Reporting Expenses and Revenues of RE-supplies: Net Present Value and Levelised Costs.

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The CC-meeting on metrics agreed to report cost functions of RE-technologies for at least two levels of deployment (realisation of particular potentials) and on Levelised Costs per MWh energy (power or heat) generated by renewable energy sources / technologies. Because not all participants were familiar to discounted cash flow analysis, a brief introduction (reminder) of basic concepts is given below.

The Spreadsheet Calculator

A request was received to generate a spreadsheet designed to help calculate cost components necessary for comparison of technologies by providing life cycle costs (levelised costs) of projects as well as net present values (NPV). For this calculation, the analyst needs to know:

- Expenses incurred by the project
    - Capital costs over the duration of installation of the project
    - Annual costs including maintenance and operating costs, energy purchase costs, major retrofits or refit costs expected for the life of the project
- Revenues generated by the project; in this case, the annual generation of energy in energy units (MWh, TWh, etc.)
- Life of the project which can be a fixed number of years (*n*) or may have an unknown life beyond the "expected" life.[1]
- Decommissioning or postmortem expense / revenue stream of the project
    - Costs associated with the termination of a project implies that the life = *n*
    - An estimate of the continuing costs / revenues of the project past its "expected" life

The spreadsheet contains instructions for data energy and provides opportunity for the user to evaluate different life times and discount rates. The basic concepts given below are designed to provide guidance to the analyst in their assessment of Life Cycle Costs associated with RE technologies and strategies.

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[1] Projects are often given a nameplate life, the "expected" life – a wind mill lasts X years, a hydro dam lasts Y years – but they may actually operate much longer (a hydro site, whose expected life is 60 years, may continue operate for 100 years) or have costs incurred beyond the actual life of the project (silviculture costs associated with cellulosic biomass generation in a particular area may be incurred well beyond the biomass generating life of that site).

Contents:

1. Use of "constant = real" values

The issue of discounting is making 'numbers' that occur at various moments in time (for simplicity: in various **years**) comparable by reducing them to a single number anchored at one particular year (point 0 in time or reference year). This is almost analogous to converting sums of money in different currencies to a single currency so they can be compared, added, etc. Also energy quantities in different metrics are not additive; one first has to convert the quantities to numbers in the same unit (MWh, GWh or TWh). Similarly, money and values available at different moments in time own a different value and have to be converted to a common basis.

We have agreed to **execute all analysis in "constant" also called "real[2]" prices [i.e., free of inflation] based in a particular year**, **2005, and expressed in USD.**

For exchanges among currencies, use Market Exchange Rates as default option. Specific studies may also use Purchasing Power Parities, but should state this clearly. **The TSU provided MER tables to be used in this conversion**.

When the monetary series in the analysis are in real prices, consistency requires that the **discount rate should be real** [free of inflationary components]. This consistency is often not obeyed because studies refer to "observed market interest rates" or "observed discount rates", i.e., nominal rates that include inflation or expectations about inflation. "Real / constant" interest rates are never directly observed, but derived from the ex-post identity: $(1+n) = (1+i) * (1+f)$ with n = nominal rate; i = real or constant rate; f = inflation rate [all in % points]. The reference year for discounting and the base year for anchoring constant prices may differ in studies.

2. Example project

We take the example of a single project with information on all its **EXPENSES** and on all its **REVENUES**. We must agree what is included and what is excluded:

- **REVENUES** = generation of RE MWh or other chosen energy unit (nothing else: when there is some other return related to the functioning of the project, one should see this as negative expenses and subtract it from the positive expenses)

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[2] The economists' term "real" may be confusing because what they call real is not the observed financial flows (named "nominal" and including inflation); "real" reflects the real purchasing power of the flows.

- **EXPENSES** = all cash that leaves the pocket of the project owner in a given year; maintenance, retrofit, refit, remediation, etc. NOTE: It **excludes** financing costs (loans, interest, mortgage payments) when the investments are fully taken into account the year they actually occur.[3]

Table 1: Example Levelised Cost Analysis

Net expenses per year in constant 2005 USD and generated MWh RE, all values fictional.

[1] **Actual year**	[2] **Project year**	[3] **Expenses USD-2005 costs**	[4] **RE generated MWh**	[5] **Disc. Expenses (3%)**	[6] **Disc. MWh (3%)**
2005	0	100,000	0	100,000	0
2006	1	40,000	600	38,835	583
2007	2	2,000	700	1,885	660
2008	3	2,000	800	1,830	732
2009	4	2,000	900	1,777	800
2010	5	2,000	1,000	1,725	863
2011	6	2,000	1,000	1,675	837
2012	7	2,000	1,000	1,626	813
2013	8	2,000	900	1,579	710
2014	9	2,000	800	1,533	613
2015	10	10,000	700	7,441	521
2016	11	2,000	1,000	1,445	722
2017	12	2,000	1,000	1,403	701
2018	13	2,000	1,000	1,362	681
2019	14	2,000	900	1,322	595
2020	15	2,000	800	1,284	513
2021	16	2,000	700	1,246	436
2022	17	2,000	600	1,210	363
2023	18	2,000	500	1,175	294
2024	19	2,000	500	1,141	285
2025	20	10,000	500	5,537	277
2026	21	2,000	1,000	1,075	538
2027	22	2,000	1,000	1,044	522
2028	23	2,000	1,000	1,013	507
2029	24	2,000	900	984	443
2030	25	2,000	800	955	382
2031		100,000	0	46,396	
Sums:	**25**	**304,000**	**20,600**	**228,471**	**14,391**

Note: Cost and production vary over time in this example (significant maintenance occurs are year 10 and 20) but may not be so in all cases. The final year, not included in the project life, is a Decommissioning Cost and is included in the Levelised Cost.

One also has to agree on **inclusion (YES/NO) of subsidies to RE projects; Recommended: NOT include, but mention separately.**

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[3] If this rule is not applied, double-counting occurs. One can choose to include the repayment (including interest) of the loan in the year the payment was made but this method is less recommended because loan interest rates typically include inflation expectations.

The columns [1] to [4] show the basic information that a textbook project analysis may deliver:

- actual years of occurrence of expenses and of RE generated;
- project years (mentioned for ease of use);
- net expenses [i.e., costs minus 'ancillary' benefits, etc.] in constant 2005 USD;
- generated RE in MWh.

Table 1 shows net expenses and generated RE fluctuate over time, as may be the case in real world RE sources and technologies. At the bottom of the columns the simple addition of non-discounted values is shown: the project spans 25 years, the simply added expenses amounts to $304,000 USD2005 and RE generated to 20,600 MWh.

3. Discounting and NPV (Net Present Value)

Private people assign less value to things in the future than to things in the present because of "time preference for consumption" or because of "return on investment (= non-consumption)". So, people discount the future. Discounting itself is a mathematical operator: dividing future cash flows by a number > 1. By discounting to the base year numbers are converted to a common metric. Discounting a series of net cash flows (= revenues - expenses) over time and adding the results (permitted now because they all are stated in the same reference year – point 0 of the analysis), the NPV is obtained:

$$NPV = \sum_{j=0}^{n} \frac{Net\ cash\ flows(j)}{(1+i)^j}$$

The value of NPV depends on the yearly net cash flows and on **two parameters**: the **lifetime *n*** of the project and the **discount rate *i***. In principle, project results are fully cross comparable when their NPVs are calculated with the same parameters *n* and *i*.

Only use REAL discount rates [values decided in Oslo in brackets]
2~3 % when analyzed from **a public interest perspective [3%]**
4~5% when **private projects without additional risk premium [7%]**
5 + RP% when **an argued risk premium (RP) is added [10%]**

Because the expenses are free of all inflation the discount rate *i* also should not include an inflation factor. This means that applied discount rates should generally be lower than observed interest rates (because inflation rates are generally > 0). From a societal (public) point of view, arguments are convincing to use a (very) low discount factor for projects that promote global common goods in the long term.

In private projects, a risk premium is often added to the discount rate; note that this method assumes that the actual risks in the project compound year after year over the time period. In exceptional cases this may be true; in many cases risks may be connected only to the investment aspect nearby in time, or at time of refurbishment or of decommissioning. For the first investment risk case, one could include risk in the capital cost of the technology using an "expected capital cost" value. Thus, the cost of, say, an efficient light bulb is $10 in year one plus the probability of having to replace it in year 2 (say 0.1 x $9, using a straight line depreciation), plus the probability of having to replace it in year 3 (0.1 x $8), plus ... Thus, it might be that the NPV of the expected capital cost is $14 instead of $10. By using the suitable method, each technology type or project can be assessed for its own risk (provided the analyst can determine and adjudicate that risk impartially). While no decision has been made about this in SRREN, we may wish to address this at the next meeting in Oxford.

Column [5] of the table shows the values of the net expenses discounted at 3%, adding to a **NPV of $228,471 USD 2005 in the 0 year of the project (in the example, the year the project began was also 2005; other years can be chosen for start years)**.

4. Levelised Cost (Life Cyle Cost LLC)

Levelised costs are used in the appraisal of conventional power generation investments, where the outputs are quantifiable MWh generated during the lifetime of the investment.

The Levelised Cost is the unique **break-even price** – constant during the full lifetime of the project – that sets DISCOUNTED REVENUES equal to the DISCOUNTED NET EXPENSES. So it is solved from the following identity:

$$\sum_{j=0}^{n} \frac{\mathrm{Re}venues(j)}{(1+i)^j} = \sum_{j=0}^{n} \frac{Expenses(j)}{(1+i)^j}$$

or:

$$\sum_{j=0}^{n} \frac{C_{Lev} * Quantities(j)}{(1+i)^j} = \sum_{j=0}^{n} \frac{Expenses(j)}{(1+i)^j}$$

Because C_{Lev} is a constant non dependent on the year index j one can bring it before the Σ sign, and one finds:

$$C_{Lev} = \sum_{j=0}^{n} \frac{Expenses(j)}{(1+i)^j} \Bigg/ \sum_{j=0}^{n} \frac{Quantities(j)}{(1+i)^j}$$

This definition of levelised cost discounts both expenses and revenues in the same way. The ‘discounting of quantities’ may seem inappropriate to some but we consider here the value of the revenues even though they are not in USD but in MWh (i.e., a MWh today is worth more to you than a MWh in the future – we assume the same time value can be applied here as we apply to costs).

In the example the C_{Lev} is the division of $228,471 by 14,391 or **$15.88 USD2005/MWh**.

5. Annuities and the annuity factor

A very common practice is the conversion of a given sum of money at moment 0 into a number *n* of constant annual amounts over the coming *n* future years. This is what households experienced as the mortgage they annually (sum of monthly payments) have to pay off for the cash they received from the bank to pay the house they bought. This is a clear example of what discounting means:

Let A = annual constant amount in mortgage payments over *n* years.
Let B = cash amount to pay for the house in year 0

How does the bank (and we) derive A from B? The answer is simply that the bank wants to receive B back at the time preference rate *i*. The NPV of the *n* times A receipts in the future therefore must exactly equal B:

$$\sum_{j=1}^{n} \frac{\mathrm{A}}{(1+i)^j} = \mathrm{B}, \text{or: } \mathrm{A}\sum_{j=1}^{n} \frac{1}{(1+i)^j} = \mathrm{B}$$

We can bring A before the summation because it is a constant (not dependent on *j*).

The sum of the discount factors (a finite geometrical series) is deductible as a particular number. When this number is calculated, one finds A by dividing B by this number.

This is known as the **Capital Recovery Factor (CRF)** but may be better known as the **ANNUITY FACTOR "δ"**:

$$\delta = \frac{i \times (1+i)^n}{(1+i)^n - 1}$$

Observe that the annuity factor δ is also dependent on the two parameters *i* and *n* (as was the NPV above). The factor is very useful for spreading an amount at a given moment in time over a number *n* of years, while taking into account the time value *i* of money. Other methods (e.g., arithmetical average) do not own that property.

6. Shortcut assessment of C_{Lev} with the annuity factor

In small projects and in back-of-the-envelop assessments one can assume there is only capital investment as an expense (= US$-2005 'B' in year 0) and a constant amount of MWh generated during all years of the lifetime (= 'Q' during years 1 …n). The basic expression of the break-even price is reduced to:

$$\sum_{j=1}^{n} \frac{C_{Lev} * Q}{(1+i)^j} = \mathrm{B}, \quad \text{or:} \quad \{\mathrm{C}_{\mathrm{Lev}} * \mathrm{Q}\}\sum_{j=1}^{n} \frac{1}{(1+i)^j} = \mathrm{B}$$

Or:

$$\mathrm{C}_{\mathrm{Lev}} * \mathrm{Q} = \mathrm{B} * \delta, \quad \text{or: } \mathrm{C}_{\mathrm{Lev}} = (\mathrm{B} * \delta)/\mathrm{Q}$$

This shortcut is only useful when simple projects are considered.

7. Lifetimes of projects and post-mortem issues

As stated in section 3, the NPV formula contains the two parameters *i* (discount rate) and *n* (lifetime; horizon of the analysis). In practice, projects that obey the simple textbook condition of disappearing completely after year *n* may be an exception. Typically, there are "**terminal conditions**". Let's consider two cases.

In the first case, a project at year *n* creates a particular "residual value" cash flow R, a revenue (e.g., one can sell the site, or scrap metals, etc.) or an expenditure (one must pay for a decommissioning or clean up). Such one-time residual cash flows R are simply added to the table in year *n*, or an extra year [*n*+1] is added to host R and discounted over (*n*+1) years. So, this brings no extra problems; the project simply terminates at *n* or [*n*+1].

Usually, one does not include the decommissioning year as a year in the life of the project. See Table 1, Year 2031.

The second case is somewhat more complex and sees the project's life with an undefined ending. Analysts know that costs in the future become less and less reliable the further the horizon stretches (further than horizon *n*). Therefore, they prefer to limit the horizon *n* to some more acceptable value (15, 20, 25 years), especially when their project lasts much longer in a so-called "stationary" state assumed to persist up to "infinity". The crucial issue here is the definition of that stationary or frozen state. Two **mutually exclusive** situations may occur:

Situation X: The frozen state represents the "average performance" of the project over the analyzed period *n* of both expenditures and energy output. This method assumes that the post-mortem life of the project continues indefinitely (recall that the impact of an extended time horizon has increasingly little impact on NPV or LCC) at expenses and revenues equivalent to the last year, *n*. This average is calculated as an "Equivalent annual value" with the annuity factor over the lifetime *n* of the project and continued into infinity. By construction, the C_{Lev} will stay the same after the considered lifetime as the C_{Lev} over the first lifetime. The mathematics are:

$$\frac{[NPV(i,n) \times \partial(i,n)]/i}{(1+i)^n}$$

This means that one first computes the **annuity of the NPV** over the lifetime of the detailed analyzed project as NPV(*i,n*) x δ(*i,n*) . This annuity is assumed to persist to infinity after the lifetime *n,* from (*n*+1) to infinity. The NPV at year 0 of the infinite series is obtained in a double step:

- Step 1: the NPV at year *n* is calculated by discounting from *n*+1 to infinity the given annuity (mathematically it means dividing by the discount rate *i*).
- Step 2: because this particular NPV over the post-mortem period is still anchored at year *n* it has to be discounted back to year 0 to obtain a NPV at year 0 (this is the division of the step 1 result by $(1+i)^n$ in the formula above).

Situation Y: A project ceases to deliver energy at time *n* but leaves a decommissioning passive expenditure Y_e bequest forever (perhaps silviculture costs for biomass; maintenance of nuclear waste is the standard example) and / or a project's expenditures end at year *n* while it continues to deliver annually a flow of energy Y_s forever (e.g., a self-running hydro station without expenditures). When this is the case, one can add to the expenditures or to the energy generation columns in the year (*n* +1) the following quantity:

$$\frac{Ye/i}{(1+i)^{n+1}} \quad \text{and/or} \quad \frac{Ys/i}{(1+i)^{n+1}}$$

This case is different from Situation X in that one has good information that the post-mortem expenses and/or revenues (or both) of the project do NOT continue at the average as in Situation X.

NOTE: A value for Y_e/i and/or Y_s/i have to be included in the spreadsheet at line *n*+1, when option Y is chosen (mutually exclusive of option X). The spreadsheet (see Section

9 below) automatically calculates this if you place the appropriate values in the n+1 cell highlighted in yellow.

8. Propositions on practical choices

Because other methods are more open to inaccuracies and differences in defining and in computing 'constant yearly operating costs' or 'constant yearly generation', etc… the standard discounting formulas as illustrated above, are recommended. Authors should provide full information, as follows:

- The <reference year> of the prices [default is 2005 as agreed, but best is to note the year anyhow] + specify that the analysis was done in constant prices, 2005 USD
- The <lifetime> of the project or span time of the analysis [<first year>, <last year>]
- The applied <discount rate> [the real rate when real or constant prices apply]
- The <base year> of discounting [most studies use the first year of the lifetime]
- The <NPV of the net revenues> in the base year
- The <NPV of the RE generated> in the base year
- The < C_{Lev} > [divide the two preceding numbers]
- The non-discounted sum of the generated RE in Wh (GWh, TWh, …)

9. A spreadsheet for analyzing cases

Associated with this document is a spreadsheet (Calculation of LCC V6 Verbruggen-Nyboer.xls) provided for ease of NPV and LCC calculations.