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LEVELISED COST OF BEHIND-THE-METER STORAGE IN INDIA

A Status Report

July 2021

AurovilleConsulting

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ACRONYMS

Adv lead-acid	:	Advanced lead-acid
Ah	:	Ampere-hour
APPC	:	Average power purchase cost
BESS	:	Battery energy storage system
BoS	:	Balance of system
BMS	:	Battery Management System
BtM	:	Behind-the-Meter
CUF	:	Capacity utilisation factor
DG	:	Diesel generator
FtM	:	Front-of-the-meter
GST	:	Good and Service Tax
HT	:	High tension
kWh	:	Kilowatt-hour
LCOE	:	Levelised cost of electricity
LCOS	:	Levelised cost of storage
LCOSS	:	Levelised cost of solar plus energy storage
LT	:	Low tension
Li-ion	:	Lithium-ion
MNRE	:	Ministry of New & Renewable Energy
PSH	:	Pumped Storage Hydropower
PSoC	:	Partial State of Charge
TANGEDCO	:	Tamil Nadu Generation and Distribution Corporation Limited
TN	:	Tamil Nadu

EXECUTIVE SUMMARY & KEY FINDINGS

OBJECTIVE AND SCOPE

This status report aims to present a snapshot of the current and projected costs of energy storage in India for behind-the-meter (BtM) applications. The levelised cost of storage is an important financial parameter indicating the feasibility of energy storage systems.

While 12 different core services/applications of stationary energy storage can be identified in the power sector (Schmidt et al. 2019), we focus only on two of these applications: electricity bill management and power backup. Electricity bill management involves the application of solar PV and battery energy storage system (BESS); power backup involves a standalone BESS.

Different applications call for different energy storage technologies based on their respective performance characteristics. For the two BtM applications, electricity bill management and power backup, we consider three technologies: lithium-ion (Li-ion), lead-acid and advanced lead-acid BESS.

CAPITAL COST AND OTHER DATA

Three user cases are considered for the levelised cost analysis: Residential, Small Non-Residential and Large Non-Residential. Table ES.1 lists the assumptions for these user cases.

Table ES.1: User cases and corresponding assumptions.

User Cases	BESS Energy capacity	BESS Power Rating
Small Residential	4 kWh	1–2 kW
Small Non-Residential	48 kWh	12–24 kW
Large Non-residential	96 kWh	24–48 kW

A bottom-up approach is taken to analyse the capital costs of BESS and solar PV. The capital cost of BESS is split between five components: i) cost of battery pack, ii) cost of enclosure and balance of system (BoS), iii) cost of inverter, iv) installation cost and v) taxes. Capital cost data for Li-ion, lead-acid and advanced lead-acid BESS were gathered from several vendors (Table ES.2). Other data on technical, operational and financial parameters were gathered through online research. Lastly to understand how the costs will evolve in future, projections are made to 2030 using a costs reduction curve for each capital cost component.

Table ES.2: Capital cost data for the three user cases and selected technologies.[1]

Capital cost of battery packs (INR/kWh)

User Cases	Technology	Minimum	Maximum	Average
Residential	Li-ion	15,000	24,938	18,310
Small Non-Residential	Li-ion	15,000	24,938	17,856
Large Non-Residential	Li-ion	14,000	24,938	17,689
All	Lead-acid	5,555	6,836	6,071
All	Advanced lead-acid	6,315	14,020	8,359

Capital cost of enclosure and BoS (% of pack)

User Cases	Technology	Minimum	Maximum	Average
All	Li-ion	4%	6%	5%
All	Lead-acid	-	-	-
All	Advanced lead-acid	-	-	-

KEY FINDINGS

Figures ES.1 and ES.2 present the results for levelised cost of solar plus energy storage for Non-Residential user case. In Figure ES.1, each bar represents the range of levelised cost evaluated for the given technology, with the vertical line segment representing the average value.

[1] *No associated capital cost is indicated by '-'.*

[2] *This doesn't preclude addition of a small amount of storage, up to 10-15% at currents energy storage costs, to realise bill savings for high tariff paying consumers (Auroville Consulting 2021a).*

Some key findings from the levelised cost analysis are as follows:

- Power backup with standalone Li-ion and advanced lead-acid BESS is currently very expensive. However, consumers are willing to pay the premium in some States for a reliable power supply. Standalone BESS is expected to become cost competitive compared to diesel generators around the middle of this decade.
- As of today, the levelised cost of solar plus energy storage hasn't reached grid parity in any of the user cases, considering the battery is sized so that at least 30% of solar energy flows through it. Hence, it is not a financially attractive option yet for electricity bill reduction.[2]
- Though energy storage is currently not viable in a lot of cases for BtM application, this is expected to change very fast. Integrating large amounts of BtM battery storage will be possible for non-residential consumers by the middle of this decade, i.e., 2025.
- For residential consumers, energy storage will become feasible towards the end of this decade. For high paying residential consumers, sizing battery to store 30% of the generated solar energy reaches grid parity post 2027.
- With solar plus energy storage becoming an increasingly attractive investment option for the high tariff paying consumer categories, the 'death spiral' threat to utility (where its highest paying consumers move to solar energy) will worsen further as these consumers are expected to increasingly adopt solar plus energy storage to meet their energy demand. The utilities need to transition from their traditional roles to that of distribution system operators (TERI 2020).
- We see that throughout the analysis period up to 2030, advanced lead-acid continues to compete with Li-ion technology and is comparable in cost. Notwithstanding lesser space requirement and weight of Li-ion BESS, both technologies will remain in play in future for BtM application for electricity bill management.

Figure ES.1: Current levelised cost of solar plus energy storage for the Small Non-Residential user case, for different amounts of solar energy flowing through the battery.

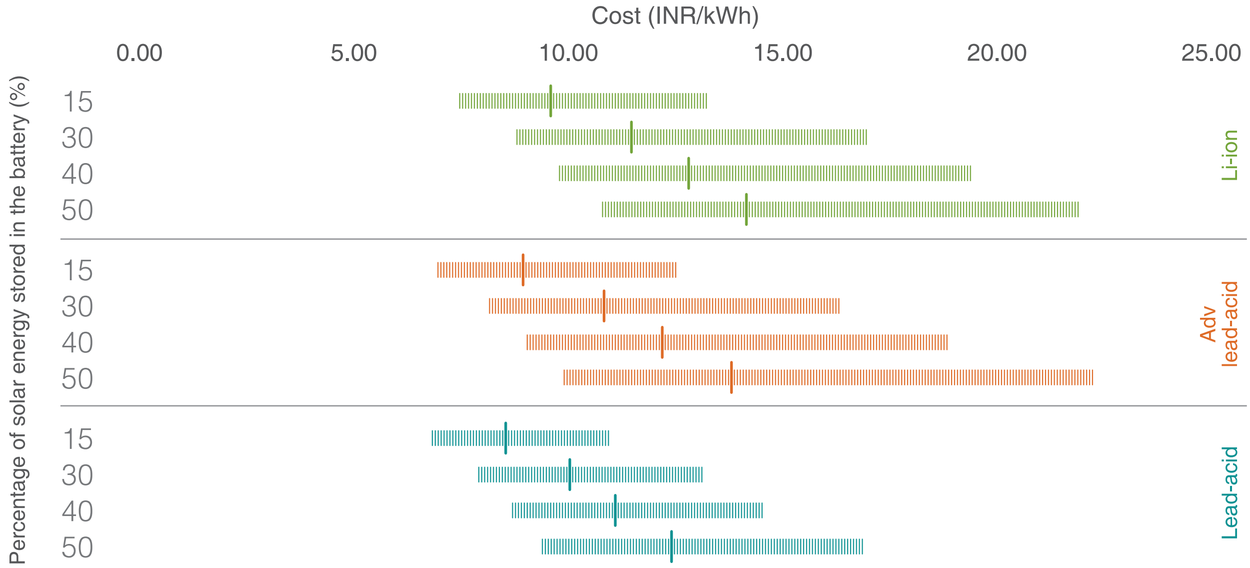
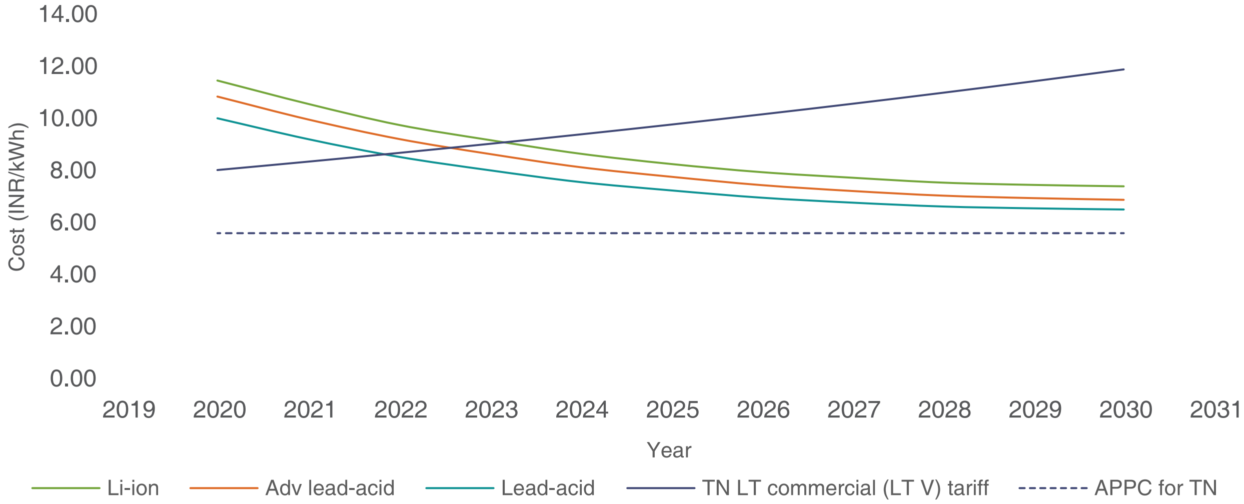


Figure ES.2: Projected decline in the levelised cost of solar plus energy storage for the Small Non-Residential user case, in the case of 30% of solar energy flowing through the battery.



01 INTRODUCTION

Energy storage is a key solution to reach India's targets for renewable energy and to eventually reach a 100% renewable energy-based power system. It provides essential flexibility/balancing services as well as ancillary services as variable renewable energy generation increases in the electricity grid. Its applications can be at the behind-the-meter (BtM) level and font-of-the-meter (FtM) level (see Chapter 3). This analysis focuses only on BtM applications.

BTM APPLICATIONS FOR ENERGY STORAGE IN INDIA

For BtM application of battery energy storage system (BESS) in India, power backup has been a key driver. From 2019 to 2025, it is estimated that power backup will continue to be the main driver and contribute to around 70% of the cumulative battery energy storage demand, around 110 GWh. Primarily lead-acid batteries have been used for this application due to their low cost and reliable operation. However, with the dropping costs, lithium-ion (Li-ion) technology will displace lead-acid in the coming years. Over the same period, 2019-2025, the pairing of BESS with rooftop solar PV is expected to contribute to 3% of the demand (ISGF 2019). In most cases, application of BESS for electricity bill management is still not viable in India, especially for lower electricity tariffs.

A recent evaluation (Auroville Consulting 2021a) of the feasibility of solar plus Li-ion energy storage for HT consumer in Tamil Nadu found the addition of a small battery storage capacity to be viable in the case of different consumers (including industry, commercial consumers). Another recent assessment for Gujarat found that for large industrial consumers, cost of battery storage would have to decrease by 50% of its current value for solar plus energy storage systems to become viable (Zinaman et al. 2020). Based on the recent cost declines in Li-ion battery storage, it is expected that such a cost decline will happen by 2023.[3]

REPORT SCOPE & OBJECTIVES

- Estimate the LCOS for BtM applications of Li-ion, lead-acid and advanced lead-acid batteries in Tamil Nadu for various user cases;
    - Two BtM applications are assessed: electricity bill management (using solar plus energy storage) and power backup (using standalone energy storage).
    - Three user cases are considered: Residential, Small Non-Residential and Large Non-Residential.
- Project the LCOS for the different user cases over the next 10 years through a bottom-up analysis of the capital costs of BESS – to predict when BtM battery storage can start seeing significant adoption.

[3] In addition to the expected cost decline of BESS, the implementation of time-of-day (ToD) tariffs and demand charges for all consumers can drive the BtM application of BESS in coming years.

02 ENERGY STORAGE APPLICATIONS

Energy storage technologies can be of several kinds: mechanical, electrochemical (BESS), thermal, electrical and chemical (IEA 2014, ISGF 2019). Apart from thermal energy storage, which is used for meeting heating and cooling demand, others can be used for electricity.

Pumped storage hydropower (PSH), which is a form of mechanical energy storage, currently forms around 94% of all grid-connected energy storage globally. However, as the long time (several years) required for commissioning of new PSH plants and challenging financial viability limit their applications for grid balancing currently to load following, i.e. storing energy during periods of low demand to meet demand during peak hours (IRADe 2020). Thus, most of the new grid-connected storage capacity coming up around the world is BESS. Within BESS, several chemistries exist, including Li-ion, lead-acid and advanced lead-acid. Of these, Li-ion technology has established itself as the dominant technology and is the only battery technology being deployed on a commercial scale in India for FtM applications (Tata Power 2019). As Li-ion battery prices continue to decline, its application in the electricity grids will increase. For example, according to one evaluation, it is expected that by mid 2020s, cost of Li-ion will drop below that of PSH for load following or providing spinning/non-spinning reserves. On the other hand, for seasonal storage, hydrogen is expected to emerge as the least cost option over the next decade (Schmidt et al. 2019).

There are five broad categories of services that energy storage provides in the power sector:

i) Energy/capacity services: The basic service of providing energy to meet the demand;

ii) Energy arbitrage: Buying of energy at lower wholesale/retail prices, and selling it when prices are higher;

iii) Ancillary services: Services to ensure quality and reliability of the power system;

iv) Electricity bill management: Realisation of savings by consumers in the electricity bill; and

v) Power reliability: Provision of backup power to electricity consumers in the event of a grid outage.

The classification of energy storage services/applications in the literature can be nuanced (EPRI 2020, Everoze 2016, POSOCO 2017, Schmidt et al. 2019, Zinaman et al. 2020). For example, Schmidt et al. (2019) identify 27 unique services, which are further grouped into 12 core services, based on similar technical requirements. Table 1 presents a summary of some of these energy storage applications. The applications are listed along the electricity value chain, starting from system or generation-level, to transmission/distribution level, and lastly to consumer-level (i.e., BtM). (The application level is separate from the interconnection point of the system; e.g., a BtM storage system can also provide system-level services).

Table 1: Application of energy storage along the electricity value chain, from generation or system-level to consumer level.

Not yet possible to monetise   Can be monetised

	Service Type	Application / Revenue Stream	Naming Convention in India	Medium for Implementation	Current Status in India
Front of the Meter	Energy arbitrage	Wholesale energy arbitrage	-	Electricity market	
	Energy / capacity	RE integration - renewable capacity firming	-	Bidding	
	Ancillary services / Operating reserves	Frequency regulation / frequency control	Secondary frequency control / Automatic Generation Control / Load frequency control	Regulatory mechanism for compensation	
		Load following / balancing reserves	-	Energy scheduling	
		Primary contingency reserve / frequency response	Fast frequency response / Primary frequency control / Primary frequency response	Mandated by regulations	
		Secondary contingency reserve / spinning or non-spinning reserves	Fast response ancillary services (FRAS) / reserve regulation ancillary services	Regulatory mechanism for compensation	
		Voltage support / reactive power support	-	Regulatory mechanism for compensation	
	Transmission services	Transmission congestion management	-	Lower transmission charges	
	Distribution services	Distribution upgrade deferral	-	Utility savings	
Behind the Meter	Electricity bill management	ToU management	-	Electricity bill	
	Electricity bill management	Renewable energy self consumption	-	Electricity bill	
	Electricity bill management	Demand charge reduction	-	Electricity bill	
	Power reliability	Backup power	-	-	

[4] *Frequency regulation and load following are services under normal operating conditions whereas contingency reserves are triggered by infrequent events.*

03 LEVELISED COST OF STORAGE METHODOLOGY

The lifetime costs (capital cost [capital expenditure or capex], and operating costs [operating expenditure or opex]) of renewable energy technologies like solar PV is captured by the metric of levelised cost of electricity or LCOE. LCOE is the ratio of present value of all costs to the present value of all energy generated by the RE system. However, unlike generation technologies, the LCOE from energy storage includes the cost of electricity for charging, either directly or indirectly (as in solar plus energy storage). Hence, a separate metric, levelised cost of storage (LCOS), needs to be defined, analogous to LCOE for solar PV:

$$\text{LCOS [INR/kWh]} = \frac{\text{Capex} + \dfrac{\sum_1^N \text{Opex}}{(1+r)^n} + \dfrac{\sum_1^N \text{Charging cost}}{(1+r)^n}}{\dfrac{\sum_1^N \text{Energy available from BESS}}{(1+r)^n}}$$

where r is the discount rate, N is battery lifetime, and capex is the total capital cost for the system.

LCOS OF STANDALONE ENERGY STORAGE VS SOLAR PLUS ENERGY STORAGE

Generally speaking, calculation of the LCOS metric for solar plus energy storage differs in following two ways from that for standalone energy storage.

i) In the case of standalone BESS[5], the cost of charging per kWh cost will be equal to the retail energy tariff of the consumer installing it. In the case of solar plus energy storage, the charging cost is internalized in the life cycle costs of solar PV.

ii) Though this applies more to utility-scale energy storage rather than BtM energy storage, in the case of solar plus energy storage, the cost of the inverter and some of the electrical balance of system (BoS) is shared between the solar PV and the battery. Hence, the calculation of LCOS in this case requires that only the additional capital costs for the BESS are taken into account (Deorah et al. 2020). Alternatively, a 'tariff adder' (Deorah et al. 2020) can be determined, which is defined as the additional cost per unit of energy that is added to the solar energy tariff. This tariff adder is different from the LCOS of the BESS above as, to calculate it, the additional costs of the BESS are spread over all the units of solar energy generated.

[6] BESS includes the battery pack (which comes with a battery management system), the enclosure and balance of system, and the inverter.

In this analysis, we separately work out the levelised cost of solar plus energy storage (LCOSS) for BtM application as:

$$\text{LCOSS [INR/kWh]} = \frac{\text{Capex}_{\text{(solar modules, BoS)}} + \text{Capex}_{\text{(storage modules, BoS)}} + \text{Capex}_{\text{(inverter)}} + \dfrac{\sum_{1}^{N} \text{Opex}_{\text{(solar PV)}}}{(1+r)^n} + \dfrac{\sum_{1}^{N} \text{Opex}_{\text{(BESS)}}}{(1+r)^n}}{\dfrac{\sum_{1}^{N} \text{(Solar energy directly self-consumed + Solar energy flowing through battery + Solar energy exported to grid)}}{(1+r)^n}}$$

The above equation assumes that no grid electricity is consumed for charging the battery. Given current and future expected economics of solar plus energy storage for electricity bill management, this is a valid assumption (storage sizes large enough to store all excess solar generation is not expected to become feasible in near future, see Chapter 5). Inverter is assumed as a separate capital cost component in the equation above, as it is shared by solar PV and battery storage. The levelised cost of electricity from the system is calculated over the life of solar PV, including all costs for battery pack and inverter replacement. (We assume a 25-year lifetime for solar PV in this analysis; whereas for standalone energy storage, LCOS is calculated over the lifetime of the battery pack.)

LCOSS is a useful metric to assess the financial feasibility of BtM solar plus energy storage systems. As, the stored solar energy can be later self-consumed to reduce grid consumption (i.e., savings in the electricity bill), an LCOSS less than the retail energy tariff of the consumer indicates grid parity for solar plus energy storage.

The key factors that determine the levelised cost of storage are listed in Figure 1. The capital cost of BESS has five components to it: i) cost of battery pack, ii) cost of enclosure and BoS, iii) cost of inverter, iv) installation cost and v) taxes. Inverter cost will vary significantly between standalone energy storage and a solar plus energy storage system. While in the standalone case, a battery inverter can be used; in a BtM solar plus energy storage system, the battery and the solar PV are connected to a hybrid inverter in the case of a DC-coupled architecture.[6]

Further, the cost of the battery pack depends on three technical parameters:

- C-rating: C-rating decides the discharge duration (also referred to as the energy-to-power ratio) of the battery pack. A rating of 1C means the energy capacity can be delivered in 1 hour, at nominal current, whereas a rating of 0.25C means, it can be delivered in 4 hours.
- Nominal voltage
- Ah rating: Ampere-hour rating determines the amount of energy the battery can store.

[6] *In a DC-coupled system, the solar energy can be stored in the battery directly, without undergoing first DC-AC and then AC-DC conversion (Ardani et al. 2017). An AC-coupled system, on the other hand, has two inverters: one for the battery and one for solar PV. Currently, the market for hybrid inverters is still developing, and the available sizes are limited.*

Figure 1: Key factors for levelised cost of storage of a battery energy storage system.

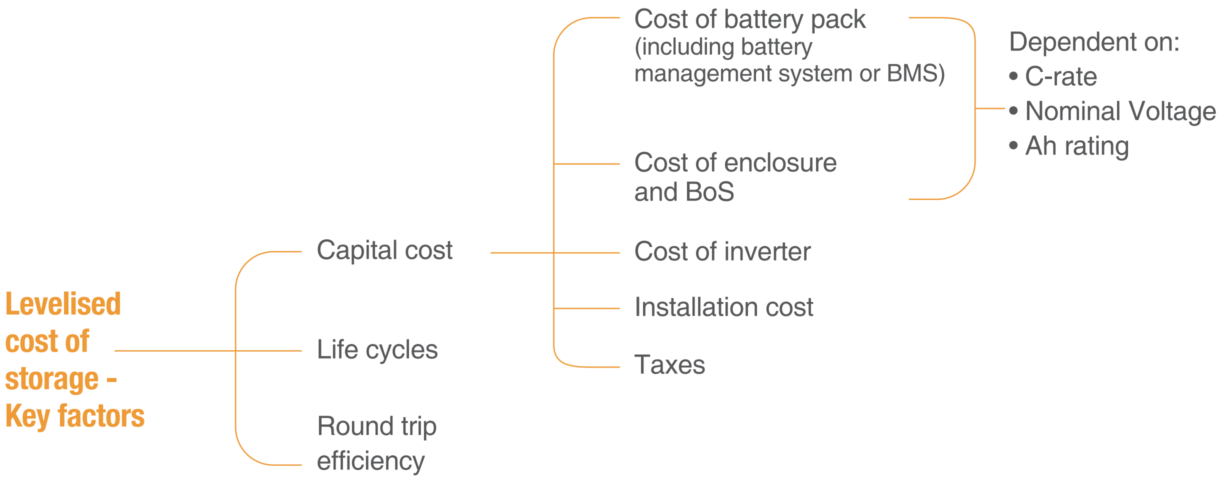


Table 2 summarises various input parameters for calculation of LCOS/LCOSS in our study, and how it compares with the methodology for calculating levelised cost adopted in other studies (Lazard 2018, Schmidt et al. 2017 and Deorah et al. 2020). (For more information on these inputs, refer to our levelised cost calculator [Auroville Consulting 2021b]). In our LCOS analysis, all life cycle costs, except the end-of-life cost of battery, have been considered. Capacity degradation has also been taken into account, which is neglected in a lot of studies (Schmidt et al. 2019). In the case of solar plus energy storage, most studies to date don't explicitly consider the battery pack replacement cost; e.g., Lazard (2018) annualizes the cost as part of opex. We consider net present value of all battery pack replacement costs for calculating the LCOSS. The cost of inverter replacement is considered at the end of 13th year.

Table 2: Comparison with other references of the inputs for the battery system for LCOS analysis.

Parameter	Auroville Consulting (2021b)	Lazard Version 4.0 (2018)	Schmidt et al. (2019)	Deorah et al. (2020)
Separate analysis for solar plus energy storage	✓	✓[7]		✓
Variance of capex with system size	✓	✓		
Capital cost	✓	✓	✓	✓
Operating cost	✓	✓	✓	✓
Battery replacement cost	✓			✓
Inverter replacement cost (for solar plus energy storage)	✓			
Retail energy tariff for charging	✓	✓	✓	
End-of-life cost			✓	✓
Subsidy/tax	✓	✓	✓	
Nominal capacity of battery	✓	✓	✓	
Depth of discharge	✓	✓	✓	✓
Round trip efficiency	✓	✓	✓	✓
Cycle life	✓	✓	✓	✓
Shelf life	✓		✓	
Construction time	✓		✓	
Degradation rate	✓		✓	✓
Self-discharge		✓		

[7] *However, they don't consider the effect of differing percentages of generated solar energy stored in the battery.*

04 CAPITAL COST & OTHER DATA

Three user cases are considered for this analysis: Residential, Small Non-Residential and Large Non-Residential. Table 3 summarises the corresponding assumptions on the BESS capacity for the three cases. In cases where the capital cost data gathered for Li-ion BESS didn't exactly match the capacity and power ratings assumed for the user cases, we used the same capital cost for the battery pack on a per kWh basis; other costs (enclosure and installation) were assumed the same.

Table 3: Assumptions for the three user cases.

User Cases	BESS Energy capacity	BESS Power Rating
Small Residential	4 kWh	1–2 kW
Small Non-Residential	48 kWh	12–24 kW
Large Non-residential	96 kWh	24–48 kW

We adopt a bottom-up approach[8] to analyse the capital costs for standalone energy storage and solar plus energy storage. Capital costs and cycle life data for Li-ion, lead-acid and advanced lead-acid BESS were gathered from several vendors. The data is presented in Table 4. Capital cost for Li-ion battery packs marginally decreases with increasing capacities for the three user cases. However, the capital cost for lead-acid battery packs per unit energy capacity remains the same. Unlike Li-ion battery pack, the architecture is simpler in the case of lead-acid batteries. The basic lead-acid cells are multiplied to achieve higher capacities.

Table 4: Capital cost data for the three user cases and the three BESS technologies.[9]

Capital cost of battery packs (INR/kWh)

User Cases	Technology	Minimum	Maximum	Average
Residential	Li-ion	15,000	24,938	18,310
Small Non-Residential	Li-ion	15,000	24,938	17,856
Large Non-Residential	Li-ion	14,000	24,938	17,689
All	Lead-acid	5,555	6,836	6,071
All	Advanced lead-acid	6,315	14,020	8,359

[8] *Each capital cost component is analysed separately and then aggregated to get the total capital cost.*
[9] *No associated capital cost is indicated by '-'*

Capital cost of enclosure and BoS (% of pack)

User Cases	Technology	Minimum	Maximum	Average
All	Li-ion	4%	6%	5%
All	Lead-acid	-	-	-
All	Advanced lead-acid	-	-	-

Installation cost (INR)

User Cases	Technology	Minimum	Maximum	Average
Residential	Li-ion	3,000	5,000	4,000
Small/Large Non-Residential	Li-ion	11,000	19,000	15,000
Residential	Lead-acid / Advanced lead-acid	-	-	-
Small Non-Residential	Lead-acid / Advanced lead-acid	500	2,000	1,250
Large Non-Residential	Lead-acid / Advanced lead-acid	1,500	5,000	3,250

Other data on technical, financial, and operational parameters were gathered through online research (2017; CERC 2020a; CERC 2020b; James 2016; May et al. 2017; PNNL 2019; Svarc 2019). Table 5 presents the data on some of the key parameters, with the rest covered in Appendix A.

The solar PV capital costs assumed are based on Ministry of New & Renewable Energy benchmark costs (MNRE 2020) and data gathered from industry. We don't consider the subsidy available from MNRE for individual residential consumers for solar systems up to 10 kW. The percentage breakup of the capital cost between solar panels, inverter, BoS, installation costs and taxes are assumed based on industry data. Assumptions on capital cost data of solar PV and inverter are listed in Appendix A.

In the case of standalone energy storage, the applicable Goods and Service Tax (GST) for BESS (including the inverter) is 18%, for Li-ion, advanced lead-acid and lead-acid technologies. In the case of solar plus energy storage, all BESS components attract a GST of 5% for the three technologies. Installation attracts a rate of 18% in both the cases.

For future projection of levelised cost, the cost reduction curves for each capital cost component are presented in Appendix B. Auroville Consulting (2021b) has more details on these cost projections. Further, capacity utilisation factor (CUF) of solar panels is assumed to increase by 0.13% every year (NREL 2020).

Table 5: Assumptions for technical, operational, cost and financial parameters for LCOS analysis.[10]

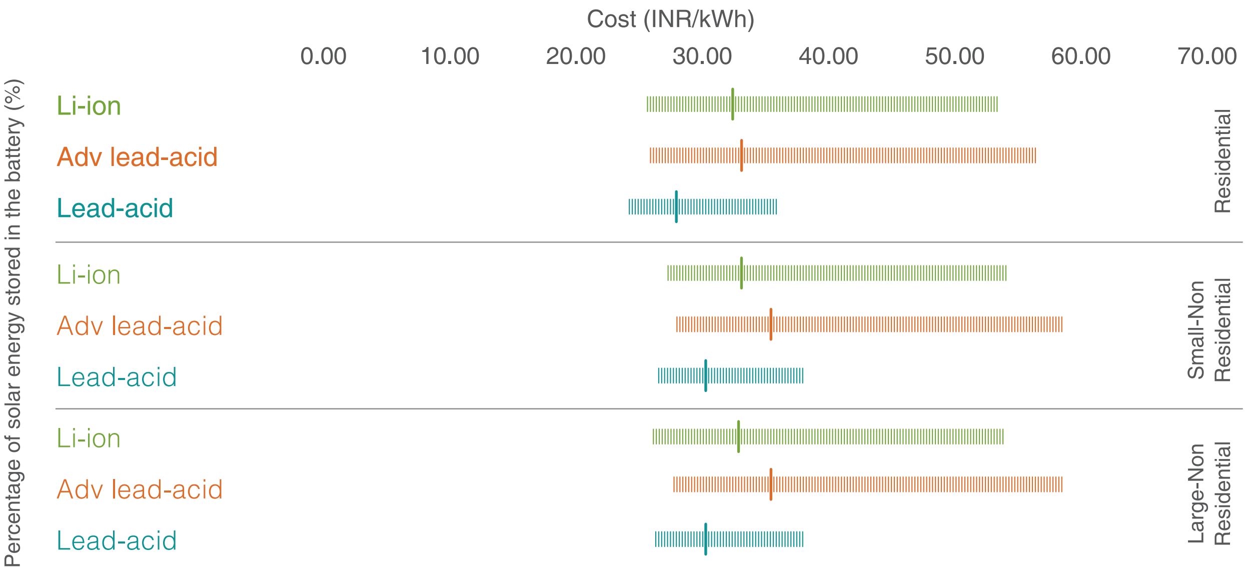
Parameter	Minimum	Maximum	Average
General battery storage-specific parameters			
Charge controller efficiency			96%
End of life capacity relative to initial capacity[11]			80%
Operating cost (Year 1) – Energy (INR/kWh-yr)	100	200	150
Cost escalation for grid electricity			4.00%
Li-ion specific parameters			
Storage round trip efficiency			95%
Depth of Discharge (DoD)			80%
Cycle life at given DoD (cycle)	1,800	4,000	3,175
Storage shelf life (year)			13
Lead-acid/advanced lead-acid specific parameters			
Storage round trip efficiency			83%
Depth of Discharge			50%
Cycle life at given DoD (cycle)	2,000	3,000	2,500
Storage shelf life (year)			10
Solar PV-specific parameters			
Capacity utilisation factor (CUF)[12]	17.00%	19.00%	18.00%
Operating cost (Year 1) (INR/kW-yr)	600	900	750
Depreciation rate for 15 years			4.65%
Annual solar panel degradation[13]	0.50%	1.50%	1.00%
Solar generation self-consumed directly			35.00%
Inverter-specific parameters			
Inverter efficiency			96%
Inverter replacement year			14
Operating cost (Year 1) – Power (INR/kW-yr)	600	900	750

[10] If a range of values is assumed for a parameter, the minimum, maximum and average are indicated; else, a single value is indicated.
[11] Battery life is the time period in which the battery capacity degrades to 80% of the rated capacity. For more details on this and the other input parameters, refer to our levelised cost calculator (Auroville Consulting 2021b).
[12] See CERC (2011) and Sootless Energy (2020).
[13] See NREL (2020) and KERC (2019).

05 ANALYSIS

Figure 2 presents the LCOS for standalone energy storage for the three user cases and each of the three technologies (Li-ion, advanced lead-acid and lead-acid). For each user case and technology, the bar represents the range of LCOS values evaluated, with the vertical line segment representing the average value. In the residential case, the electricity tariff for charging the battery is assumed to be the same as the current marginal retail energy tariff (i.e., tariff for the highest tier) for a large domestic consumer (LT 1-A) in Tamil Nadu: INR 6.60/kWh. For the two Non-Residential user cases, the retail energy tariff of an LT commercial consumer (LT V) in Tamil Nadu is assumed: INR 8.05/kWh (TANGEDCO 2017).

Figure 2: Cost of standalone energy storage.



As the variation in capital costs across the different capacity sizes (the three user cases) is small (Table 4), the LCOS evaluated doesn't change much. It increases a little from the Residential case to Small Non-Residential case due to an increase in the charging tariff. For standalone Li-ion storage, the average LCOS varies from INR 32.38/kWh to INR 33.11/kWh for the three user cases. For advanced lead-acid, it varies from INR 33.23/kWh to INR 35.41/kWh, and for lead-acid, it varies from INR 27.97/kWh to INR 30.16/kWh.

Figures 3.1 to 3.3 presents the LCOSS for solar plus energy storage for the three user cases. For each user case, LCOSS is presented for each of the three technologies, and four different solar PV capacities, corresponding to different percentages of generated PV going through the battery: 15%, 30%, 40% and 50%. In other words, 30% solar energy flowing through the battery would mean the battery is sized so that it can store 30% of the generated solar energy. The 50% case means integrating a larger battery size compared to the 30% case.

Figure 3.1: Cost of solar plus energy storage for Residential user case.

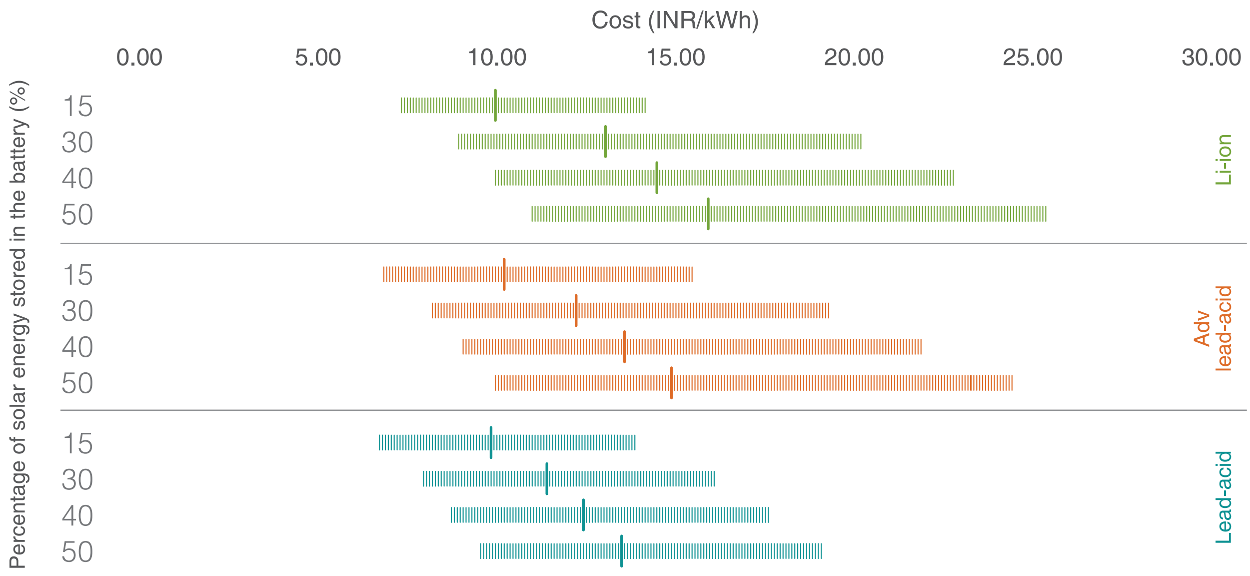


Figure 3.2: Cost of solar plus energy storage for Small Non-Residential user case.

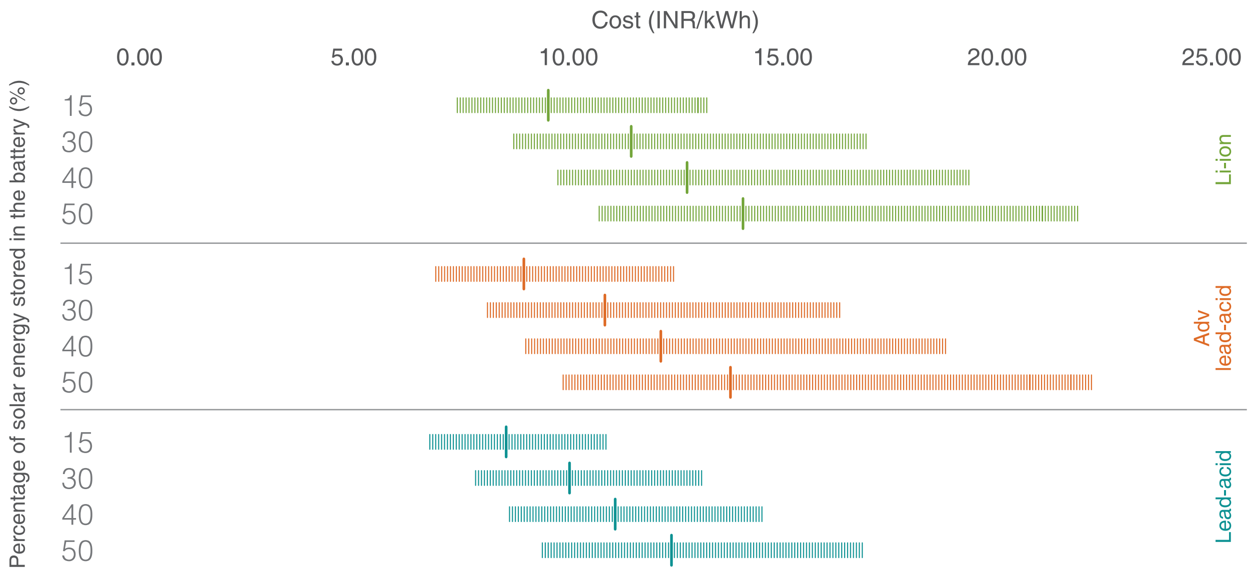
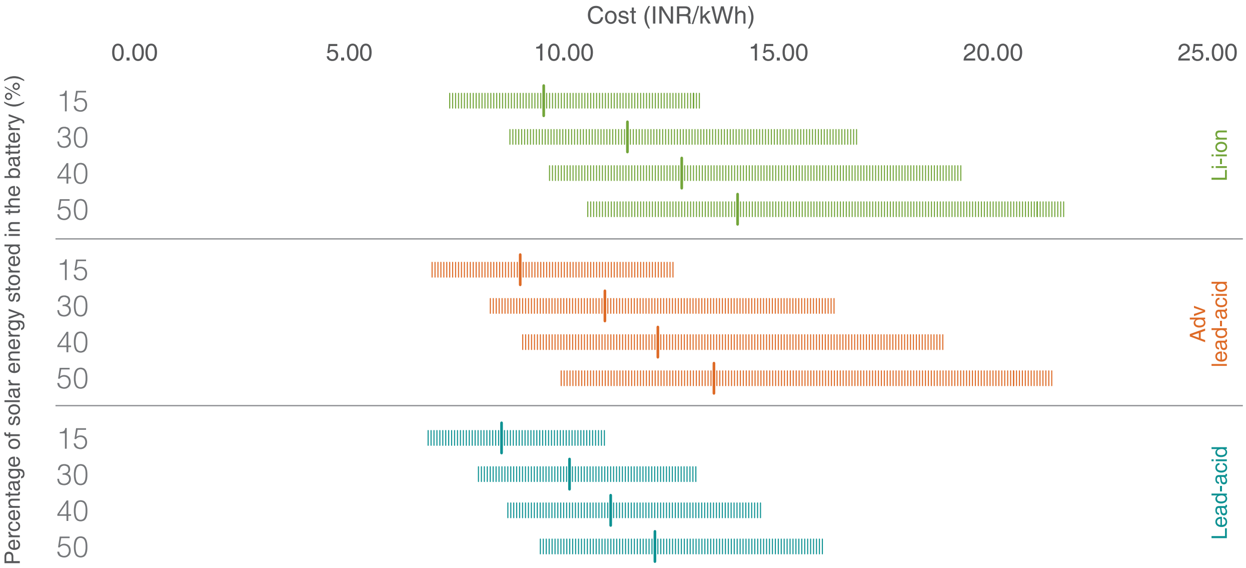


Figure 3.3: Cost of solar plus energy storage for Non-Residential (Large) user case.



For Li-ion BESS and the case of 30% solar PV generation flowing through the battery, the average LCOSS for Residential, Small Non-Residential and Large Non-Residential user cases are INR 13.04/kWh, INR 11.49/kWh, and INR 11.48/kWh. The corresponding values for advanced lead-acid BESS are INR 12.17/kWh, INR 10.87/kWh and INR 10.97/kWh. The decrease in LCOSS, in general, with increasing capacity size is due to the fall in capital costs for the battery system and the solar PV.

Following insights can be drawn from the above:

- Power back up with standalone Li-ion and advanced lead-acid BESS is currently very expensive. However, with an average of more than 3 hours of daily power cut in India (Agrawal et al. 2020), consumers are willing to pay the premium for a reliable power supply in some States.
- Comparing with the current retail electricity tariffs in Tamil Nadu, in none of the cases, the LCOSS has reached parity, considering the battery is sized so that at least 30% of solar energy flows through it. Hence, solar plus energy storage is not a financially attractive option yet for electricity bill reduction.[14]
- For standalone energy storage, the cost of Li-ion technology is already lower than that of advanced lead-acid, due to its better performance characteristics (depth of discharge and round trip efficiency).
- In general, the levelised costs of advanced lead-acid and Li-ion BESS are comparable. Compared to advanced lead-acid, Li-ion technology has much higher energy density (lesser space requirement) and specific energy (lesser weight). Weight is usually not a problem for stationary storage applications. Hence, other than any space constraints, both Li-ion and advanced lead-acid technologies can be considered for BtM storage applications.[15]
- Even though lead-acid BESS has significantly lower LCOSS, it is less suited for BtM application, which requires regular charge-discharge cycles. Regular cycling can be expected to lead to partial state-of-charge (PSoC) often, which can quickly degrade battery capacity, requiring it to be replaced (May et al. 2018).

[14] *This doesn't preclude addition of a small amount of battery storage, up to 10-15% at currents battery storage costs, to realise bill savings for high tariff paying consumers.*
[15] *Also see Svarc (2019).*

While energy storage is not feasible in a lot of cases currently, the coming 10 years will be changing that. It is expected to be dominated by energy storage, just as the previous decade saw solar PV recording big growth (EV Tech News 2020). A steep drop in costs will make it a financially attractive option for most consumer categories over the coming years. To analyse the expected cost decline, we project the average levelised costs computed above to 2030. Figure 4 and Figures 5.1–5.3 present the results for standalone energy storage and solar plus energy storage respectively. Levelised cost is projected by using the average values of parameters listed in Table 4 and Table 5 along with the cost reduction curves given in Appendix B.

In the case of standalone energy storage, the projected cost declines are compared with an assumed cost of backup power from diesel generator (DG) of INR 23/kWh (Oviroh and Jen 2018). Though the cost of DG from diesel generator is assumed constant over the analysis period, in reality, it can be expected to increase with increasing fuel cost.

In the case of solar plus energy storage, the levelised cost projections are compared with the existing retail electricity tariffs in Tamil Nadu: the levelised cost for Residential user case is compared with the domestic (LT 1-A) retail energy tariff of INR 6.60/kWh, and that of Non-Residential user cases is compared with the LT commercial (LT V) retail energy tariff of INR 8.05/kWh (TANGEDCO 2017). These tariffs are assumed to increase at 4% year, which is a moderate assumption to make.[16] In addition, the projected levelised costs are compared with the average power purchase cost (APPC) of the utility, as an indicator of feasibility: INR 5.63/kWh.[17] Since electricity tariffs vary a lot with consumer categories in the existing cross-subsidised structure, we also use APPC as a single reference point for comparison across the user cases.[18]

The Non-Residential user cases in Figures 5.1–5.3 illustrate that the highest tariff paying consumers (the commercial consumers in Tamil Nadu) will start seeing energy storage as a viable option to reduce their electricity bills as early as 2023considering the case of 30% solar energy flowing through the battery. And, by 2025, even sizing the battery to store up to 50% of generated solar energy becomes viable. In the case of high-paying residential consumers in Tamil Nadu, the above timeline for the case of 30% solar energy flowing through the battery is delayed by 4 years, i.e., 2027.

The cost projections highlight the following:

- Though energy storage is currently not viable in a lot of cases for BtM application, this is expected to change very fast. Integrating large amounts of BtM energy storage for electricity bill reduction will be possible for non-residential consumers by the middle of this decade, i.e., 2025.
- For residential consumers, energy storage will become feasible towards the end of this decade. For high paying residential consumers, the case of sizing the battery to store 30% of the generated solar energy reaches grid parity post 2027.
- With solar plus energy storage, the 'death spiral' threat to utility (where its highest paying consumers move to solar energy) will worsen further, as these consumers are expected to increasingly adopt solar plus energy storage to meet their energy demand. The policy makers will have to draw up a roadmap to transition the utilities from their traditional roles to that of distribution system operators (TERI 2020). Privatisation of the public utilities would help in driving this transition.
- We see that throughout the analysis period up to 2030, advanced lead-acid continues to compete with Li-ion technology. Notwithstanding any space and weight concerns, both technologies will remain in play in future for BtM application for electricity bill management.
- Even by 2030, the levelised cost of solar plus energy storage remains significantly higher than the APPC of the utility. However, this is compensated by other benefits that BtM solar plus energy storage offers to the utility: avoided distribution/transmission losses, deferral of distribution upgrades and fixed capacity costs.

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[16] In the four years to 2017-18, TANGEDCO's average billing rate increased at a compound growth rate of more than 4.5%.
[17] This is based on our analysis of TANGEDCO's profit and loss statement for 2017-18.
[18] Note that APPC, apart from the variable cost of energy, also includes the fixed costs paid to the generators. On the other hand, it excludes the transmission and distribution losses.

Figure 4: Cost projections for standalone energy storage for Residential user case.

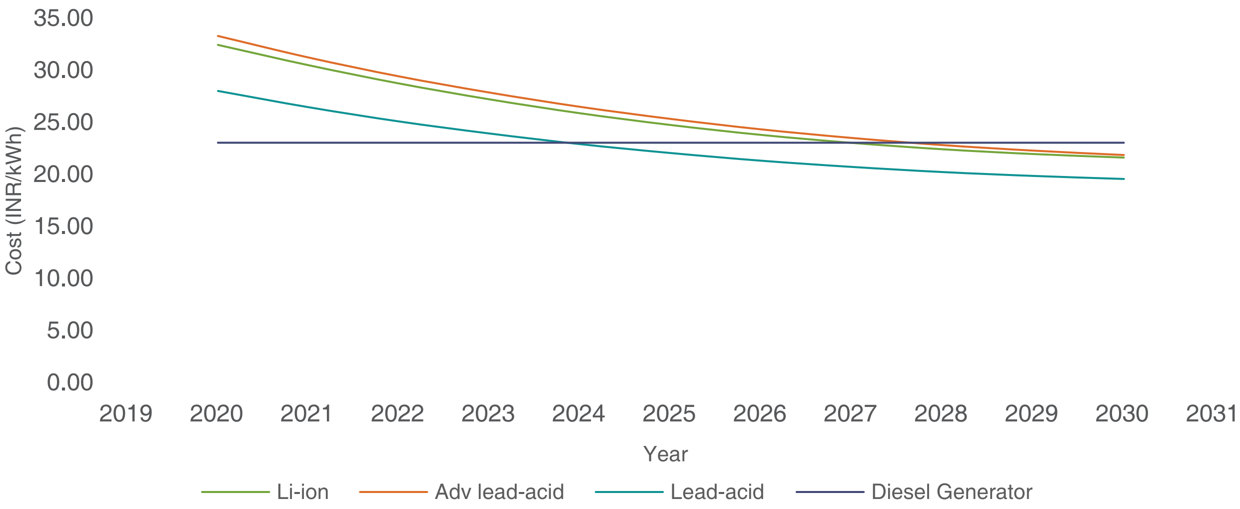


Figure 5.1: Cost projections for solar plus energy storage for Residential user case, for 30% (top) and 50% (bottom) solar energy flowing through the battery.

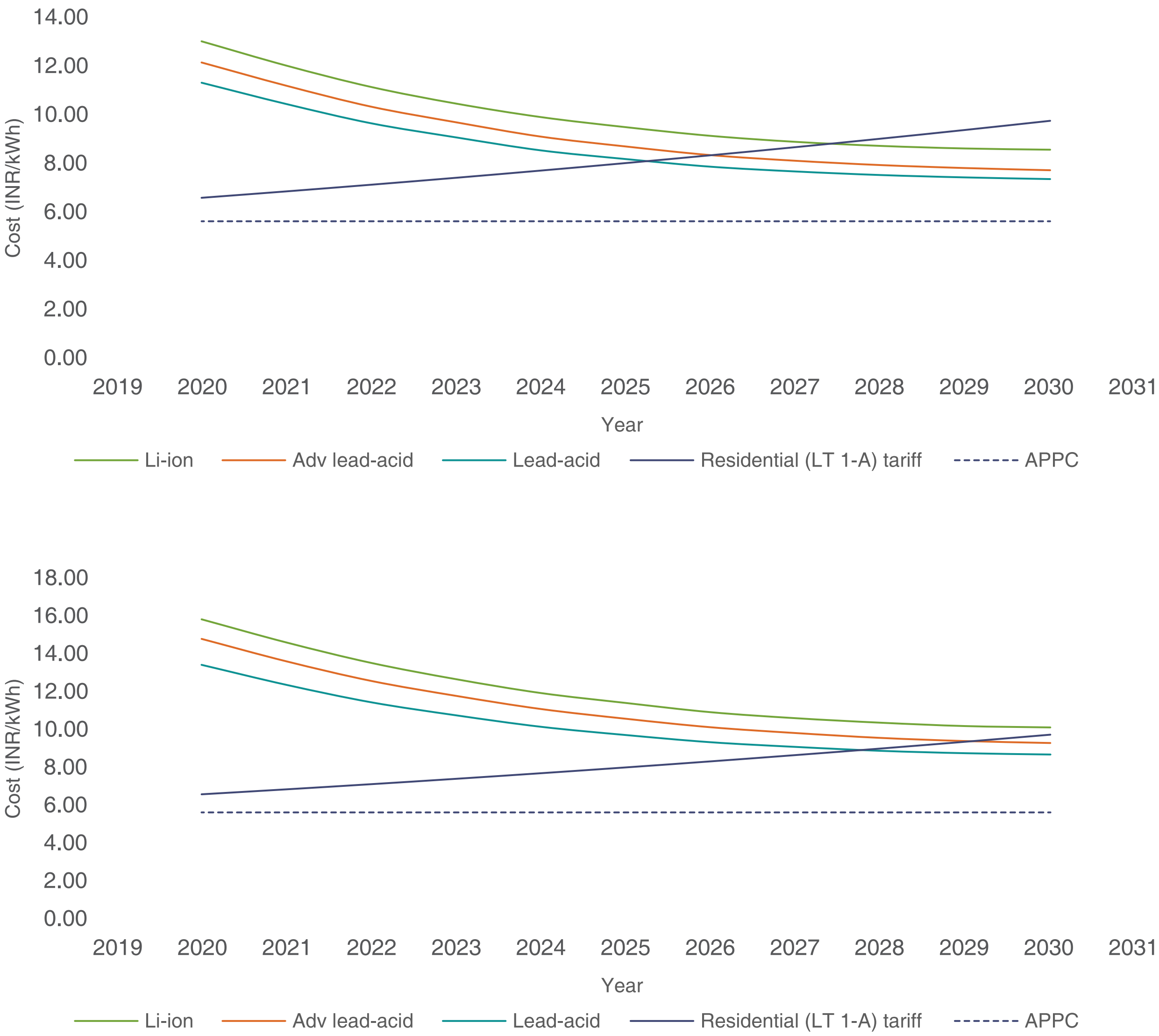
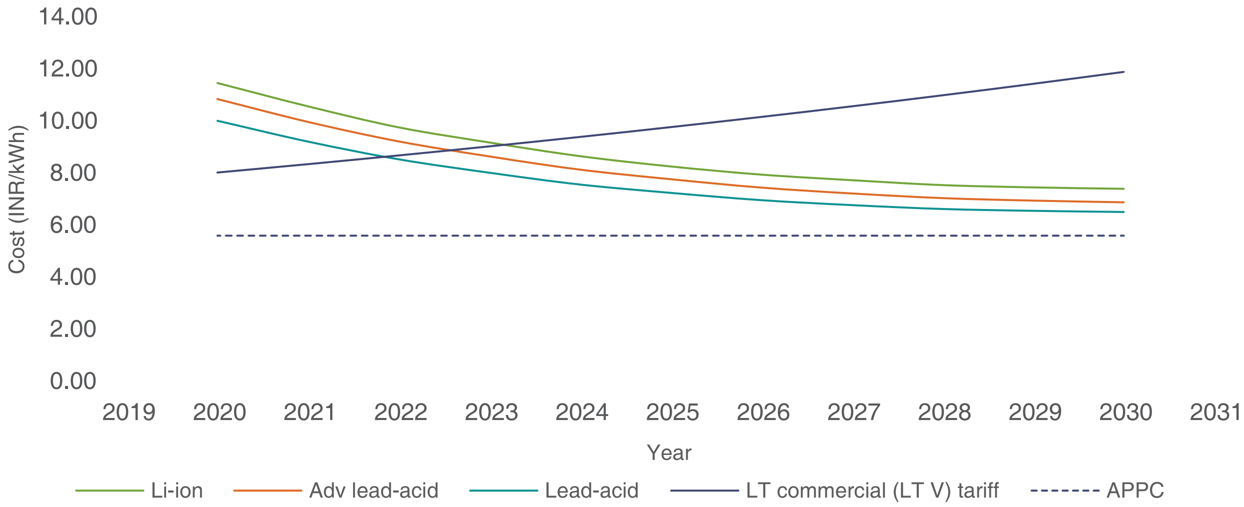


Figure 5.2: Cost projections for solar plus energy storage for Residential user case, for 30% (top) and 50% (bottom) solar energy flowing through the battery.



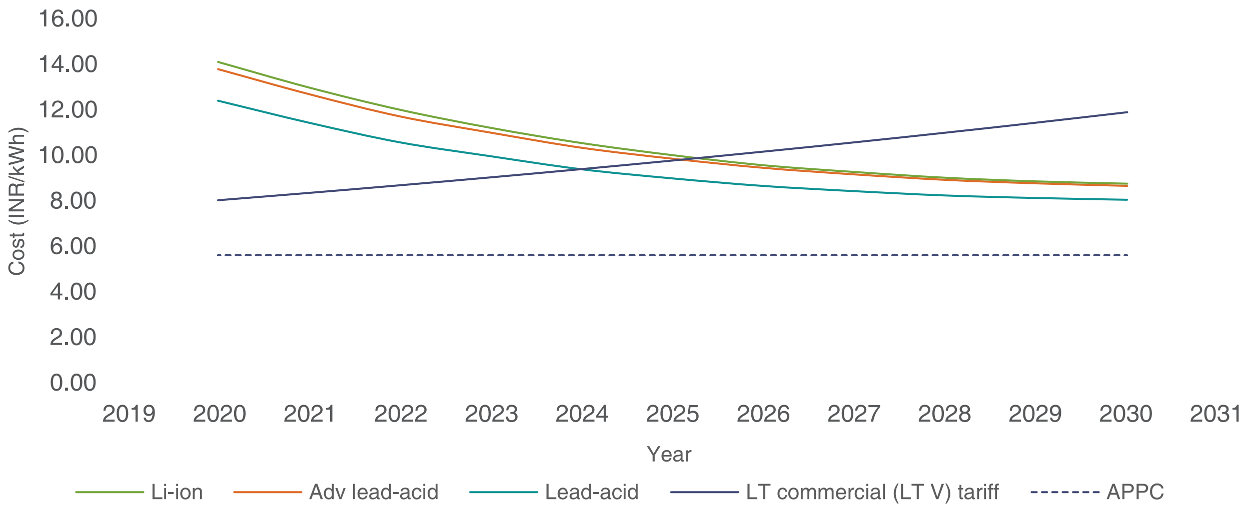
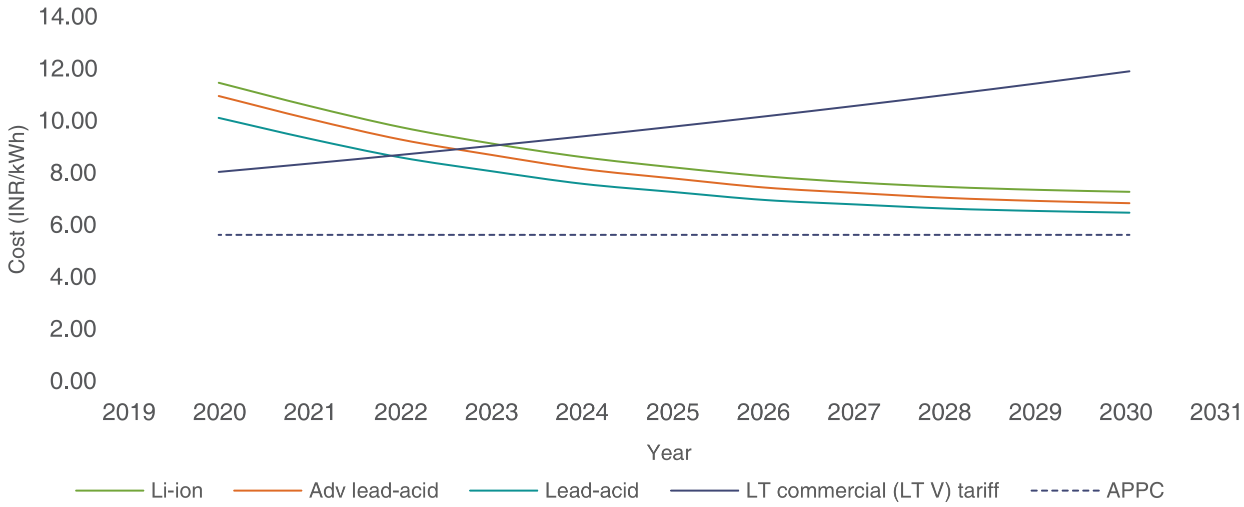
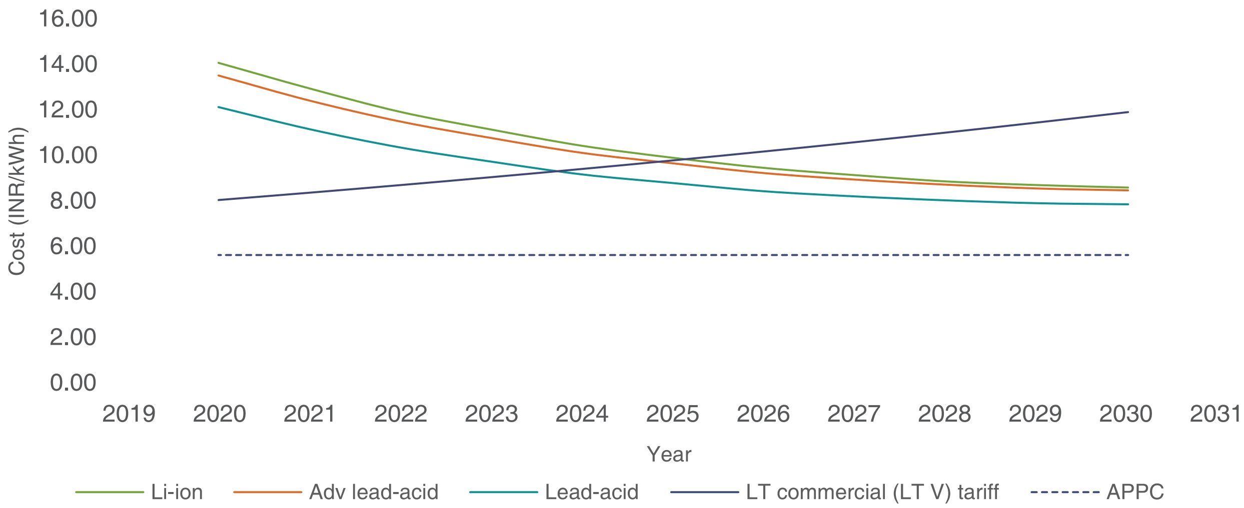


Figure 5.3: Cost projections for solar plus energy storage for Residential user case, for 30% (top) and 50% (bottom) solar energy flowing through the battery.





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APPENDIX A
CAPITAL COST DATA & OTHER ASSUMPTIONS

Table A.1: Assumed capital cost data for solar PV.

Parameter	>1 to 3 kW			>3 to 10 kW		
	Minimum	Maximum	Average	Minimum	Maximum	Average
Capital Cost	42,000	89,000	65,500	41,000	60,000	50,000
Solar panel cost (%)			38.0%			38.0%
Inverter cost (%)			28.0%			28.0%
BoS cost %			17.0%			17.0%
Installation cost %			8.8%			8.8%
Soft costs (taxes) %			8.2%			8.2%

Parameter	>10 to 30 kW			>30 to 100 kW		
	Minimum	Maximum	Average	Minimum	Maximum	Average
Capital Cost	38,000	45,000	41,500	38,000	42,000	40,000
Solar panel cost (%)			44.0%			49.0%
Inverter cost (%)			21.0%			16.0%
BoS cost %			18.0%			20.0%
Installation cost %			8.8%			6.8%
Soft costs (taxes) %			8.2%			8.2%

Table A.2: Capital cost data for inverters.

Type	Minimum	Maximum	Average
Off-grid inverter cost	4,100	5,200	4,500
Hybrid inverter cost	30,000	40,000	35,700

Table A.3: Assumptions on general operational and financial parameters for the LCOS analysis.

Parameter	Minimum	Maximum	Average
Discount rate	8.61%	8.61%	8.61%
Equity	-	-	30%
Return on Equity	15.00%	16.96%	15.60%
Loan tenure (year)			15
Moratorium (year)			1
Interest on loan			9.67%
Annual increase in O&M Expenses			3.84%
Insurance (% of depreciated asset value)			0.00%
Working Capital O&M (month)			1.00
Working Capital – Receivables (month)	1.50	3.00	2.00
Working capital - Maintenance spares (%)			15.00%
Interest on Working Capital			11.17%
Salvage value at end of life			10%

APPENDIX B
COST PROJECTIONS FOR SOLAR PV AND BESS[20]

Figure B.1: Cost reduction curve relative to 2018 for Li-ion technology for behind-the-meter applications.

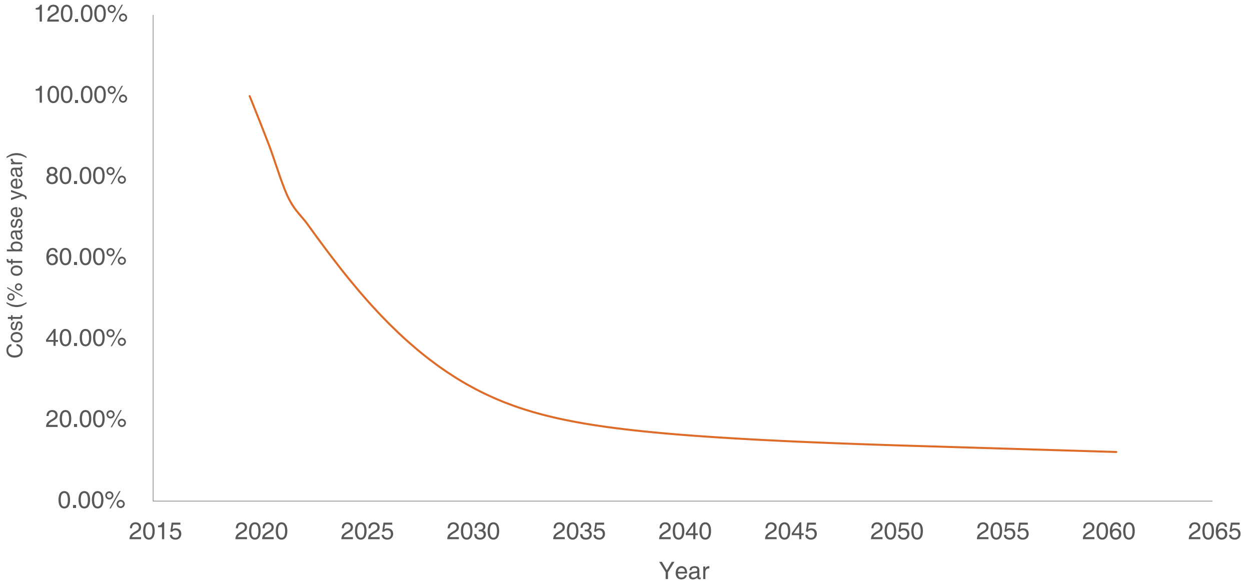
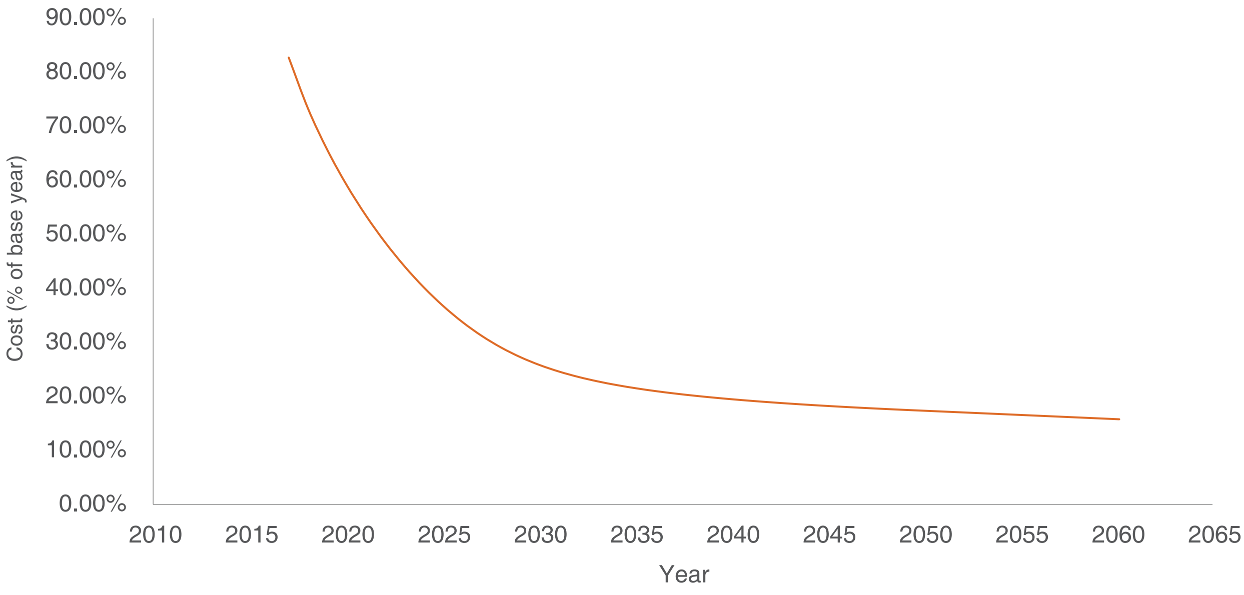


Figure B.2: Cost reduction curve relative to 2017 for lead-acid (and advanced lead-acid) technology for behind-the-meter applications.



[20] *See Auroville Consulting (2021b) for more details on the cost reduction curves presented in this section.*

Figure B.3: Assumed cost reduction curve relative to 2020 for power conversion systems or inverters.

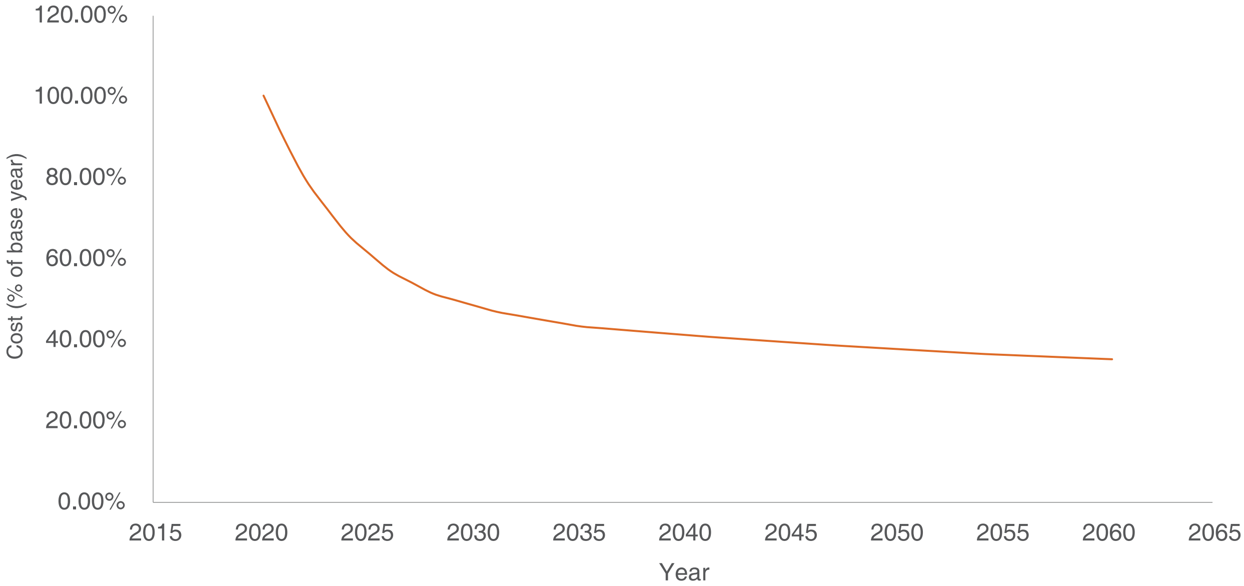


Figure B.4: Assumed cost reduction curve relative to 2020 for solar modules.

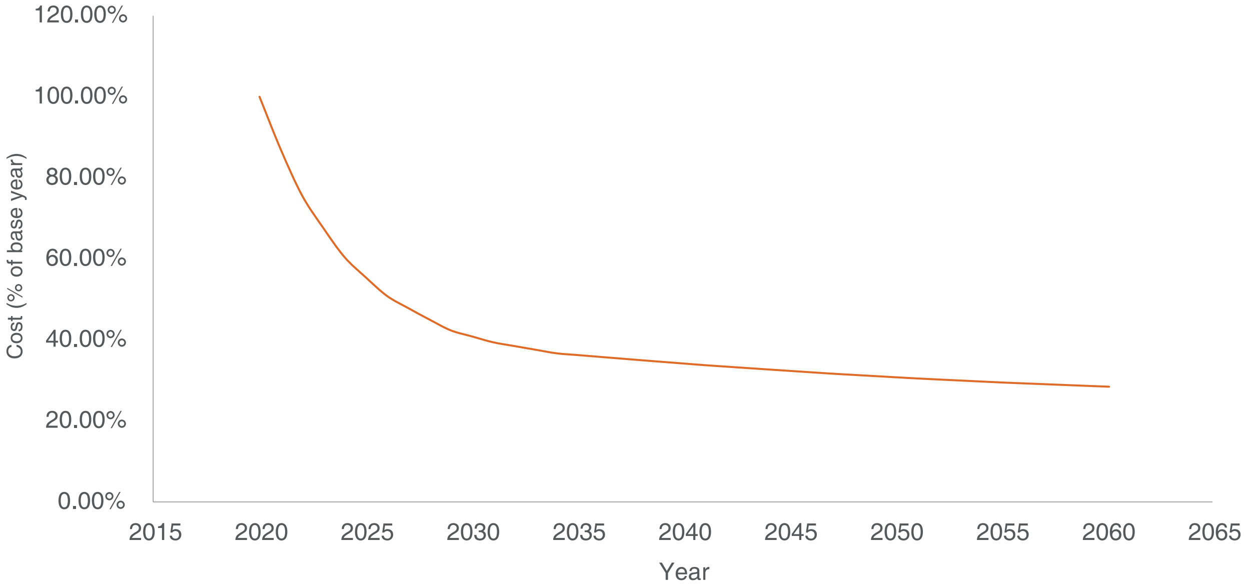


Figure B.5: Assumed cost reduction curve relative to 2020 for balance of system for BESS and solar PV.