How are Lifetime Avoided Emissions (LAE) for battery energy storage systems (BESS) calculated?

In order to achieve Net Zero targets by 2050, the deployment of battery energy storage systems (BESS) at scale will be crucial to accompany the build-out of clean energy across the grid. Likewise, it is becoming increasingly important to measure and assess the environmental impact of investments in such climate change mitigation activities. This requires the creation of methodologies to measure decarbonisation efforts across multiple asset classes.

Aquila Clean Energy and the FfE jointly developed an approach to calculate the lifetime avoided emissions (LAE) of a stationary utility-scale battery energy storage system. LAE are determined by estimating the climate impact of battery production and the avoidance of greenhouse gas emission during the operational phase. The emissions in the operational phase are quantified by calculating the difference in the hourly electricity grid carbon intensity at the points in time of charging the battery and discharging the battery.

This study shows that the lifetime avoided emissions associated with BESS are positive, since the charging and discharging cycles of the BESS lead to the avoidance of grid emissions and outweigh the emissions associated with the production of the battery after a certain period.

Motivation and starting point

Capital flows directed towards global sustainability challenges are on the rise. Quantifying the environment impact of investments and their climate mitigation is therefore becoming increasingly important, with a key indicator consisting in the LAE. In collaboration with Aquila Clean Energy, FfE developed a methodology to calculate the LAE for stationary battery systems and applied it to a specific battery system.

Batteries are a key part of a decarbonised future energy system. Storing electricity balances out the volatility of renewable energy sources and ensures a stable power grid. Therefore, measuring the opportunity that BESS offers in LAE is just one of the many benefits that the technology presents.

Methodology

To calculate the LAE, the following general methodology is applied.

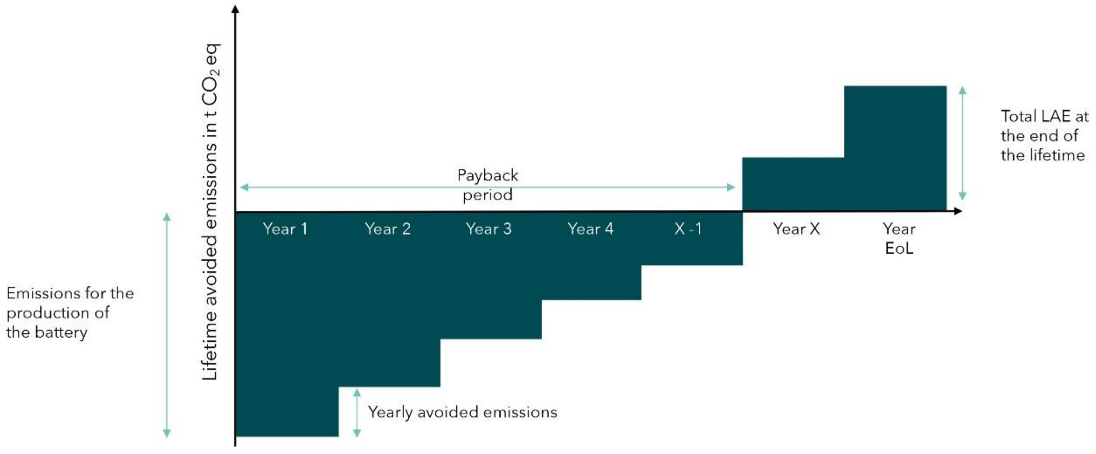

Figure 1: Calculation of Lifetime Avoided Emissions of Battery System.

LAE are determined by adding to the lifecycle climate impact of the battery system per kWh of storage capacity the avoided emissions during the operational phase. The latter are quantified with hourly load profiles. The hourly load profiles for future years are obtained with the flexibility assessment model eFlame using prices obtained from the energy system model ISAaR. As shown in Figure 1, after a certain time, the cumulative yearly avoided emissions are higher than the initial emissions to produce the battery. This time span is the payback period.

Emissions to produce the battery

Prior to any emission avoidance, there are emissions incurred at the beginning of the asset's lifetime, as shown in Figure 1, which constitute the Life Cycle Assessment (LCA) emissions generated to produce the battery. These include emissions from resource extraction, transportation, energy consumption, and other emission sources to produce the anode, cathode, battery management system, and pack housing of the battery. The case study utilises average LCA emissions per battery kWh informed by a literature review.

Calculation of avoided emissions

The emissions generated when producing the battery are subsequently offset during each year of its operation. Avoided emissions are determined by calculating the difference in the hourly electricity grid carbon intensity at the points in time of charging the battery and discharging the battery. To measure this, an hourly LCA emission factor of the national electricity mix and optimised load profiles of the battery system are required.

The data basis for the calculation of the LCA emission factor of the electricity is the composition of the current and future electricity mix, as well as emission factors for all conventional and renewable electricity generation plants. The emission factors consider the greenhouse gas emissions from all life cycle phases of the technologies, as shown in Figure 2.

Figure 2: Life cycle phases considered for power plants.

The electricity mix is provided by FfE's energy system model "ISAaR".[1] For the quantification of the hourly emission factors, the hourly generation per technology is multiplied with the LCA emission factors for each technology.

To calculate the hourly load curves of the battery system, hourly resolved day-ahead prices from the "ISAaR" model are utilised. The model FfE-"eFlame" generates a price optimised load curve, which means the battery is charged at low price levels and discharged at high price levels. One exemplary load profile for the first 1000 hours of the year 2040, with price optimized charging and an average 1.5 full cycles of the battery per day, is shown in figure 3.

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[1] To model future years, the climate protection scenario "solidEU", originating from the project "eXtremOS", is chosen. The ISAaR model generates hourly generation mixes for each European country in 5-year steps.

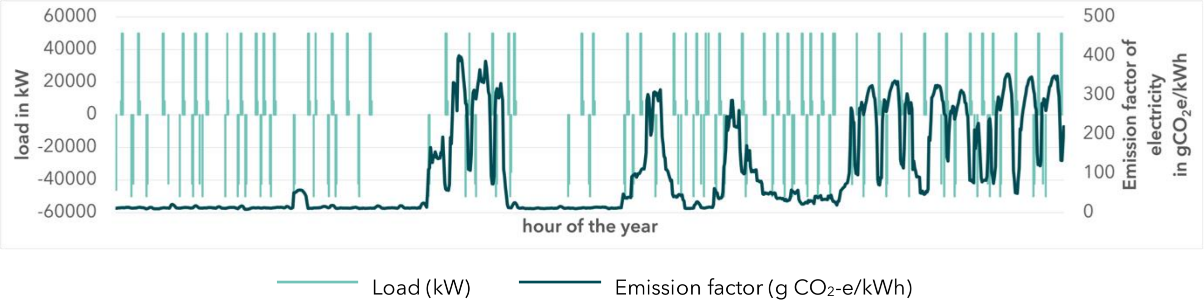

Figure 3: Exemplary results for price optimised charging in 2040 (1.5 full cycles per day).

The load curve (light green) represents the price optimised charging and discharging load profile of the battery, the dark green curve shows the LCA emission factor of the electricity mix. The battery is charged when the load curve is positive. When the battery is discharged, electricity from the grid is replaced and emissions are avoided to the extent that the discharged electricity has a lower carbon intensity. The overall emission balance during the operational phase is calculated accordingly over the lifetime of the asset, using available price scenarios for future years to interpolate the results. The methodology also considers the degradation of the battery with a downscaling of the capacity according to the expected degree of degradation for each year.

To get a better understanding of the taken assumptions and their effect on the total result, a sensitivity analysis with ten different scenarios for different optimization targets (emission optimized and price optimised) and limits of cycles per day (1, 1.5 or no limitation of full cycles per day) is conducted.

Finally, to calculate the total LAE at the end of the asset's lifetime, the LCA emissions generated in the production of the battery are deducted from the asset's yearly avoided emissions.

Main results and conclusion

Based on the methodology and assumptions laid out, battery systems yield positive LAE and therefore make a positive contribution to combating climate change.

When considering avoided emissions during the operational phase, the correlation between prices and emissions in the energy system plays an important role. As the LAE calculation shows, the price-optimised load profile of the battery implies overall emissions avoidance. This can be explained by electricity prices correlating with the increased production of electricity from renewable sources, lowering prices as more (renewable) electricity is generated. This correlation can differ for different regions and years and the frequency and magnitude of emission spreads across the grid have a strong impact on the avoided emissions during the operational phase as well.

It is worth noting that the emissions accrued during the production of the battery system have a significant impact on the total LAE. The scale of emissions during production is mainly driven by the battery chemistry, the energy density of the battery, the ratio between electricity and heat demand, the manufacturing location, and the resulting electricity mix.

The contribution of BESS to the energy transition and a decarbonised power system goes beyond the direct avoidance of emissions since batteries will be an increasingly integral part of the future energy system. BESS enables the integration of clean energy by freeing up grid capacity and provides ancillary services that ensure the stability of the electricity grid. These benefits should be considered in conjunction with avoided emissions to fully capture the role of utility-scale battery storage in the decarbonisation of the power sector.