Project Decision Metrics: Levelized Cost of Energy (LCOE)

Let's return to our wind power and natural gas power plant example from earlier in this lesson. Suppose that both power plants were selling electricity into the same deregulated generation market and both had the same expected operational life. Which plant would be more profitable? Since both plants would be facing the same market price for the electricity that they sell, the more profitable plant would be the one that had the lower average cost per Megawatt-hour of electricity over its entire lifetime.

The Levelized Cost of Energy (LCOE) can be used to help evaluate problems like this one, and is one of the most commonly used metrics for assessing the financial viability of energy projects. It is used particularly often in situations like the one we just discussed – comparing the lifetime costs of different technologies for electric power generation. The LCOE can, however, be applied to other energy projects as well (like oil and gas wells, or refineries).

The LCOE is defined as the energy price ($ per unit of energy output) for which the Net Present Value of the investment is zero.

The LCOE is thus the average revenue per unit of energy output (so this would be $/MWh for a power plant, or $/barrel for an oil well, for example) over a project's lifetime such that the plant breaks even. The LCOE is sometimes called the Unit Technical Cost (UTC). It represents the lifetime average cost of energy for a specific project.

We will now get into the mathematics of calculating the LCOE. We will first present the most generic LCOE formula, and then we will discuss some simplifications of the formula.

LCOE is defined as the solution to the equation:

$$\sum_{t=0}^{T}\frac{C_t+M_t}{(1+r)^t}=\sum_{t=0}^{T}\frac{LCOE\times Q_t}{(1+r)^t}=LCOE\sum_{t=0}^{T}\frac{Q_t}{(1+r)^t},$$

where C_t represents all capital costs incurred in year t (these may be zero except during the first few years of the project); M_t represents all operational costs incurred in year t, and Q_t represents the total output of the project in year t. The term $C_t + M_t$ represents the *annual costs* of the project (which may include payments on capital, fuel, labor, land leases and so forth). The term Q_t represents the annual energy output of the plant.

Note that if all capital costs are incurred in year zero, then the term C_t factors out of the LCOE equation. In this case you will sometimes see the capital cost term referred to as "Total Installed Cost" (TIC) or "Overnight Cost" (OC). In this case we write the LCOE equation as:

$$\sum_{t=0}^{T}\frac{M_t}{(1+r)^t}+TIC=\sum_{t=0}^{T}\frac{LCOE\times Q_t}{(1+r)^t}=LCOE\sum_{t=0}^{T}\frac{Q_t}{(1+r)^t}$$

In some other contexts (for those of you taking AE 878 through the RESS program, for example), you may see the discount rate *r* referred to as the "Weighted Average Cost of Capital" (WACC). We will devote an entire lesson later in the term to the relationship between the discount rate and the WACC (sneak preview: if the entity making the project investment is a for-profit entity, then the discount rate and WACC should be the same thing), and methods for calculating what the WACC should be.

We can thus solve for LCOE as:

$$LCOE=\frac{\sum_{t=0}^{T}\frac{C_t+M_t}{(1+r)^t}}{\sum_{t=0}^{T}\frac{Q_t}{(1+r)^t}}.$$

There are a couple of ways to make this calculation easier. Often times when evaluating prospective energy projects we make two assumptions:

- First, annual output of the project is constant in each year.
- Second, the variable cost of production per unit of output is constant each year.

In this case, the *Q* and *M* terms from the LCOE equation are the same in each year, and we can write the LCOE as the sum of two terms:

1. Levelized Fixed Cost (*LFC*), which calculates the average payment required to "amortize" or pay off capital costs over *T* years.
2. Levelized Variable Cost (*LVC*), which calculates the average payment required to cover per-unit operational costs.

If the variable cost of production (this would include fuel, labor and any variable operations/maintenance costs) don't change, then the LVC is just equal to this total variable cost per unit of output. Referencing the LCOE equations above, LVC would just be equal to $M \div Q$. (The LVC may also just be given in the problem statement, as in the examples below.)

Calculating LFC is a little bit more complicated. Assume that the project involves a discount rate *r;* the life of the project is *T* years; and the capital costs are paid in one lump sum *TIC* at the beginning of the project. *LFC* solves the equation:

$$TIC=\sum_{t=1}^{T}\frac{LFC}{(1+r)^t}\div Q,$$

which we can rewrite as:

$$LFC = \frac{TIC}{\sum_{t=1}^{T} \frac{1}{(1+r)^t}} \div Q.$$

Using some mathematics of finite sums (if you are really curious, Wikipedia has a detailed article on the "geometric series," which describes the denominator of the LFC equation since *r* is less than one – see http://en.wikipedia.org/wiki/Geometric_series), we can rewrite the deominator as $\frac{1-(1+r)^{-T}}{r}$.

Thus,

$$LFC = \frac{TIC}{\frac{1-(1+r)^{-T}}{r}} \div Q = \frac{TIC \times r}{1-(1+r)^{-T}} \div Q$$

and finally, we have our expression for LCOE:

$$\begin{aligned} LCOE &= LFC + LVC \\ &= \left(\frac{TIC \times r}{1-(1+r)^{-T}} \div Q \right) + LVC \end{aligned}.$$

Along these same lines, another (less messy) way to write the LCOE when output and variable costs are constant over time uses the "fixed charge rate" (FCR*)*. The FCR is just the fraction of the Total Installed Cost (TIC) that must be set aside each year to retire capital costs (which includes interest on debt, return on equity and so forth – we'll discuss these in more detail in future lessons). Thus, TIC × FCR is the annuity payment (the sum of principal plus interest payments, like you would have with a home mortgage or a college loan) needed to pay off the investment's capital cost. The FCR is calculated as:

$$FCR = \frac{r}{(r+1)^T - 1} + r.$$

(You may see or have seen the FCR equation written with the WACC rather than the discount rate *r*. Remember that for our purposes, there is really no difference between the two.)

Using the fixed charge rate, the LCOE can be written as:

$$LCOE = \left(\frac{TIC}{Q} \times FCR\right) + \frac{M}{Q}.$$

In this simpler version of the LCOE equation, note that the first term $\left(\frac{TIC}{Q} \times FCR\right)$ is just the Levelized Fixed Cost (LFC) and the second term (*M/Q*) is just the Levelized Variable Cost (LVC).

Here is an example: Suppose that a power plant costs $10 billion to build and has an expected life of 30 years. The variable cost of producing one MWh of electricity is $20. It will operate 24 hours a day, 360 days a year at a capacity of 1000 MW. (Note: to get output, multiply capacity and hours of operation over the plant's life). What is the levelized cost of energy if the interest rate is 5%?

Here is the answer: First, we calculate the total amount of electricity produced annually:

(360 days per year) × (24 hours per day) × 1000 MW=8.64 million MWh per year.

This is *Q* in our LCOE formula. LVC is equal to $20 per MWh. So, we calculate LCOE as:

$$LCOE = \left(\frac{TIC \times r}{1-(1+r)^{-T}} \div Q\right) + LVC$$

$$LCOE = \left(\frac{\$10bil \times 0.05}{1-(1+0.05)^{-30}} \div 8.64mil\right) + 20$$

$$= \$75.29 / MWh + \$20 / MWh = \$95.29 MWh.$$

As an exercise for yourself, calculate the LCOE for the natural gas power plant and the wind power plant that we laid out earlier in this lesson. As a reminder, the wind plant has a capital cost of $1.2 million and a variable cost of $5/MWh. The natural gas plant has a capital cost of $600,000 and a variable cost of $50/MWh. Each plant produces 2,628 MWh per year. Assume a 10% annual discount rate and a 20-year life for each project. You should find that the wind plant has LCOE = $58.63/MWh and the gas plant has LCOE = $76.82 per MWh.

The LCOE can be used to compare energy projects to prevailing market prices. If the market price is higher than the LCOE, then the margin per unit of output is positive (Market price – LCOE is greater than zero) and the project should be profitable. If the market price is lower than the LCOE, then the project will have negative margins and will not be profitable. There are some pitfalls to using LCOE in this way to evaluate variable renewables like wind and solar, since the LCOE is often compared to the average electricity price. If you think about it, this comparison is biased against solar and biased towards wind because solar is more likely to be producing electricity during the daytime (when prices are high) and wind is more likely to be producing electricity during the nighttime (when prices are usually low). A more consistent approach, which is just as relevant for fossil-fired power plants as for renewables, would be to compare the LCOE to the average price when you would expect the power plant to be generating electricity.