TÉCNICO LISBOA

Renewable Energy Sources and Dispersed Power Generation

Chapter 2

Economic Assessment of Renewable Energy Projects

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LIST OF ACRONYMS

IRR – Internal Rate of Return.

LCOE – Levelized Cost Of Energy.

NPV – Net Present Value.

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1 INTRODUCTION

There are plenty of opportunities to use the sun, wind, water, wood, as energy sources to produce electricity. However, it is necessary to assess the economics of the project in each case. If the renewable based electricity proves to be more expensive than the electricity produced using classical sources, the use of the new technology is discredited, leading the public opinion to evolve in an undesirable way.

Where different technical solutions are possible or where various investment opportunities are offered, it is also necessary to evaluate the available projects, so that one can decide the ones to be carried out and the ones to be disregarded.

The proper assessment of the economic viability of investments in dispersed renewable electricity generation facilities is a necessary condition for the deployment of new energy technologies to be made in a robust and convincing way. This justifies the introduction of this chapter on economic evaluation criteria for projects related to the installation of electricity production units using renewable resources.

Nevertheless, the reader is warned that only some limited aspects of the energy economics are discussed here. We shall focus on the main subjects that usually concern engineers who are called to give a view on the economic viability of investments in renewable based production of electricity.

Economic and financial assessment can be carried out at constant prices, when the effects of inflation are ignored, or at current prices, if these effects are accounted for. In periods of controlled inflation and considering that inflation equally affects revenues and expenses, an analysis at constant prices can be carried on. This option is followed in the following text.

Before we begin, it is worth to clarify the meaning of two important factors related to the power plants operation, that will be used throughout this paper: the capacity factor (Cf) and the annual utilization factor (h_a).

$$Cf = \frac{P_{avg}}{P}$$

equation 1.1

$$h_a = \frac{E_a}{P} = \frac{P_{avg}8760}{P} = 8760Cf$$

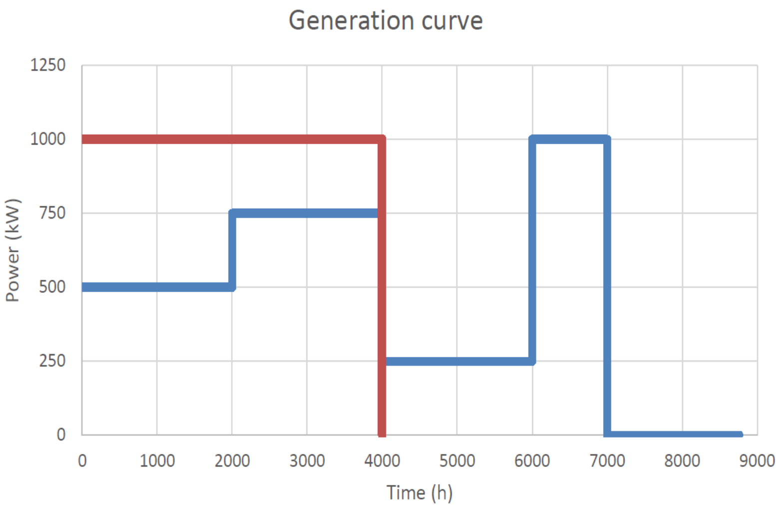
equation 1.2

In the above equations, P_{avg} is the average power, P is the maximum or installed or rated capacity and E_a is the annual produced electricity.

The annual utilization factor is measured in "hours" and represents the number of hours that a power generation installation would operate at rated capacity to produce the very same energy that it has produced operating under its own generation diagram, during the whole year. An example may help in understanding the meaning of the annual utilization factor.

Let us assume the generation diagrams (representation of power as a function of time) depicted in Figure 1-1.

The annual energy production is given by the area below the generation diagram (E_{a1} = 4 GWh; E_{a2} = 2 GWh). The installed capacity is the same ($P_1 = P_2$ = 1 MW). However, it can be seen that to produce the same energy, power generation installation 1 would need to operate for 4000 h and installation 2 for 2000 h at rated power, instead of the 8760 h that they have actually operated. Power plant 1 is being better exploited than power plant 2, because the rated capacity is being used more equivalent time.



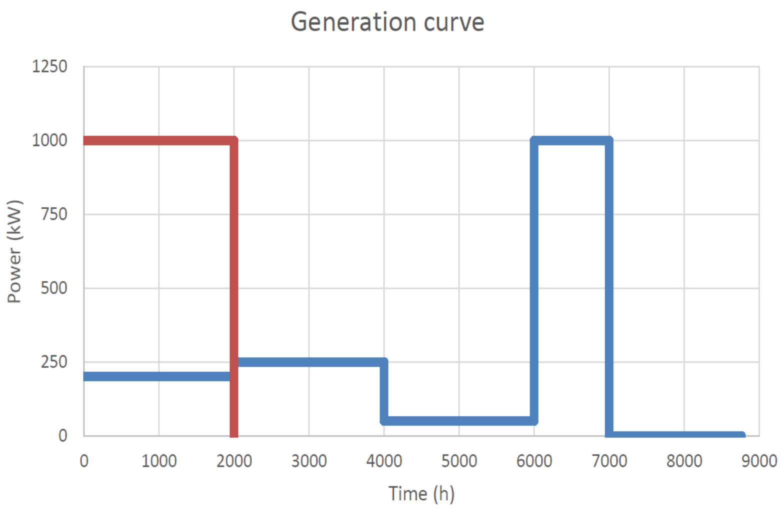


Figure 1-1: Example of two generation diagrams: blue: actual generation diagram; red: equivalent generation diagram with rated capacity operation.

2 ELECTRICITY AVERAGE COST

2.1 ANNUAL AVERAGE COST

In order to calculate the average annual cost, i.e. the cost of each unit of electricity produced in one specific year, the annual overall costs C_a (€) are divided by the annual electricity production E_a (MWh).

The cost computed in this way will change from one year to another and, as so, is not adequate to evaluate the global economic relevance of a particular electric power source. Yet, it is important to judge the economics of a project in a particular year.

The average annual cost c_a (€/MWh) can, in general, be stated as:

$$c_a = \frac{C_a}{E_a} = \frac{(i' + c_o)I_t}{E_a}$$

equation 2.1

in which:

- i': annual fixed capital cost (%)
- c_o: other annual fixed costs, (e.g. O&M) (%)
- I_t: total investment (€)

It should be remarked that we are assuming that the renewable energy project does not present variable costs, related to fuel and environmental costs. Also, we are assuming that the other costs are fixed costs.

Let us divide the numerator and the denominator by the power plant rated capacity, P:

$$c_a = \frac{(i' + c_o)I_{01}}{h_a}$$

equation 2.2

We recall that the utilization factor, h_a, is given by:

$$h_a = \frac{E_a}{P}$$ equation 2.3

and that I_{01} is the unitary investment (€/MW), i.e. the investment per unit of capacity.

2.2 Discount Rate

The annual average cost, which was introduced in the previous paragraph, may be used to monitor the project economics in a year by year basis, but it is not a proper criterion to evaluate the economic interest of projects. There are cases in which the average annual cost of a given project is the lowest, but the same project is not the most economically interesting, when analysed in an integrated perspective over a lifetime.

A known difficulty in the economic evaluation of projects results from the fact that cash inflows and outflows are staggered in time according to the most varied sequences. It is common knowledge that it is not indifferent to pay (or receive) a certain amount of money today or to pay (or receive) the same amount after a few years. The use of the discount rate allows to overcome this difficulty.

Between paying a certain amount immediately or paying it within ten years, the natural choice is for the payment after ten years. It is not the hope that the lender disappears in between that justifies the option; furthermore, the explanation does not rely on thinking that in the long term the same amount eroded by inflation corresponds to a much smaller real value.

The amount to be paid in the future may be invested during this period, after which the actual accumulated amount may be much higher than the amount that has to be paid. The money invested over time will give a real income, which justifies the option for the forward payment.

It should be emphasized that this reasoning is done with a constant price model, in which inflation is absent. Income obtained thanks to inflation is illusory, because the inflated currency loses purchasing power: the "profit" obtained in devalued currency may correspond to a real loss.

Let F_0 (€) be an amount of money available in the present time (t=0). If this amount of money is invested during t years, the total accumulated amount after t years will be F_t, which is obtained by:

$$F_t = F_0(1+a)(1+a)\ldots(1+a) = F_0(1+a)^t$$ equation 2.4

a (%) being the annual real yield of capital.

We can conclude that a payment, F_0, made today is equivalent to a (larger) payment made after t years. Conversely, a payment, F_t, made within t years amounts to a (lower) payment, F_0, made today, being:

$$F_0 = \frac{F_t}{(1+a)^t}$$ equation 2.5

It is said that F_0 is the present (or discounted) value of a payment made in time t, and F_t is the future value. The rate at which one can convert payments (or incomes) made at different times to the present time is called the discount rate.

It can then be stated that discounting is a concept associated with an arithmetic process that allows to convert an amount of money referred to a given date to the equivalent amount on another date (usually the present time). Thus, values distributed over different time instants can be converted to discounted values at the present time, and, providing that they are expressed in the same units, can be added.

The foregoing also shows that the concept of discount rate is linked to the concept of real rate of return of an investment, also known as opportunity cost of capital. Thus, the discount rate is nothing more than the minimum profitability that the investor requires to invest in a given project.

Usually, enterprise sponsoring organizations have their own guidelines for setting the discount rate, which should reflect the minimum rate of return available for the capital invested and the risk associated with the investment option.

For the private sector, it is important that the discount rate is determined by examining known similar transactions, because the project will be implemented in a market environment. On the other hand, governmental organizations may use the reference discount rate recommended by the state banking institutes, for the economic activity sector in which the project is to be deployed.

Finally, it should be noted that the discount rate does not coincide – except in a perfect market, which does not exist – with the bank interest rate, although the two rates are somewhat related. For instance, if the investment is financed through a loan (which is a common practice) at a fixed interest rate, this will influence the required rate of return and, therefore, the discount rate.

2.3 LEVELIZED COST OF ENERGY (LCOE)

The average annual cost is significant for each year. However, it is less significant if the evaluation period extends from the time of the investment decision till the end of the power plant lifetime.

In order to obtain the discounted average cost, usually known as Levelized Cost Of Energy (LCOE), the different cost parcels (e.g. investment, O&M and others) and the total electricity production are separately discounted over the lifetime of the renewable power plant or during a given analysis time period. Discounting means to compute the present value.

Let us denote the each discounted cost parcel by c_{di} (€) and the total discounted electricity production by E_d (MWh). So, the LCOE (€/MWh) will be given by:

$$LCOE = \frac{\sum_{i=1}^{n_c} c_{di}}{E_d} \qquad \text{equation 2.6}$$

where n_c is the number of cost parcels.

Discounting consists of calculating the amount of payments and revenues made on different dates as if they were all made at time t=0 (for example, the time at which the economic evaluation of the project is being carried out).

A general model may admit that both money inflows (energy sales) and money outflows (investment, O&M, ...) are erratically distributed during the analysis timeframe. However, in this paper, we will assume that:

- Expenses are due on the first day of the year during which they are paid.
- Revenues enter on the last day of the year during which they are actually received.

We will know detail each cost parcel and the discounted electricity production:

2.3.1 Discounted cost parcel 1 – Investment cost

A fairly general model may consider that the investment is distributed over N years prior to t=0 and n-1 years after t=0 (n is project lifetime). Given these conditions, the discounted investment cost, c_{d1}, is:

$$c_{d1} = I_{td} = \sum_{j=-N}^{n-1} \frac{I_j}{(1+a)^j}$$

equation 2.7

where a is the discount rate (%), I_j (€) is the investment in year j and I_{td} (€) is the total discounted investment.

Of course, if the investment is fully concentrated at the initial time instant (t=0), the investment cost does not require any discounting and is given by (I_t is the total investment):

$$c_{d1} = I_t$$

equation 2.8

The capacity of renewable power plants is relatively small and the equipment deployment is a rapid procedure. As so, consideration of this hypothesis usually involves a minimal error.

2.3.2 Discounted cost parcel 2 – O&M cost

We shall consider that the O&M costs are fixed costs and as so they may be introduced as a percentage of the total investment. We recall that the total investment is a fixed cost as it depends on the capacity of the power plant. Variable costs (fuel costs and CO2 emissions costs) are not considered as we are dealing with renewable based power plants.

The discounted O&M costs are due during the power plant lifetime (which begins in t=1) and may be computed as:

$$c_{d2} = I_t \sum_{j=1}^{n} \frac{c_{omj}}{(1+a)^j}$$

equation 2.9

where c_{omj} (%) are the O&M costs in year *j*, given as a percentage of the total investment I_t.

2.3.3 Discounted electricity production

The electricity production may be discounted as follows:

$$E_d = \sum_{j=1}^{n} \frac{E_{aj}}{(1+a)^j} = P \sum_{j=1}^{n} \frac{h_{aj}}{(1+a)^j}$$

equation 2.10

where E_d (MWh) is the discounted electricity production, E_{aj} (MWh) is the electricity production in year *j*, *P* (MW) is the power plant rated capacity and h_{aj} (h) is the power plant utilization factor in year *j*.

Accordingly to equation 2.6, the LCOE is given by:

$$LCOE = \frac{c_{d1} + c_{d2}}{E_d} = \frac{\sum_{j=-N}^{n-1} \frac{I_j}{(1+a)^j} + I_t \sum_{j=1}^{n} \frac{c_{omj}}{(1+a)^j}}{P \sum_{j=1}^{n} \frac{h_{aj}}{(1+a)^j}}$$

equation 2.11

2.4 LCOE Simplified Model

Let us assume that:

- The total investment is concentrated at the initial instant, t=0, and is denoted by I_t.
- The annual utilization factor is constant throughout the power plant life time and equals h_a.
- O&M expenses are constant over the power plant lifetime and equal c_{om}.

We shall define the factors k_a and i as (note that the sum of the series is given by the indicated analytical expression):

$$k_a = \sum_{j=1}^{n} \frac{1}{(1+a)^j} = \frac{(1+a)^n - 1}{a(1+a)^n}$$

$$i = \frac{1}{k_a} = \frac{a(1+a)^n}{(1+a)^n - 1}$$

equation 2.12

Given these conditions, equation 2.11 becomes:

$$LCOE = \frac{I_t + c_{om} I_t k_a}{E_d k_a} = \frac{I_t (i + c_{om})}{E_d}$$

equation 2.13

Or, if one divides by the power plant rated capacity, the LCOE may be computed through:

$$LCOE = \frac{I_{01}(i + c_{om})}{h_a}$$

equation 2.14

Example 2—1:

The capacity factor of a 10 MW wind park is 28.54%. The investment is 1.2 M€/MW, the expected lifetime is 20 years and the annual O&M costs are 1.5%.

Compute the LCOE (€/MWh) for a 7% discount rate.

Solution:

The solution is given by equation 2.14:

$$LCOE = \frac{I_{01}(i + c_{om})}{h_a} = \frac{1.2 \times 10^6 (0.0944 + 0.0150)}{0.2854 \times 8760} = 52.51 € / \mathrm{MWh}$$

3 ECONOMIC ASSESSMENT INDEXES

The evaluation criteria for profitability that are commonly used to measure the economic interest of projects may appear to be objective, but in reality they are not. They count for sure on future expenses and revenues, and the future is, as we know, more or less uncertain. Thus, when the parameters that determine the evaluation (costs, revenues, equipment lifetime, O&M costs and others) are admitted as certain, this results more from the mental attitude of the evaluator than from objective evidence. As a consequence, it is more correct to state that the project's economic assessment is to be obtained based on a forecast of the required data.

In what follows, we assume that cash outflows occur irregularly from t=0 to t=n-1 and that revenues are also obtained irregularly from t=1 to t=n. The previous convention is kept for the dates on which expenses and revenues are due.

Net Present Value (NPV) and Internal Rate of Return (IRR) are the most commonly used economic assessment indexes for the evaluation of investment projects in dispersed renewable power plants.

3.1 NPV – NET PRESENT VALUE

3.1.1 NPV general model

NPV is the difference between discounted cash inflows and outflows, the so-called cash-flows, during the project's lifetime (*n* years):

$$NPV = \left(\sum_{j=1}^{n} \frac{R_j}{(1+a)^j} + \frac{V_S}{(1+a)^n} \right) - \left(\sum_{j=0}^{n-1} \frac{I_j}{(1+a)^j} + I_t \sum_{j=1}^{n} \frac{c_{omj}}{(1+a)^j} \right) \quad \text{equation 3.1}$$

where R_j is the revenue coming from the electricity sales in year j and V_S is the salvage value due in $t=n$.

A positive NPV is a sign of the economic viability of the project. It means that the results achieved cover the initial investment, as well as the minimum remuneration required by the investor (represented by the discount rate), and also generate a financial surplus. A zero NPV means full recovery of the initial investment, plus the minimum income required by investors and no more than that, so the profitability of a project with these characteristics is uncertain. A negative NPV is a clear indication of the economic non-viability of the project.

It is interesting to note that the higher the discount rate considered in the NPV calculation, the lower NPV will be obtained, since a higher return on the project investment is required.

3.1.2 NPV simplified model

If the simplified model assumptions, introduced earlier in this paper, hold true, and furthermore the salvage value may be neglected, and the annual revenue is constant and equal to *R* during the project's life time, then equation 3.1 becomes:

$$NPV = \left(R - e_{om}\right)k_a - I_t \qquad \text{equation 3.2}$$

where e_{om} are the total annual O&M expenses.

3.2 IRR – INTERNAL RATE OF RETURN

3.2.1 IRR general model

The Internal Rate of Return (IRR) is the discount rate that cancels the NPV. Then, from equation 3.1 results that the IRR (%) will satisfy:

$$\left(\sum_{j=1}^{n}\frac{R_j}{(1+IRR)^j}+\frac{V_S}{(1+IRR)^n}\right)=\left(\sum_{j=0}^{n-1}\frac{I_j}{(1+IRR)^j}+I_t\sum_{j=1}^{n}\frac{c_{omj}}{(1+IRR)^j}\right) \qquad \text{equation 3.3}$$

The IRR assessment immediately places the interest of the project on the financial market evaluation scale, which is not the case of the NPV.

An IRR greater than the discount rate considered in the NPV computation means that the project is able to generate a rate of return higher than the opportunity cost of capital. We are therefore facing an economically viable project. The opposite situation means that the required minimum profitability is not achieved.

3.2.2 IRR simplified model

In the general case, the IRR computation from equation 3.3 can be solved using iterative methods, which makes the IRR calculation a complicated task. This scenario is somewhat attenuated in the simplified model conditions. The equation to be solved is as follows, IRR being the unknown:

$$R_N \frac{(1+IRR)^n - 1}{IRR\,(1+IRR)^n} = I_t \qquad \text{equation 3.4}$$

where R_N is the net annual revenue:

$$R_N = R - e_{om} \qquad \text{equation 3.5}$$

It is apparent that equation 3.4 is easier to solve, although it does not dispense the use of iterative methods, for example, a simple Gauss method can be applied. For this purpose, equation 3.4 can be written in a form suitable to apply the method (take note that (k) is the order number of the iteration).

$$IRR^{(k+1)} = \frac{R_N}{I_t} \frac{\left(1+IRR^{(k)}\right)^n - 1}{\left(1+IRR^{(k)}\right)^n} \qquad \text{equation 3.6}$$

Usually, convergence, with a small error (let's say 0.01), is obtained in 3 to 4 iterations. To obtain a faster convergence a Newton-type method can be used, but it is much more complicated to implement.

3.2.3 IRR approximate computation

Often, in practice, an expedite IRR calculation is required for a fast estimate. For this purpose, it is usual to use an approximate IRR computation by means of a linear interpolation. It has already been mentioned that NPV decreases with the discount rate increase. Figure 3-1 illustrates the nonlinear, typical variation of the NPV with the discount rate.

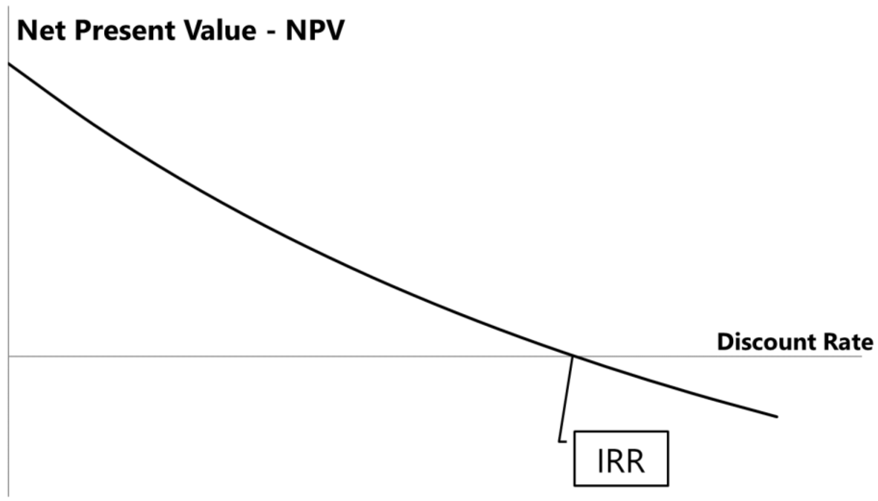


Figure 3-1: Variation of NPV with the discount rate.

As depicted in the figure, the IRR is the discount rate that cancels the NPV. The IRR value can be obtained, approximately, by linearizing the section of the curve around the point of nullification. For this purpose, two NPV values are calculated, one positive (NPV_1) and one negative (NPV_2), corresponding to the discount rates a_1 and a_2, respectively. It is easy to verify that the line passing through these two points has a zero at the abscissa point:

$$IRR \approx a_1 - (a_2 - a_1)\frac{NPV_1}{NPV_2 - NPV_1} \qquad \text{equation 3.7}$$

Example 3—1

Retake Example 2—1 and compute the NPV and IRR, considering that the Feed-In Tariff is 75 €/MWh.

Solution:

Considering the given data, we will use the NPV simplified model (equation 3.2).

$$\begin{aligned} NPV &= \left(R - e_{om}\right)k_a - I_t = \\ &= (75 \times 10 \times 0.2854 \times 8760 - 0.0150 \times 1.2 \times 10^6 \times 10) \times 10.5940 - 1.2 \times 10^6 \times 10 = \\ &= 5{,}956{,}854€ \end{aligned}$$

As far as the IRR is concerned, if the simplified model (equation 3.4) is used:

$$IRR^{(k+1)} = \frac{R_N}{I_t}\frac{\left(1+IRR^{(k)}\right)^n - 1}{\left(1+IRR^{(k)}\right)^n} =$$

$$IRR^{(k+1)} = \frac{1{,}695{,}000}{12{,}000{,}000}\frac{\left(1+IRR^{(k)}\right)^{20} - 1}{\left(1+IRR^{(k)}\right)^{20}}$$

Iteration (k)	IRR
0	10%
1	12.03%
2	12.67%
3	12.82%
4	12.86%
5	12.87%

The result is IRR=12.87%.

Using the IRR approximate computation (equation 3.7):

$$IRR \approx a_1 - (a_2 - a_1)\frac{NPV_1}{NPV_2 - NPV_1} =$$

$$= 0.07 - (0.13 - 0.07)\frac{5{,}956{,}854}{-93{,}046 - 5{,}956{,}854} =$$

$$= 0.1291$$

Note that for a_2=13%, NPV_2=-93,046 €. The other required point is a_1=7%, NPV_1=5,956,854 €.

The result is IRR=12.91%, which is a very good approximation of the real IRR.