MIT Portugal

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Renewable Energy Resources (RER)

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Economic assessment of renewable energy projects

Chapter 2

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Profitability of a project

- Capital costs (€/MW)
- Minimum rate of return (%)
- Price paid for the electricity (€/MWh)
- Annual utilisation factor (h)

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DISCOUNT RATE

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Discount Rate

r: Discount Rate

$$F_0$$

$$F_1 = F_0 + rF_0 = F_0(1+r)$$

$$F_2 = F_0(1+r) + rF_0(1+r) = F_0(1+r)(1+r) = F_0(1+r)^2$$

$$F_n = F_0(1+r)^n$$

$$F_0 = \frac{F_{t1}}{(1+r)^{t_1}}$$

- Cash inflows and outflows are spread over a period of time and time has a monetary value
- For instance, if possible, the natural choice is to pay in the future.
- **Why?**
  - The amount to be paid in the future may be invested.
  - The actual accumulated amount may be much higher.
  - The money invested over time will give a real income.

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- Discount rate or effective interest rate (**r**)
  - Allows to convert a value referred to a date to an equivalent amount referred to another date (usually the present time)
  - Appreciation of the investment
  - Minimum profitability that the investor requires to invest in a given project
  - Capital recovery at a certain remuneration + risk reward

LEVELIZED COST OF ENERGY (LCOE)

Production cost

$$C_T = C_F + C_V = CP + cW_a$$

CT is the total annual cost (€)

$$F_0 = \frac{F_{t1}}{(1+r)^{t_1}}$$

r is the rate of return or discount rate

$$I_{01} = \frac{A_T}{(1+r)} + \frac{A_T}{(1+r)^2} + \ldots + \frac{A_T}{(1+r)^n} = A_T \sum_{j=1}^{n} \frac{1}{(1+r)^j}$$

I01 is the investment per MW (€/MW)

AT is the investment annuity

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

$$\alpha = \frac{1}{k_a} = \frac{r(1+r)^n}{(1+r)^n - 1}$$

$$I_{01} = A_T \frac{(1+r)^n - 1}{r(1+r)^n} = A_T k_a$$

$$A_T = \frac{r(1+r)^n}{(1+r)^n - 1} I_{01} = \alpha\, I_{01}$$

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Production cost

$$C_F = CP = (\alpha + \beta)\, I_{01} P$$

The fixed O&M costs must be added to the annuity. They are assumed to be proportional to the investment per MW, the proportionality factor being β.

$$C_T = (\alpha + \beta) I_{01} P + c W_a$$

The variable cost ***c*** includes the fuel cost and the cost of CO2 emissions, when applicable.

$$C_{T01} = \frac{C_T}{P} = (\alpha + \beta) I_{01} + c h_a$$

Annual total production cost per installed MW

I01 is the overnight cost

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LCOE and marginal cost

$$LCOE = C_{avg} = \frac{C_T}{W_a} = \frac{CP}{W_a} + c = \frac{C}{h_a} + c = \frac{(\alpha + \beta)I_{01}}{h_a} + c$$

LCOE – **Levelized Cost Of Energy**

$$c_{mrg} = \frac{\partial C_T}{\partial W_a} = c$$

Marginal cost - Cost of the last unit produced

To ensure the economic sustainability of the power station in the short-term, the marginal cost must be recovered through the sale of electricity (price p).
This condition imposes: ***p>=cmrg***

To ensure the economic sustainability of the power station in the long run, the average cost must be recovered through the sale of electricity (price p).
This condition imposes: ***p>=*LCOE**

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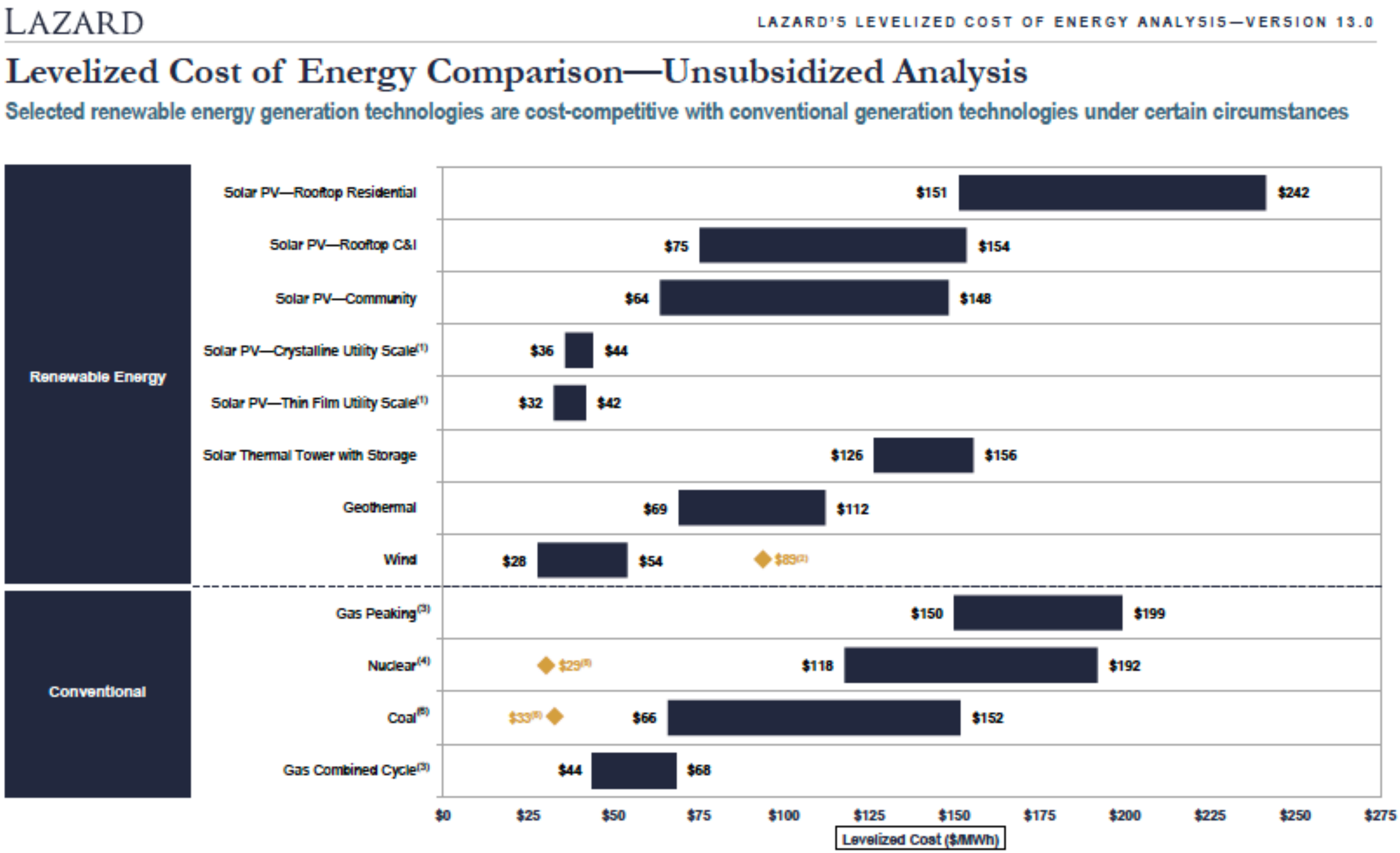
LCOE Comparison ($/MWh)



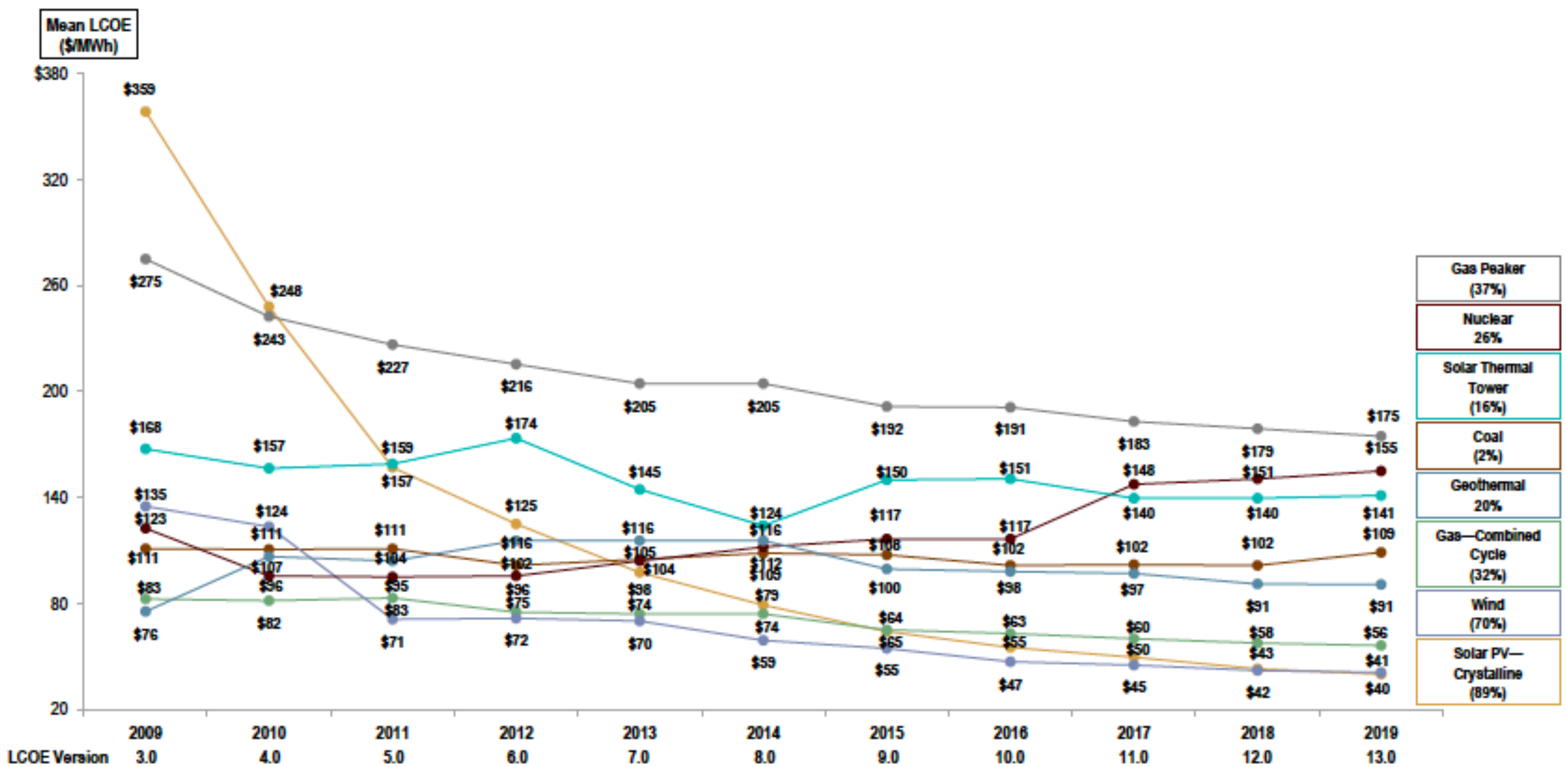
https://www.lazard.com/media/451086/lazards-levelized-cost-of-energy-version-130-vf.pdf

LCOE Comparison ($/MWh)

Levelized Cost of Energy Comparison—Historical Utility-Scale Generation Comparison

Lazard's unsubsidized LCOE analysis indicates significant historical cost declines for utility-scale renewable energy generation technologies driven by, among other factors, decreasing capital costs, improving technologies and increased competition

Selected Historical Mean Unsubsidized LCOE Values[1]



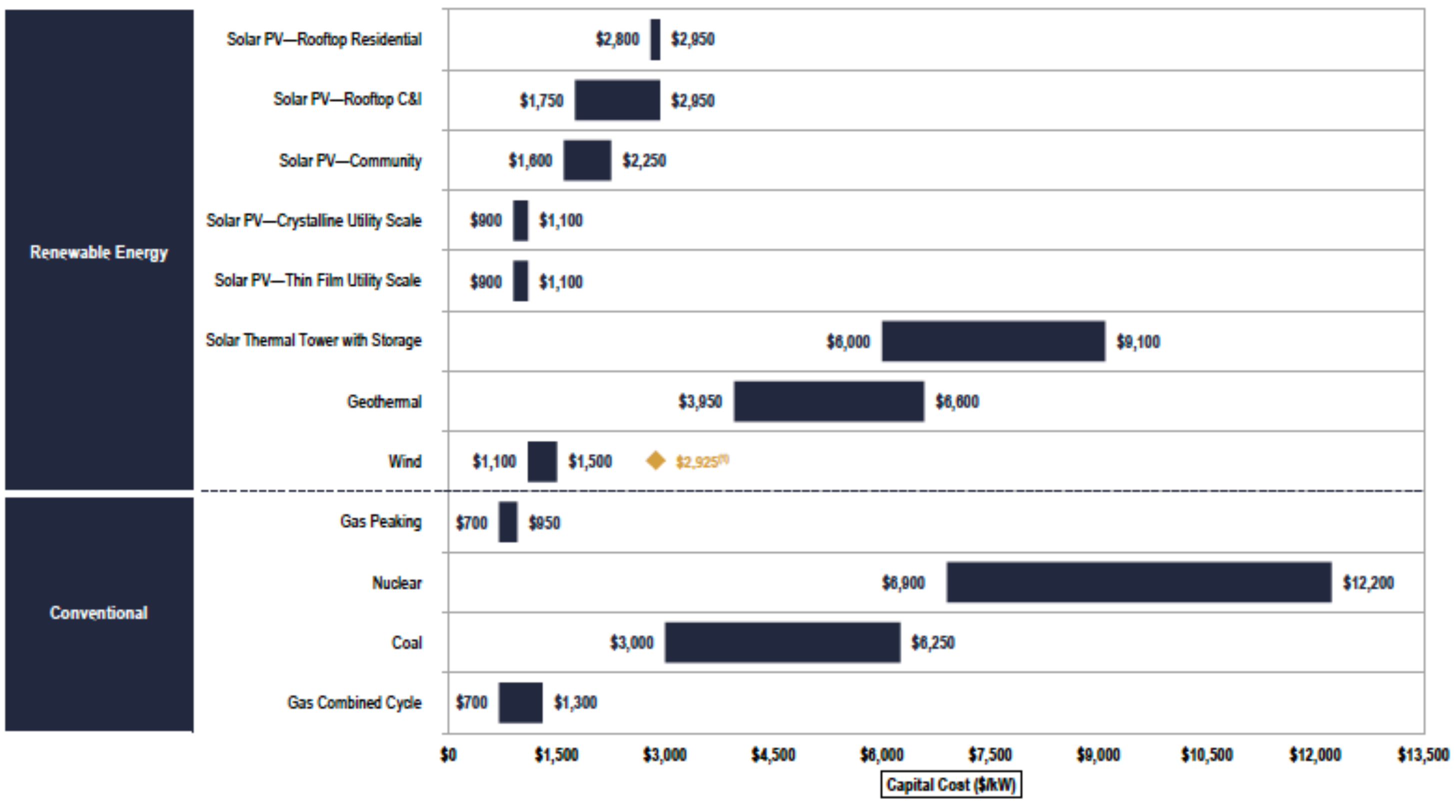
Source: Lazard estimates.

(1) Reflects the average of the high and low LCOE for each respective technology in each respective year. Percentages represent the total decrease in the average LCOE since Lazard's LCOE—Version 3.0.

Capital Cost Comparison ($/kW)

Capital Cost Comparison

In some instances, the capital costs of renewable energy generation technologies have converged with those of certain conventional generation technologies, which coupled with improvements in operational efficiency for renewable energy technologies, have led to a convergence in LCOE between the respective technologies



Source: Lazard estimates.
(1) Represents the estimated midpoint of the total capital cost for offshore wind.

Example for Portugal

		Wind	PV
n	years	25	25
h_a	h	2300	1800
r		5%	5%
beta		2%	1%
I_{01}	M€/MW	1.1	0.9

Compute the LCOE (€/MWh)

	Wind	PV
LCOE (€/MWh)	43.50	40.48

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ECONOMIC ASSESSMENT INDEXES

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Economic assessment of projects

$$NPV = \sum_{j=1}^{n} \frac{Inc_j}{(1+r)^j} - \sum_{j=0}^{n-1} \frac{Outc_j}{(1+r)^j}$$

In electricity generation projects, the **incomes** result from electricity sale.
The **outcomes** include investment, fuel costs, O&M expenses, annuity of loans.

If annual incomes and outcomes are constant and equal to R and D

$$NPV = (R - D)k_a - I_T$$

If NPV > 0
project is economically profitable, the costa are recovered, the minimum rate of return of capital is achieved and a surplus is obtained.
If NPV = 0
project is feasible, the costs are recovered and the minimum rate of return of capital is achieved.
If NPV < 0
project is not economically profitable.

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Economic assessment of projects

$$0=\sum_{j=1}^{n}\frac{Inc_j}{(1+IRR)^j}-\sum_{j=0}^{n-1}\frac{Outc_j}{(1+IRR)^j}$$

IRR – Internal Rate of Return
portrays the real rate of return of the project

$$(R-D)\frac{(1+IRR)^n-1}{IRR(1+IRR)^n}=I_T$$

Nonlinear equation => **Gauss method**

$$IRR^{(k+1)}=\frac{(R-D)}{I_T}\frac{(1+IRR^{(k)})^n-1}{(1+IRR^{(k)})^n}$$

If IRR>*r*, the project is economically viable.

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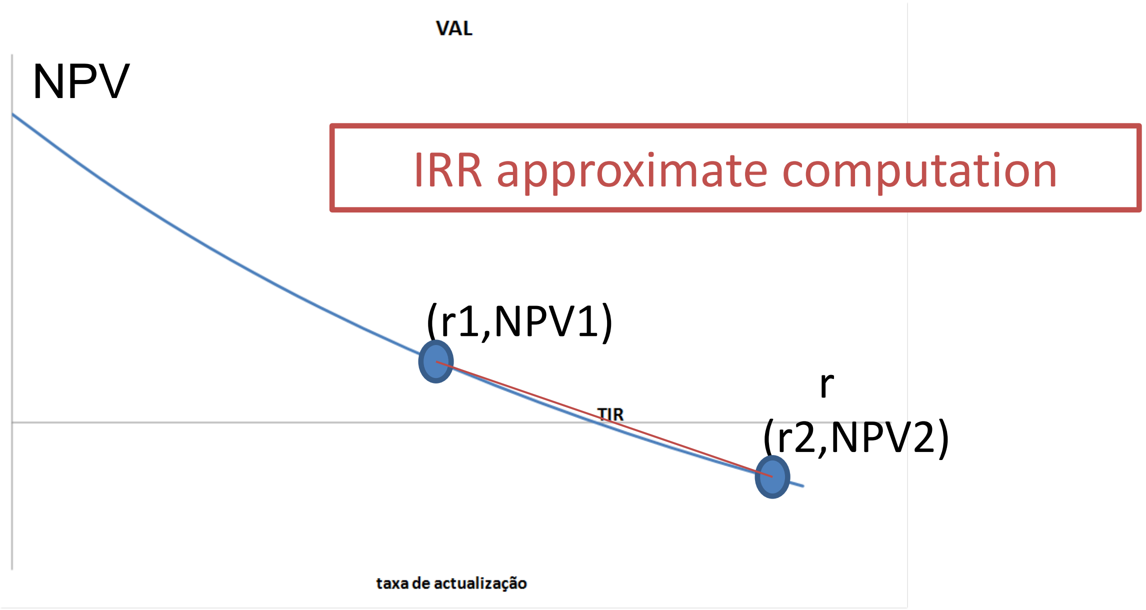
Economic assessment of projects



Linear interpolation (aprox.)

$$IRR \approx r_1 - (r_2 - r_1)\frac{NPV_1}{NPV_2 - NPV_1}$$

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CURIOSITY – T&D COSTS

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Transmission network (2010) – Indicative prices – **Lines**

		k€/km
400 kV overhead lines	Double circuit	460
	Single circuit	280
220 kV overhead lines	Double circuit	290
	Single circuit	200
220 kV underground cables	Single circuit	2000
220 kV line uprating		50

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Source: REN

Transmission network (2010) – Indicative prices – **Power equipment**

	k€
Phase-shift transformer 450MVA, 400/150 kV	10,000
Transformer 450 MVA, 400/220 kV	4000
Transformer 250 MVA, 220/150 kV	3000
Transformer 126 MVA, 220/60 kV	2500
Capacitors 220kV, 120 Mvar	4000
Capacitors 60kV, 50 Mvar	1000

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Source: REN

Indicative LV equipment prices (2010)

OH line / UG cable reference	OH or UG	Cross-section (mm^2)	Maximum current (A)	Price (k€/km)
LXS 4x25+16	OH	25	100	6.7
LXS 4x50+16	OH	50	150	8.3
LXS 4x70+16	OH	70	190	9.1
LXS 4x95+16	OH	95	230	9.4
LSVAV 4x35	UG	35	130	32.0
LSVAV 4x95	UG	95	235	37.0
LSVAV 3X185+95	UG	185	355	42.5

Grid (kVA)	TS price (k€)
50	9.4
100	10.1
250	14.7
400	20.1
630	22.8

OH: overhead
UG: underground
TS: transformer station

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Source: EDP Distribuição

Example

- The capacity factor of a 10 MW wind park is 28.54%. The selling price of electricity is 50 €/MWh. 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, the NPV at a discount rate of 5% and the IRR.

Solution

$$LCOE = \frac{I_{01}(i + c_{om})}{h_a} = \frac{1.2\times10^6(0.0802 + 0.0150)}{0.2854\times8760} = 45.71\ €/\text{MWh}$$

$$NPV = (R - e_{om})k_a - I_t =$$
$$= (50\times10\times0.2854\times8760 - 0.0150\times1.2\times10^6\times10)\times12.4622 - 1.2\times10^6\times10$$
$$= 1{,}335{,}213€$$

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

$$IRR^{(k+1)} = \frac{1{,}070{,}052}{12{,}000{,}000}\frac{\left(1 + IRR^{(k)}\right)^{20} - 1}{(1 + IRR^{(k)})^{20}}$$

0	10,00%	7,59%
1	7,59%	6,85%
2	6,85%	6,55%
3	6,55%	6,41%
4	6,41%	6,34%
5	6,34%	6,31%
6	6,31%	6,29%
7	6,29%	6,29%

$$IRR \approx a_1 - (a_2 - a_1)\frac{NPV_1}{NPV_2 - NPV_1} =$$
$$= 0.05 - (0.07 - 0.05)\frac{1{,}335{,}213}{-663{,}854 - 1{,}335{,}213}$$
$$= 6.34\%$$

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