Navigating the maze of energy storage costs

Storage | The anticipated growth in stationary energy storage will be dependent on a significant decrease in costs, but the many different storage applications and technologies make comparisons of costs a complex undertaking. Florian Mayr and Hannes Beushausen of Apricum – The Cleantech Advisory describe what to consider to determine the costs of energy storage in a meaningful way

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The future market for stationary energy storage systems (ESS) is one of the most heavily discussed topics in the power industry today. Significant growth is expected in particular for stationary battery systems, which accounted for only 2GWh globally in 2015 but are expected to grow to 33GWh by the end of the decade.

One of the key drivers – and prerequisites – of this growth is a significant cost decrease and the resulting competitiveness of energy storage systems compared to traditional, non-storage solutions. At the same time, an increasing number of ESS technologies has become available for commercial application in a variety of use cases, each with a different cost of energy storage that needs to be compared in detail, to be meaningful.

But what does "cost of energy storage" really mean?

While there is general consensus to use levelised cost of energy (LCOE) for comparing different energy generation technologies, such as solar parks, wind farms and coal plants, there is no universally applied metric for calculating the cost of energy storage.

As a result, the assessment of costs for different energy storage solutions can become a tough exercise for all stakeholders: storage system manufacturers have a hard time explaining cost advantages over their competition, investors struggle with making an educated decision for financing and end users do not know which energy storage solution is most economical in the targeted application.

In this article, we will examine what to consider for calculating meaningful, comparable ESS costs.

Let's start with two simple but important rules:

Meaningful cost assessment is key for all stakeholders, such as ESS manufacturers, investors and end users

1. Cost comparison for same use cases only

In contrast to technologies for generation, which have a single use case (i.e., the generation of electricity), energy storage technologies can serve a variety of use cases, including both in-front-of-the-meter (e.g., supply of reserve power, black start support, dispatchable PV) and behind-the-meter applications (e.g., increase of self-consumption). Each use case requires different operating parameters, which affect the costs, and each storage technology optimises along these parameters differently according to its relative strengths and weaknesses.

Therefore, cost comparisons of energy storage only make sense for a common and clearly defined use case. Furthermore, only energy storage systems that were designed to serve the technical requirements of a specific use case should be compared: a storage technology with higher costs than an alternative technology is not necessarily "worse" or "less advanced", it is probably just meant for a different application.

2. Choose the right basis

The cost of energy storage is typically based either on the provided energy (i.e., kWh, MWh) or on the power capacity (kW, MW). The appropriate basis to choose depends on the value that energy storage is adding in the specific use case, i.e., in many cases, the costs that are avoided through application of energy storage.

Consider the two following examples:

- In an island grid, an ESS could be used to shift PV generated electricity to the evening to meet peak demand instead of using electricity generated with a diesel genset. An investor would therefore want to compare the cost of adding energy storage with the cost of diesel-based generation, which is denominated in US$/kWh. Therefore calculating the cost of storage on an energy basis is the right starting point.

- The peak demand behind a power transmission line exceeds the available capacity. To remove the bottleneck, the grid operator could install a battery storage system to serve the excess demand or extend the grid infrastructure. The cost of a transmission line is typically based on its power capacity denominated in US$/MW. Therefore a comparison with the cost of storage based on an energy basis is not applicable but should instead be done on a power basis.

With this clarified, we will focus on calculating the cost of ESS on an energy basis as follows.

Know your cost influencers

The key to comparing apples with apples is to make sure that individual cost figures are calculated at the same level of detail and are based on comparable assumptions. The prerequisite for this is a deep understanding of the different factors influencing the costs of an ESS, i.e., upfront costs, O&M costs, charging costs, useable energy over lifetime, residual value and financing costs.

Upfront costs: Already at this basic level, a close look is required when comparing different energy storage solutions. Are all necessary investments for the complete and connected system included in the initial quote? Very often, for example, costs for the necessary inverters, safety engineering or for shipping and installation are not covered. To assess these costs correctly, specific characteristics of the individual energy solutions have to be considered, such as the impact of gravimetric and volumetric energy densities on transportation and space requirements.

Operation & maintenance costs: Like all infrastructure assets, energy storage requires periodic minor and major servicing. Depending on the components that need to be replaced, and how frequently, this can cause significant additional technology-specific costs. For example, a redox-flow battery features mechanical parts such as pumps that can require maintenance not needed for other battery technologies.

Charging costs: The cost of charging the ESS needs to be taken into consideration, but is often left out. Losses during a complete charge-discharge cycle (i.e., reduced roundtrip efficiencies) mean that more energy has to be purchased at a certain price for charging the system than can be sold when discharging – often constituting a significant cost factor depending on the charging electricity price.

Also, the energy consumption of the system differs considerably from technology to technology and depends on local conditions such as ambient temperatures, which should be included in the costs. For example, Li-ion chemistries can require energy intensive air-conditioning to maintain favourable operating temperatures.

For behind-the-meter applications, particular caution should be exercised in determining the efficiency. For example, the load of households is often dominated by times with low loads. This translates to low discharge power for a residential storage system, which in turn results in significant energy losses compared to nominal power usage. As a result, the actual efficiency of home storage systems is often significantly lower than the rated (maximum) efficiency of the systems published in the data sheets.

Useable energy over the lifetime: The cost of an ESS intended for energy-based applications should be put in relation to the energy output of the ESS expected over its lifetime. For batteries, the lifetime often refers to the projected cycle lifetime (e.g., 5,000 cycles), which is the number of complete charge-discharge cycles a battery is expected to perform before its nominal capacity falls below 70–80% of its initial rated capacity as a result of continuous degradation.

Different storage types claim different cycle lifetimes. It is important to understand that a very high number of projected cycles is not necessarily an advantage, depending on a) the ESS' calendar life and b) the number of cycles required per year.

The calendar life is simply the elapsed time before a storage solution becomes unuseable, whether it is in active use or inactive. For batteries it mainly depends on the chemistry and manufacturing specifics of the ESS (e.g., life period of the electrolyte, quality of sealing rings and welded joints) as well as on the voltages applied and the battery temperatures – as a rule of thumb, calendar life drops by 50% for each 10°C increase above 20°C.

The number of cycles required per year depends on the nature of the individual use case. It is determined by the required number of full cycles per day and the number of operating days per year. For example, a replacement of peaker plants through energy storage in the USA typically requires one full cycle per day for 300 days of the year, leading to 300 cycles per year. In contrast, frequency regulation demands up to five cycles per day for 350 days per year, so requiring 1,750 cycles annually.

It is also important to note that the same use case can lead to a different number of required yearly cycles depending on the geography. In sunny California, it is fair to assume that a residential storage system with the purpose of increasing the self-consumption of rooftop PV reaches 300 complete charge-discharge cycles annually. In Germany, however, the same use case would instead require 200 to 250 cycles per year. This is mainly due to the more significant variations between summer and winter: the German winter has little sunshine and does not allow the battery to fully charge during the daytime, while the extended daylight in summer leads to residential storage not fully discharging during the night. Hence, the number of full-cycle equivalents over the year is much lower than in California.

If an ESS in question has a calendar life of 20 years and the targeted use case requires only 300 cycles per year, a cycle lifetime of 300x20 (6,000) cycles would be sufficient – anything beyond does not add extra value and should not be included in the cost calculation. If the remunerations to be received are limited to a period shorter than the ESS' calendar life, for example in the case of a power purchase agreement, the relevant number of cycles is reduced even further.

Finally, the useable energy of batteries greatly depends on the depth of discharge or DOD. For most chemistries, the lower the DOD applied, the higher the number of cycles and the roundtrip efficiency (see above) – but obviously the lower the amount of energy that can be discharged in each cycle as well. Consequently, cost figures should not only include the (relevant) number of cycles and roundtrip efficiency, but also the corresponding DOD.

$$\text{NPV of cost} = \text{NPV of remuneration}$$

With NPV = net present value

$$\sum_{n=0}^{N} \frac{cost(n)}{(1+r)^n} = \sum_{n=1}^{N} \frac{remuneration(n)}{(1+r)^n}$$

With cost(*n*)/remuneration*(n)* = cost/remuneration in year *n*, *r* = discount rate, and *N* = lifetime in years

$$\sum_{n=0}^{N} \frac{cost(n)}{(1+r)^n} = \sum_{n=1}^{N} \frac{E_{out}(n) \times LCOS}{(1+r)^n}$$

With $E_{out}(n)$ = electricity discharged in year *n* and *LCOS* = price for each kWh

$$\sum_{n=0}^{N} \frac{cost(n)}{(1+r)^n} = LCOS \times \sum_{n=1}^{N} \frac{E_{out}(n)}{(1+r)^n}$$

LCOS is constant over time, i.e., levelised

$$LCOS = \frac{\sum_{n=0}^{N} \frac{cost(n)}{(1+r)^n}}{\sum_{n=1}^{N} \frac{E_{out}(n)}{(1+r)^n}}$$

Figure 1. Formula showing the calculation for levelised cost of stored energy

Residual value: Even after an ESS has reached the end of its lifetime, it bears a certain residual value based on the achievable sales price for the individual components including inverters, switchgear and transformers. Obviously, the shorter the period of time an ESS has been used, the higher the residual value. In extreme cases, the residual value can be negative if costly dismantling and recycling has to be paid at end of life.

Financing costs: The time value of money dictates that time has an impact on the value of cash flows. In other words, future cash flows have a lower present value than cash flows generated or paid today. Therefore a discount factor reflecting the financing costs, typically the weighted average cost of capital (WACC), needs to be applied to all outflowing (i.e., O&M and charging cost) and inflowing cash (i.e., the remuneration for the useable energy and residual value).

Levelised cost of stored energy

In order to reflect all of the cost influencers explained above in a simple metric, it makes sense to assume a constant – or levelised – price per kWh over the applicable lifetime of the ESS. The resulting cost metric is called levelized cost of stored energy (LCOS). In other words, the LCOS is the constant and thus levelised price per kWh at which the net present value of the ESS project is zero.

Although a bit counterintuitive, it is important to "discount" also the useable energy (electricity discharged), as can be seen in the derivation of the LCOS formula in Figure 1.

The LCOS formula can be structured along the individual components of CAPEX, O&M, residual value and charging costs, as shown in Figure 2.

By applying LCOS, the significant impact of including or leaving out any of the described cost influencers becomes obvious, as illustrated in the following examples.

Example 1: Dispatchable PV in island grid

For the use case of dispatchable PV, i.e., shifting PV generated electricity to the evening to meet peak demand, a Li-ion battery would end up with an LCOS of US$0.35/kWh given the conditions assumed in our example (see graph, Example 1, on following page). When compared to non-storage solutions such as expensive diesel-based generation in island grids, Li-ion is already economically viable for this use case.

$$LCOS = \frac{CAPEX}{\#cycles \times DOD \times C_{rated} \times \sum_{n=1}^{N} \frac{(1-DEG \times n)}{(1+r)^n}}$$
$$+ \frac{O\&M \times \sum_{n=1}^{N} \frac{1}{(1+r)^n}}{\#cycles \times DOD \times C_{rated} \times \sum_{n=1}^{N} \frac{(1-DEG \times n)}{(1+r)^n}}$$
$$- \frac{\frac{V_{residual}}{(1+r)^{N+1}}}{\#cycles \times DOD \times C_{rated} \times \sum_{n=1}^{N} \frac{(1-DEG \times n)}{(1+r)^n}}$$
$$+ \frac{P_{elec\text{-}in}}{\eta(DOD)}$$

With:

$\#cycles$ = full charging/discharging cycles per year
DOD = depth of discharge
C_{rated} = rated capacity
DEG = annual degradation rate of capacity[1]
N = project lifetime in years
r = discount rate (e.g., weighted average cost of capital)
$O\&M$ = O&M cost (assumed to be constant)
$V_{residual}$ = residual value (after project lifetime)
$P_{elec\text{-}in}$ = charging electricity tariff (assumed to be constant)
$\eta(DOD)$ = round-trip efficiency at *DOD* (assumed to be constant)

1) Assuming linear degradation

Figure 2. LCOS reflecting individual components of CAPEX, O&M, residual value and charging costs

Example 2: Residential storage

Germany is the world's largest market for residential battery storage systems with ~30,000 systems installed today, predominantly for the purpose of increasing PV self-consumption.

Interestingly, for potential customers who are purely financially motivated, i.e., who want to reduce the total procurement cost of electricity, installing rooftop PV plus residential storage is often not feasible yet without subsidies, as seen in the graph below: the costs for storing a kWh simply exceed the savings from self-generated PV power (reflected in charging costs) compared to the electricity price from the grid. Key drivers for the rather elevated cost of residential storage include not only the initial investment, but also the low numbers of cycles used in Germany and the decreased effective efficiency, as described earlier.

However, a PV system combined with energy storage can still offer a lower average energy procurement cost than pure grid supply over a year, as not every self-generated kWh needs to be stored – although in this case the PV system is "subsidising" the storage unit (see graph Example 2 on following page).

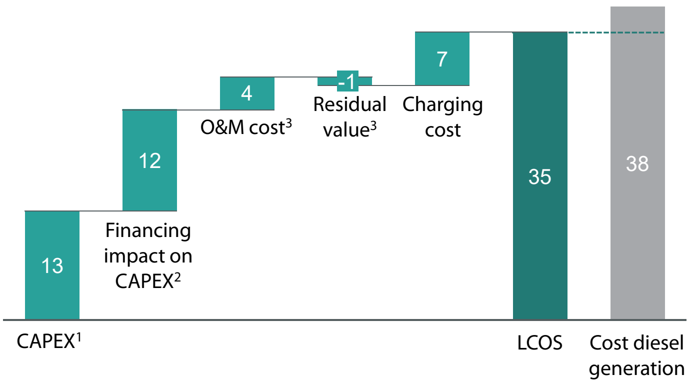
Hence, if the reason for increased self-consumption is not purely return driven, but is also motivated by, for example, the wish to be more independent from the utilities, residential storage is a viable solution to achieve this objective. The majority of the residential installations in Germany are in fact based on rather non-financial rationales. Also, if the current incentive programme for solar plus storage from the German government is factored in, the economics can further improve.

Impact of meaningful cost calculations on attractiveness of energy storage

We have seen that the consideration of all relevant costs still allows for an economical application of energy storage in specific use cases, depending on the available alternatives with which the ESS is competing.

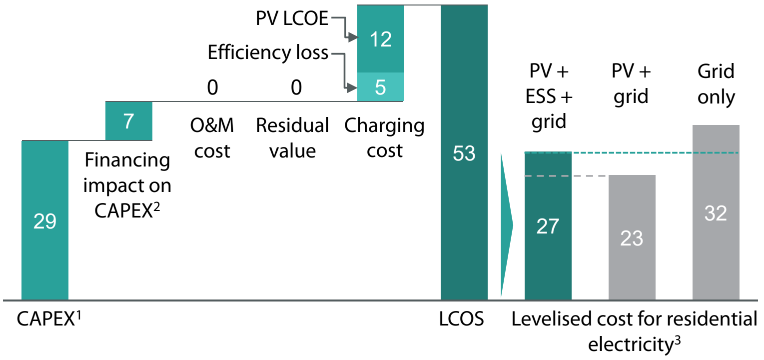
Many more attractive opportunities for energy storage are available if applications related to power capacity are considered alongside the energy-based use cases covered in this article. A prominent example is the provision of ancillary services to the grid, which is successfully done through ESS in many markets

Example 1: Cost components and LCOS for a utility-scale stationary battery storage system for dispatchable PV in island grid [US$¢/kWh]



1) Divided by undiscounted total energy; 2) Impact of discounting total energy;
3) Discounted and divided by discounted total energy
Source: Apricum analysis, Assumptions:
Technology: Lithium-ion battery technology with CAPEX of 500 US$/kWh, based on 6 MWh/MW with 300 US$/kW and 450 US$/kWh
Use case: dispatchable PV with 350 cycles per year at 80% DOD
Lifetime and degradation: project lifetime 15 years; battery lifetime of 6,000 cycles
O&M: constant annual O&M cost of 10 US$/kWh p.a. (2% of initial CAPEX)
Charging: constant charging cost of 0.06 US$/kWh with 92% ESS efficiency
Discount rate: 10% (assuming 50% of debt at 8% and 50% equity at 12%)
Residual value: assumed to be 20% of initial CAPEX
Diesel generation: LCOE calculation over 20 years with fuel cost 1 US$/l (incl. transport) with 2% yearly increase (variable cost 0.36 US$/kWh)

Example 2: Cost components and LCOS for a residential storage system to increase PV self-consumption in Germany [US$¢/kWh]



1) Divided by undiscounted total energy; 2) Impact of discounting total energy; 3) Over 20 years
Source: Apricum analysis, Assumptions:
Technology: Lithium-ion battery system with CAPEX of 1,000 US$ per usable kWh
Use case: increase PV self-consumption with 250 cycles per year at 100% DOD
Lifetime and degradation: system lifetime 15 years; battery lifetime of 5,500 cycles
O&M: battery system is assumed to be maintenance free (no O&M cost)
Charging: constant charging cost with PV LCOE of 0.12 US$/kWh with 70% battery efficiency
Discount rate: 3% (assuming 100% equity)
Residual value: residual value neglected
Levelised power procurement cost:
Grid only: 2015 average household electricity price of 0.32 US$/kWh; no price increase
PV + grid: 36% of self-consumption; excess power sold at feed-in tariff of 0.14 US$/kWh; 10 kW_p PV system size; yield of 900 kWh/kW_p; lifetime 20 years; 0.5% annual degradation
PV + ESS + grid: 5 kWh ESS system size; all other assumptions as stated above

around the world.

It has to be stressed that our analysis was limited to single use cases only. In reality, most energy storage systems installed today are meant to address various applications simultaneously to generate additional revenue streams and create cost synergies – so-called benefit stacks. For example, residential storage systems do not only allow for more self-consumption of rooftop PV power, but could also provide back-up power and, if aggregated, could provide ancillary services. Grid-scale energy storage systems can offer a combination of black start capacity, peak shaving and demand charge reduction, among others.

Last but not least, the overall trend of decreasing costs of energy storage will continue to enhance the competitiveness of energy storage solutions significantly: the costs for the balance-of-system alone are expected to decline by up to 40% by 2020, according to GTM Research.

Implications for energy storage stakeholders

It is most important to be aware of the various factors influencing ESS costs and how to apply them correctly depending on the individual use cases. In consideration of certain limitations as described above, LCOS can be an easily calculable, sufficiently detailed metric that enables a meaningful comparison of different storage technologies, as well as between storage and non-storage solutions, in energy-based applications.

Cost metrics like LCOS should be applied with caution, though. Even if the underlying assumptions of a cost comparison are clearly communicated (e.g., which ESS technology is applied, value of benefit stacking considered), the results might still "stick" – and are quoted as a reference for the general viability of ESS in completely different, non-applicable situations. As perception often creates reality, energy storage may be ruled out before a detailed assessment related to the specific use case is done.

Nevertheless, standardisation of the methods for calculating storage costs is definitely needed to increase transparency and therefore help to set the right level of expectations regarding the feasibility of energy storage solutions today. This will allow the market to weed out business cases where ESS is not feasible presently and focus on the already considerable – and consistently growing – number of economically viable projects. As a result, the energy storage industry as a whole will benefit from further increased confidence in ESS as a viable alternative to non-storage solutions. ■

Authors

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