# Levelized Cost of Storage Derivation

Table 3: Term definitions

|  |  |  |
| --- | --- | --- |
| Variable | Description | Unit |
|  | Storage medium energy capacity |  |
|  | Rated Output energy capacity |  |
|  | Rated Input energy capacity |  |
|  | Rated Power Capacity |  |
|  | Power Capacity Capital Cost |  |
|  | Energy Capacity Capital Cost |  |
|  | Electricity Price during charge |  |
|  | Electricity price during discharge |  |
|  | Discount rate |  |
|  | Round trip efficiency |  |
|  | Number Cycles per year |  |
|  | Discharge Duration |  |
|  | System Lifetime |  |
|  | Effective System Lifetime from discount rate |  |
|  | Effective System Lifetime from discount rate |  |
|  | Capacity Factor |  |
|  | Discharge Efficiency |  |
|  | Variable Operation and Maintenance |  |
|  | Fixed operation and Maintenance |  |
|  | Fixed operation and Maintenance |  |

Our technoeconomic analysis stems from a few different sources in the literature. 6–8 The purpose of this section is to review energy storage economic models in the literature and develop a simplified and a corresponding long duration figure of merit. We begin by constructing the Total Cost of Ownership (TCO) of the system. Generally following Albertus6 we write :

The first two terms in this equation are the overnight energy and power capital costs. The next set of terms represent constant payments that must be made to charge the system and pay variable and fixed operation and maintenance costs. These payment terms are indexed by the period in years during which they are paid and discounted by the discount factor The final term is the cost to replace the storage medium at some point in the system lifetime. We can see that the discounted storage medium replacement costs can be incorporated as an inflated and we neglect this term.

The can be equated to the present value of the revenue generated over the system lifetime, . We consider an arbitrage revenue stream where money is generated upon discharge of the rated energy capacity at the price . Albertus also considers a constant revenue stream for on-demand power capacity.6

For the system to be economically viable,

We can simplify the discount summations by considering the payments and income as constant values throughout the lifetime of the system (e.g. ). This is an often made implicit assumption in levelized cost of storage analyses that calculate the average price difference that must be charged over the lifetime of the system. In the case of constant annuities, the terms can be pulled out of the summations.

The remaining summations can be simplified with a geometric series into a term which we call an ‘effective lifetime’, .

represents the effective (shortened) number of years to one could collect the constant cash flows to achieve the same result as collecting the discounted cash flows over the real lifetime of the system. Figure 1 shows as a function of both the (the real lifetime) and . Figure 1a shows that for a 10% discount rate, which is close to what is assumed in many levelized cost studies, asymptotically approaches approximately 10 years. Figure 1b shows that for most lifetimes and discount rates around 10%. Therefore, we assume = 10 years.

The above equation shows that for constant cash flows over the lifetime of the system, the discount rate effectively acts as a shortening of the system lifetime as future cash flows are heavily discounted. This means that technologies with long lifetimes to not be viewed as favorably as otherwise and this is among the criticisms of discounted cash flow analysis for selecting energy technologies.[]

Chart, line chart

Description automatically generated

Figure 2: a) vs for different discount rates and b) vs discount rate (r) for different fixed

With the simplification described above the TCO=PVR equation becomes

We first simplify the number of terms with the relationships and .

We can then divide through by the discounted lifetime energy output to determine . Because we have assumed an average constant electricity price and divided by the total electricity output of the system over its lifetime this can replace with the LCOE. We also use the relationship

We can subtract from both sides to determine the required average price arbitrage, or the levelized cost of storage, . This metric has also been referred to as the ‘required average price spread’ and assumes that electricity arbitrage is the primary source of revenue.8

will be determined by DD but also the capacity factor , where . . We assume maximum accumulated discharge duration throughout a year is 4380 hours, following Albertus. This means that a CF = 1 means the charging and discharging times are equal and the system is in constant operation throughout the year.

We can then rewrite as

This equation can be rewritten converting the units of and to hours

In the text we neglect the OM terms.