capex cost of BESS less the operating savings on the base case of grid provided electricity plus diesel operating costs. However, for these segments (unlike Telecom towers) electricity costs are a very small proportion of their total operating cost structure, so we have assumed a range of penetration rates at current economics, assuming this is the market share that eco –sensitive customers willing to pay a price premium can represent.

3.2.3. Implications

At current price levels of Li-Ion BESS, the replacement of DG sets with 'advanced chemistry' batteries is at the cusp of economic viability

Table 5
Cost economics of BESS replacement across different applications, based on different power nodes (kVA ranges).

RANGE	APPLICATION	ADDITIONAL CAPEX, INR PER KWH ($/kWh)	OPEX SAVINGS, INR PER KWH ($/kWh)	PAYBACK PERIOD (years)	IRR	PREMIUM PAID
15-45 kVA	Housing complexes, small commercial complexes, restaurants	30,527	4279	7.1	7%	12%
45-75 kVA	Infrastructure, hospitality (hotels and inns), government institutions, and nursing homes	30,666	2134	14.4	6%	31%
75-375 kVA	Real Estate, Healthcare, Hospitality	30,805	2150	14.3	6%	31%

Note: The numbers depicted refer to the higher power demand requirement in the range specified, E.g. In 15–45 kVA range, calculations are done assuming power demand of 45 kVA, and a power backup requirement of 6 h daily; Other Assumptions – Average Diesel Fuel Price taken as Rs.70 per Liter; Transport charges of fuel to the destination is assumed as Rs.2 per Liter; Electricity tariff taken as Rs.6 per unit.

… but rather than merely deferring this for another three years, we should also consider other non-subsidy levers to accelerate achieving economic viability and faster adoption, for example:

- The rate of return is highly sensitive to BESS prices, a 25% reduction in Li-Ion BESS prices makes the economics viable for entire range of 15-375kVA. These price levels of $250–265/kWh Li-Ion BESS prices are predicted to be reached in the next three years (Wesley and Frazier, 2019), but we should also explore opportunities to reach this faster through greater reductions in non-battery BESS components through frugal engineering and modular design etc.
- The rate of return is also sensitive to fuel prices, with 10% increase in diesel prices (from current price levels of Rs.70 per liter/$1.1 per liter) the scenario becomes economically viable …
- … although segment specific diesel pricing is not practical to implement in the short run, one policy approach to mimic this is to levy an annual DG operating license cost of INR 1250 per kWh pa (or $19.2 per kWh pa), assuming average DG operation of 3–6 h per day – this will help achieve economic viability and boost BESS penetration. Further it is a more consistent policy signal than knee-jerk DG bans during high air pollution months (Wesley and Frazier, 2019);
- With boost to renewable capacity generation the solar tariffs are expected to drop to INR.2.3 per unit (i.e, 4 cents per unit) by 2030, according to The Energy and Resources Institute (TERI) study (2017). The economics of BESS is sensitive to the electricity tariffs, and a reduction of 33% from the tariff levels of Rs.6 per unit to Rs.4 per unit (9 cents to 6 cents per unit) will lead to a positive rate of return
- In several states the electricity tariff for C&I segments is between Rs.8 to 10 per unit (12–15 cents per unit), this further reduces the IRR. Policies like differential tariff pricing for BESS users and an operating license model for DG set makes the economics favorable, and can help encourage faster BESS adoption where these customer segment can achieve economic viability at prevailing BESS prices
- Understanding these sensitivities help in driving policy and business recommendations, and can help reduce the premium paid by environmentally conscious customer to adopt BESS.

3.3. Scenario for solar + battery storage for rooftop solar installations

The adoption of rooftop solar plants has grown to a significant installed base over the past five years. The share of rooftop solar to-date is estimated at around 16% of the cumulative solar installation in India, reaching 5855 MW (MW) by 2019 (Bridge to Telecom Regulatory Authority of India, 2019) of which 74% demand is from the C&I segment due to higher prevailing tariffs, 14% from the Residential sector and the remaining 13% from the public sector. IEEFA (Buckley and Garg, 2019) forecasts that for the next three years, rooftop solar installations could grow at a CAGR of 50% suggesting a cumulative 13 GW of installed capacity by FY 2021–22 (Fig. 10).

Table 6
Summary of Economic Analysis for Solar + BESS vs. DG power backup application.

Applications	Life Expectancy of the SPV + Storage System			Payback Period (years)
	10 years	15 years	20 years	
Scenario 1: Replacement of DG with Solar + Storage	4%	9%	11%	8.1
Scenario 2: Where SPV is already installed, DG set for power backup replaced with BESS	8%	12%	14%	6.7

Note: Calculations based on following assumptions: Average Electricity tariff is INR.8 per unit; Battery Power Backup requirement of 6 h; Cost of SPV is INR.1 Lakh per kWP; Power requirement of 375 kVA; Unit Storage cost of BESS is $350/kWh.

Our analysis (Table 6) suggests that solar plus BESS storage (scenario 1) is at the cusp of economic viability for replacing DG power back-up and the business case would become even stronger in cases of lower power consumption applications. Also combining solar plus storage could add to the reliability vs DG alternatives in locations with more fluctuating durations of grid outages (within a given cumulative outage time range of say 2–6 h) as that would enable better BESS utilization and availability.

Further BESS instead of power backup appears already economically viable for those that have existing roof-top solar installations i.e. the incremental capex is only for BESS storage (refer scenario 2, Table 6). This analysis is for C&I applications at range of 75–375 kVA power demand, and is sensitive to the life span of the system, and the same key levers e.g. differential tariffs, additional annual CESS for DG operation etc. (as detailed in section 3.3 above) would further improve the economics. We therefore estimate a BESS demand potential of nearly 25 GWh by 2023 (assuming 50% penetration of Lithium Ion BESS in 13 GW potential, for a 4-h backup) for power back up applications from installations with rooftop solar.

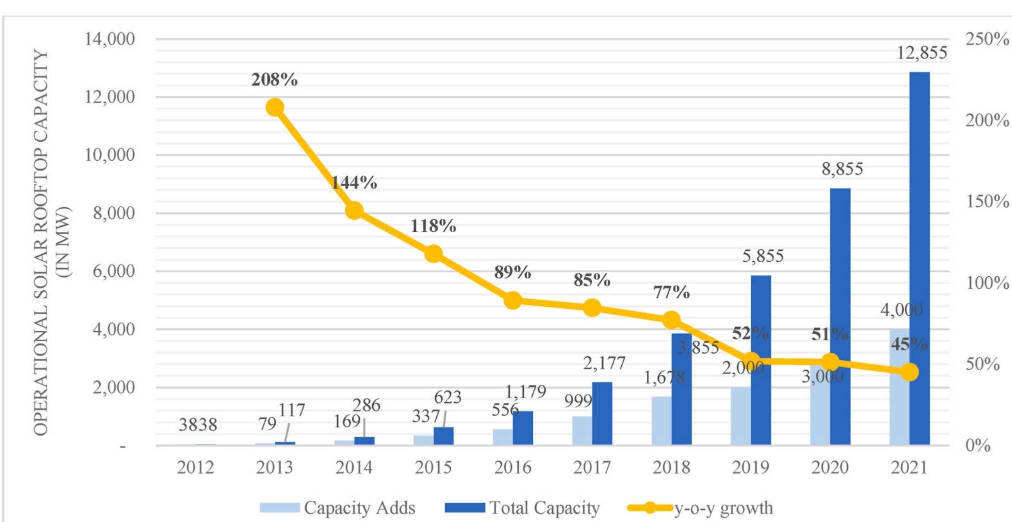

Fig. 10. Solar Rooftop Capacity and Growth Over the Years, data from (Bridge to Telecom Regulatory Authority of India, 2019; Buckley and Garg, IEEFA Estimates, 2019)

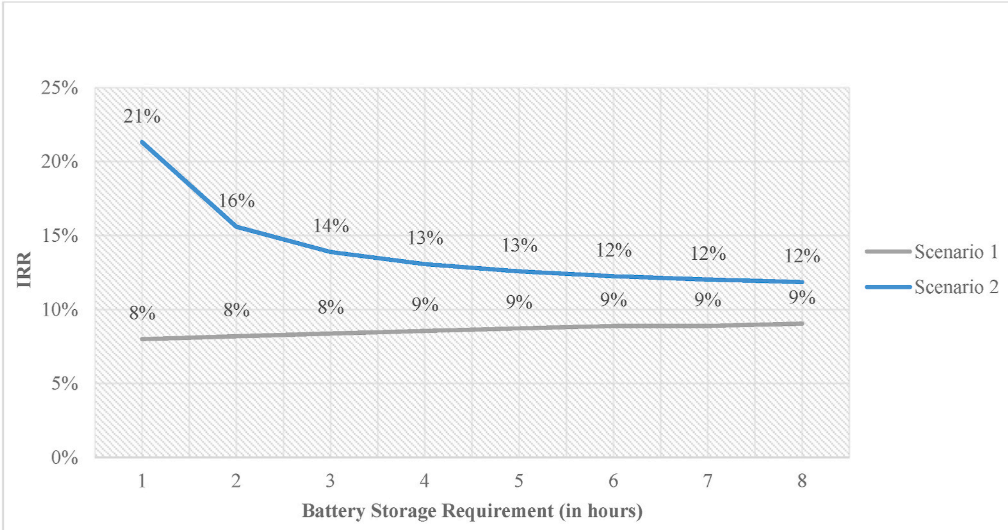

Fig. 11. Sensitivity Analysis for Solar Rooftop installation, hours of battery backup.

3.3.1. Model analysis

BESS + Solar rooftop installation for 15–75 kVA and 75–375 kVA range applications, as a replacement for grid which has DG backup is nearly economically viable. The IRR is 9%, and the payback period is 8.1 years, assuming the life expectancy of the BESS + SPV system is 15 years and a battery storage requirement of 6 h (Fig. 11). Market predictions for life expectancy of BESS and Storage systems is 25 years, and in such cases the economics become more favorable. The sensitivity to the number of hours of battery storage requirement is higher in cases where the SPV is already installed, and further DG set is being replaced with BESS systems (Scenario 2). In such cases the grid charging costs of the batteries is saved in the OPEX.

Further, a few analysts point to the conclusion that solar plus BESS storage is economically viable i.e. that it provides electricity at costs comparable to grid tariffs (Gulia and Jain, JMK Research & Analytics, 2020), this would imply even wider applications beyond DG power backup. Newer technologies and exploratory studies, such as dynamic thermal rating (DTR) systems, can be beneficial in further enabling renewable energy to be utilized and distributed to consumers by alleviating the congestion of power networks (Teh and Lai, 2019; Teh and Metwaly, 2020).

Some of the players who could serve this storage demand potential could include: Amplus Solar, Hero Future Energies, SunSource Energy, Sterilite Power and RAYS Power Infra. They already provide solar solutions in both OPEX and CAPEX model. Currently the division between the OPEX and CAPEX is approximately 40:60 but with additional capex involved in battery storage, these dynamics could change. However, a key chicken – egg problem constraint is the prevailing higher BESS costs due to high levels of customization, and a very interesting issue for detailed investigation is what is the extent of step change reduction possible in BESS capex especially its non-battery components.

3.4. Scenario for Li-ion BESS use instead of conventional UPS for space saving benefits eg data centers, ATMs

The above are examples of an additional sub-set of behind the meter applications where space constraints and/or the cost of real estate justifies the economic viability of Li-ion BESS, despite their prevailing much higher capex, versus conventional uninterruptible power supply (UPS) systems.

Table 7
Market Potential estimates of BESS application in Telecom Sector, over next three years (2020–23).

Application	Estimated BESS demand GWh (assumed adoption %age)		
	High	Medium	Low
Replacement of DG sets older than 10 years (annual demand)	11.2 (50%)	3.4 (15%)	2.2 (10%)
Demand from Additional Telecom towers built over 2020–2023	2.8 (70%)	0.6 (15%)	0.4 (10%)
Telecom sub-total (demand for the next three years 2020–2023)	**14.0**	**4.0**	**2.6**

Note Key Assumptions: Power Rating of DG set for Telecom is 10 kVA, Power Factor = 0.8, Actual Power Demand = Apparent Power (kVA) x Power Factor (Pf) = 8 kW, Average Power backup required for 8 h; Assumed 100,000 Telecom towers to be built in the next three years, per the National Telecom Policy (TRAI, 2019).

4. Estimated benefits of faster adoption of BESS in DG replacement segments

4.1. Market potential of stationary BESS in DG replacement segments

4.1.1. Market potential of BESS in DG replacement for telecom sector

Around 350,000 of the existing 460,000 installed telecom towers in India (assuming DG sets of Telecom Towers in 2012 are up for replacement over the next three years) are potentially up for DG set replacement, as they are nearing the end of their life span which is generally about 10 years for a DG set. Given the strong economic viability of BESS in this application (per section 2.2 above), this replacement of ageing DG sets offers a potential of 2–11 GWh per annum over the next three years of BESS demand assuming adoption levels ranging from 10 to 50% (Appendix-1).

Per TRAI estimates (2019) of an additional 100,000 towers to be constructed by 2023. This will create an additional potential of 0.4–2.8 GWh for energy storage, assuming a penetration levels of 10–70% of BESS. Our estimate for the total market potential for Telecom segment is thus in the range of 3–14 GWh in the next three years (as summarized in table below, Table 7).

4.1.2. Market potential of BESS in Non-Telecom DG replacement applications

We estimated the potential in Residential, Commercial and Industrial

Table 8
Market Potential estimates of BESS application in Non-Telecom Sector application over next three years (2020–23).

Application	Estimated BESS demand GWh (assumed adoption %age)		
	High	Medium	Low
New BESS Demand (annual demand)	11.1 (30%)	3.7 (10%)	1.8 (5%)
Replacement of DG sets older than 10 years (demand for the next three years 2020–2023)	114.4 (30%)	38.1 (10%)	19.1 (5%)
Non-Telecom Sub-Total (demand for the next three years 2020–2023)	**131.1**	**54.8**	**35.7**
TOTAL BESS DEMAND, Telecom + Non-Telecom, in GWh (demand for the next three years 2020–2023)	**145.1**	**58.7**	**38.3**

Key Assumptions: Median Power Rating in 15–75 kVA range of DG set is 35 kW and for 75–375 kVA is 180 kW, Average Power backup required for 6 h.

segments considering multiple scenarios (Appendix 2). The 15–75 kVA segment for the market potential assessment includes the hospitality, small commercial complexes and small restaurants. The 75–375 kVA application ranges across real estate, healthcare, hospitality industries for our assessment.

Scenario-1 (Refer Part-A, Appendix-2 for detailed calculations), estimates the annual demand for battery energy storage, assuming adoption levels of 5–30% among the DG set users as 0.2 to 1.2 GWh in the 15–75 kVA range and 1.6 to 9.9 GWh in the 75–375 kVA range.

Scenario-2 assesses the BESS potential from replacement of DG sets which are nearing their life expectancy, with new Li-Ion BESS for power backup, and it forms a considerable amount of the market potential. We assume penetration levels ranging from 5 to 30% of the DG sets nearing its life span that require replacement, for both the segments over the next three years from 2020 to 2023 (Refer Part-B, Appendix-2).

This adds up to an estimated BESS demand potential range of 40–145 GWh[4] for the next three years (2020–23) in both the Telecom and the Non-Telecom segment (Table 8) – which is comparable to IESA's estimates for the DG segment of 138 GWh for the three-year period of 2019–2022 and more than IESA's estimates for BESS demand in EV segment in the next three years of 40 GWh (ISGF, 2019).

Per our estimates, this could represent a business opportunity of more than $4–16 billion annual revenues and $6–21 billion in market value for 'BESS as a service 'players for the next three years (2020–23) demand potential in stationary DG replacement applications. This is after assuming unit storage price of Li-Ion BESS is $330/kWh (as median price for the period 2020–2023).

Table 9
Energy Storage Potential of EV Segment (in GWh), data from (ISGF, 2019).

ELECTRIC VEHICLES	2019–22	2022–27	2027–32	Total by 2032
E2W	4	55	496	555
E3W	26	69	136	231
E24	8	110	725	843
Electric Bus	2	13	57	72
Total Electric Vehicles (GWh)	**40**	**247**	**1414**	**1701**

4.2. Comparison to the EV segment

The National Electric Mobility Mission (Phase I and II of FAME) and other related policies have articulated a suite of fiscal incentives and favorable regulatory environment, to make a big push for EV adoption in India. In FY 2019 EV sales reached 759,600 units (Fig. 12), dominated by sales of electric three wheelers (630,000), electric two–wheelers (126,000), and electric cars (3,600) with current capacity of 7–14 GWh (NITI Aayog & World Energy Council, 2018) per annum. Calculations based on battery size specifications taken for two scenarios; 1) Battery Size in Scenario-A: 2-eW is 3 kWh, e−3W is 10 kWh, 4 W is 30 kWh; 2) Battery Size in Scenario-B: 2-eW is 7 kWh, e−3W is 20 kWh, 4 W is 60 kWh.

Per FAME II targets for India EV sales penetration are 30% of private cars, 70% of commercial cars, 40% of buses and 80% of two and three-wheelers by 2030. If achieved, this would create an additional BESS demand from the EV segment estimated to be 1701 GWh by 2032 (Table 9). Per IESA estimates, by 2022, the total potential of EVs is 40 GWh, which is largely driven by EV 3-wheelers till 2022, but the demand is projected to transition to electric cars and two wheelers by 2032, and this segment is projected to constitute significant share (27.7%) of the total BESS potential estimated for India by 2022.

The government further announced intentions to spend INR 40,000 crore as benefits and subsidies between 2020 and 2030 to accelerate FAME adoption. However, there are concerns against achieving the desired targets. India's pure EV penetration remains quite low, with ~0.1% in passenger vehicles and ~0.2% in Two-wheelers (SIAM, 2017). NITI Aayog and RMI, predicts the EV sales penetration of 30% for private cars, 70% for commercial cars, 40% for buses, and 80% for 2 and 3

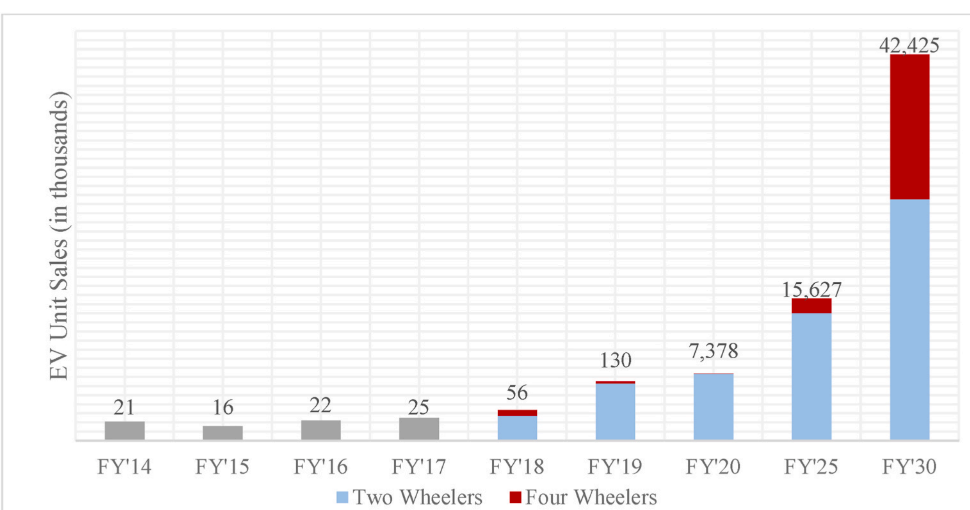

Fig. 12. EV Sales (in past five years) and EV Projections for India (till 2030), data from (NITI Aayog & World Energy Council, 2018)}
Note: Three-wheeler segments not included in the above numbers.

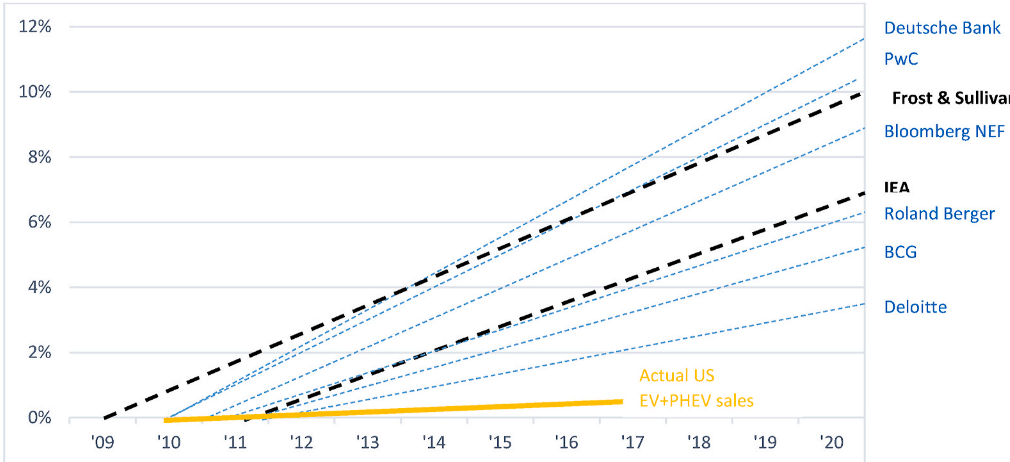

Fig. 13. Prior generation of electric car projections out of sync with reality (EV + PHEVs as % of total car sales), data from (Cembalest, J.P. Morgan Energy Report, 2018)

wheelers by 2030 when the initial target for EV penetration was 100% by 2030 (RMI Report, 2019).

However, case study of the developed markets shows contrary results to the predictions in the EV segment, which witnessed a slow growth when compared to the forecasts. Overly optimistic EV projections were made by some of the same forecasters a decade ago (see Fig. 13 below). In 2018, EV penetration levels at global scale was forecasted to be in between 6 and 8%, while actual is 2.2% (2.1 million EVs units sold).

On similar lines, with revised FAME targets to achieve 30% penetration by 2030, India can anticipate an adoption levels of ~10–15% in a realistic scenario, assuming medium optimistic adoption levels. Due to consideration of external deterrents to EV industry like investment and maintenance of charging infrastructure as well as lack of affordable models to the end consumers.

5. Conclusions and implications

Although the dominant discourse focuses on EVs, our analysis in this paper shows that there is a bigger near term opportunity in India for Stationary BESS to replace diesel gensets for power backup. Interestingly India offers a meaningful level of scale for power-backup applications, for adoption directly by end-users. BESS as an alternative to Diesel Generator (DG) for power backup is economically viable in the Telecom sector and for roof-top solar installations; further non-subsidy levers e.g. differential tariffs and an annual cess on DG use, can drive economic viability in large campuses e.g. residential, schools and commercial buildings. These applications could offer a BESS demand ranging from 40 to 145 GWh over the next three years – which is more than the BESS demand estimates for EV segment of 40 GWh.

These conclusions raise some very interesting public policy and business strategy implications[1]:

- Given the economic viability and significant benefits outlined in sections 2 - 4 above, it is indeed an interesting issue to ponder why adoption up to this potential has not yet taken off, and what will it take to achieve this potential?
- What are the key challenges to higher BESS penetration in the identified ‘low hanging fruits’ applications (refer 3.2, 3.3) and how can they be overcome ?
- How significant is the value capture potential and scale of investments to pursue such an opportunity and what potential business models could be relevant?
- What would be the net impact on India’s Current Account Deficit (CAD) after the offset between higher Lithium ion battery related imports for the BESS versus the corresponding crude oil import savings in reduced diesel genset usage?
- How significant can the impact be of this accelerated adoption on urban pollution (given diesel gensets contribute significantly to urban particulate matter air pollution)?
- How significant can the contribution be of this accelerated adoption towards *India’s CO_2 emission* reduction targets ? What is the scope of deploying new technology options for BESS alongside dynamic thermal rating (Teh and Metwaly, 2020)

CRediT authorship contribution statement

Tejpavan Gandhok: Conceptualization, Investigation, Methodology, Project Initiation & administration, Resources, Supervision, Validation, Visualization, Writing – review & editing. **Pranusha Manthri:** Data curation, Formal analysis, Investigation, Methodology, Software, Visualization, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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9. APPENDICES

APPENDIX -1

Market Potential Assessment for Telecom Towers

Assumptions Specific to Telecom Segment				
Average Power Demand per Tower (kW)				8
No, of towers up for replacement in next three years				350,000
No, of towers to build by 2023				100,000
Average Power Demand for upcoming Telecom towers (kW)				5
Average Power Backup (#hours)				8
Scenario		Low	Mid	High
Telecom Towers (DG Replacement Scenario) [a]	Penetration Level	**10%**	**15%**	**50%**
	# Tower	35,500	52,500	1,75,000
	Potential (in GWh)	**2.2**	**3.4**	**11.2**
Potential from Additional Telecom Towers (2019–2020) [b]	Penetration	**10%**	**15%**	**70%**
	#Towers	10,000	15,000	70,000
	Potential (in GWh)	**0.4**	**0.6**	**2.8**
Total Storage Potential from Telecom (in GWh)		**2.6**	**4.0**	**14.0**

[a] 350,000 towers are up for replacement over the next three years, as the DG sets are nearing their life expectancy of 10–15 years.

[b] Proposed 100,000 Telecom towers in the next five years under National Telecom Policy (TRAI, 2019).

APPEDIX -2

Assessment of Market Potential for Non-Telecom Segment

Assumptions Specific to Residential, C&I Segment	
For 15–75 kVA range	
Diesel Genset Sales Non-Telecom (FY 2019 figures)	19,327
Median Power Consumption (kW)	35
Average Power Backup (#hours)	6
For 75–375 kVA range	
Diesel Genset Sales Non-Telecom (FY 2019)	30,430
Median Power Consumption (kW)	180
Average Power Backup (#hours)	6

Part A: Additional BESS Potential Created every year

TOTAL (Both Segments)		Low	Mid	High
Range (15–75 kVA)	Penetration Rates	5%	10%	30%
	Potential (in GWh)	**0.2**	**0.4**	**1.2**
Range (75–375 kVA)	Penetration Rates	5%	10%	30%
	Potential (in GWh)	**1.6**	**3.3**	**9.9**
Sub-Total of New Annual BESS Demand (in GWh)		**1.8**	**3.7**	**11.1**

[a] Number of DG sets sold in the year 2019 in 15–75 kVA range is 19,327 units (excluding the Telecom segment), and the adoption rates refer to number of DG sets that will be replaced with BESS annually in consecutive years.

[b] Number of DG sets sold in the year 2019 in 75–375 kVA range is 30,430, and the adoption rates refer to number of DG sets that will be replaced with BESS annually in consecutive years.

Part B: Replacement of Old DG sets nearing the end of their lifespan:

DG Unit Sales	2006	2007	2008	2009	2010	2011	2012	Total DG Sets up for Replacement (Units)
15-75 kVA	121,200	127,500	131,950	122,950	130,900	140,500	151,200	926,200 (84%)
75-375 kVA	21,500	22,800	23,500	24,100	25,400	27,000	28,800	173,100 (16%)
Total Segment	142,700	150,300	155,450	147,050	156,300	167,500	180,000	1,099,300

Source: Sharma and Shah (2017); Frost and Sullivan (2010)..

Note: All DG Set Sales from 2006 to 2012 are considered to be up for replacement, due to extended warranty.

Scenario for replacement of Old DG sets				Potential (GWh)		
Penetration Levels [a]	5%	10%	30%	Low	Mid	High
15-75 KVA range	46,310	92,620	2,77,860	9.7	19.5	58.4
75-375 KVA	8655	17,310	51,930	9.3	18.7	56.1
Sub-Total of DG Replacement Scenario	54,965	1,09,930	3,29,790	**19.1**	**38.1**	**114.4**

[a] Adoption rate refers to the % of total DG sets between 2006 and 2012 that will be replaced with BESS; Assumed power backup provided for 6 h for calculation of potential, and median of 35 kW for 15–75 kVA range, median of 180 kW for 75–375 kVA range.

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