Integrated course „Energy Economics“
- Financial management -

Chair of Energy Systems | Department of Energy Systems
Technische Universität Berlin

Outline

- Fundamentals of finance
- Time value of money
- Capital structure and cost of capital
- Capital budgeting: NPV method
- NPV vs IRR
- Levelised cost of electricity (LCOE)
- Real options

Recap: Time value of money, NPV and IRR

Compounding:

$$K_T = K_0 \cdot (1+i)^T$$

Net Present Value:

$$NPV = \sum_{t=0}^{T} \frac{CF_t}{(1+i)^t} = -I_0 + \sum_{t=1}^{T} \frac{CF_t}{(1+i)^t}$$

Discounting:

$$K_0 = K_T \cdot \frac{1}{(1+i)^T}$$

IRR:

$$NPV = 0 = -I_0 + \sum_{t=1}^{T} \frac{CF_t}{(1+IRR)^t}$$

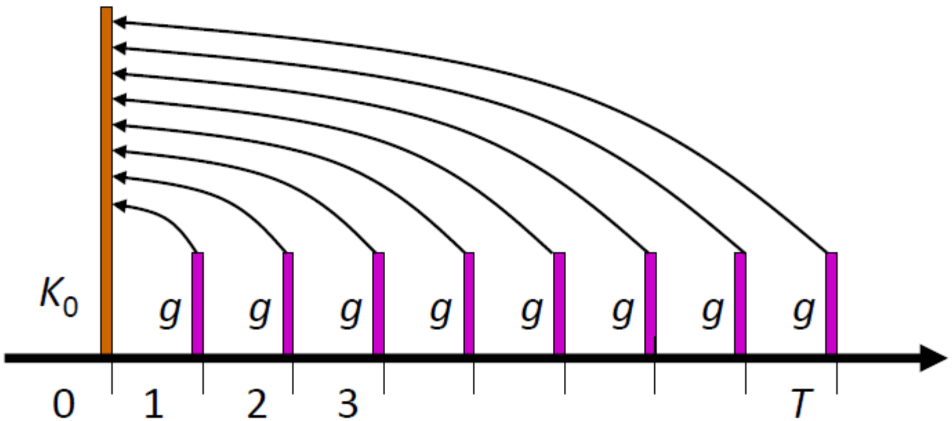
K = Capital
i = Interest rate / Discount rate
T = Time horizon / Economic lifetime
K_0 = Present value
K_T = Value at the Time horizon

CF_t = Cash Flow in period t
I_0 = Investment in period 0
i = Interest rate / Discount rate
T = Time horizon / Economic lifetime
t = Period

Recap: Annuity

Annuity is a level stream of regular payments during a fixed number of periods.

K_0 = Present value
g = Periodical payment
i = Interest rate
q = $(1+i)$ Interest factor
T = Number of periods



Value at the end of period 0

$$K_0 = g \cdot \left(1 + \frac{1}{q} + \frac{1}{q^2} + \ldots + \frac{1}{q^T}\right) = g \cdot \frac{q^T - 1}{q-1} \cdot \frac{1}{q^T} = g \cdot \frac{1-q^{-T}}{q-1}$$

$$K_0 = g \cdot \frac{q^T - 1}{q-1} \cdot \frac{1}{q^T} = g \cdot \frac{1-q^{-T}}{q-1}$$

$$K_0 = g \cdot Annuity\ factor_{i,T} \qquad with \qquad Annuity\ factor_{i,T} = \frac{1}{i} - \frac{1}{i(1+i)^T}$$

Annuity factor

Years	3.0	3.5	4.0	4.5	5.0	6.0	7.0	8.0	9.0	10.0
					Interest rate [%]					
1	0.971	0.966	0.962	0.957	0.952	0.943	0.935	0.926	0.917	0.909
2	1.913	1.900	1.886	1.873	1.859	1.833	1.808	1.783	1.759	1.736
3	2.829	2.802	2.775	2.749	2.723	2.673	2.624	2.577	2.531	2.487
4	3.717	3.673	3.630	3.588	3.546	3.465	3.387	3.312	3.240	3.170
5	4.580	4.515	4.452	4.390	4.329	4.212	4.100	3.993	3.890	3.791
6	5.417	5.329	5.242	5.158	5.076	4.917	4.767	4.623	4.486	4.355
7	6.230	6.115	6.002	5.893	5.786	5.582	5.389	5.206	5.033	4.868
8	7.020	6.874	6.733	6.596	6.463	6.210	5.971	5.747	5.535	5.335
9	7.786	7.608	7.435	7.269	7.108	6.802	6.515	6.247	5.995	5.759
10	8.530	8.317	8.111	7.913	7.722	7.360	7.024	6.710	6.418	6.145
11	9.253	9.002	8.760	8.529	8.306	7.887	7.499	7.139	6.805	6.495
12	9.954	9.663	9.385	9.119	8.863	8.384	7.943	7.536	7.161	6.814
13	10.635	10.303	9.986	9.683	9.394	8.853	8.358	7.904	7.487	7.103
14	11.296	10.921	10.563	10.223	9.899	9.295	8.745	8.244	7.786	7.367
15	11.938	11.517	11.118	10.740	10.380	9.712	9.108	8.559	8.061	7.606
20	14.877	14.212	13.590	13.008	12.462	11.470	10.594	9.818	9.129	8.514
25	17.413	16.482	15.622	14.828	14.094	12.783	11.654	10.675	9.823	9.077
30	19.600	18.392	17.292	16.289	15.372	13.765	12.409	11.258	10.274	9.427
35	21.487	20.001	18.665	17.461	16.374	14.498	12.948	11.655	10.567	9.644
40	23.115	21.355	19.793	18.402	17.159	15.046	13.332	11.925	10.757	9.779
45	24.519	22.495	20.720	19.156	17.774	15.456	13.606	12.108	10.881	9.863
50	25.730	23.456	21.482	19.762	18.256	15.762	13.801	12.233	10.962	9.915

Capital recovery factor

Years	Interest rate [%] 3.0	3.5	4.0	4.5	5.0	6.0	7.0	8.0	9.0	10.0
1	1.030	1.035	1.040	1.045	1.050	1.060	1.070	1.080	1.090	1.100
2	0.523	0.526	0.530	0.534	0.538	0.545	0.553	0.561	0.568	0.576
3	0.354	0.357	0.360	0.364	0.367	0.374	0.381	0.388	0.395	0.402
4	0.269	0.272	0.275	0.279	0.282	0.289	0.295	0.302	0.309	0.315
5	0.218	0.221	0.225	0.228	0.231	0.237	0.244	0.250	0.257	0.264
6	0.185	0.188	0.191	0.194	0.197	0.203	0.210	0.216	0.223	0.230
7	0.161	0.164	0.167	0.170	0.173	0.179	0.186	0.192	0.199	0.205
8	0.142	0.145	0.149	0.152	0.155	0.161	0.167	0.174	0.181	0.187
9	0.128	0.131	0.134	0.138	0.141	0.147	0.153	0.160	0.167	0.174
10	0.117	0.120	0.123	0.126	0.130	0.136	0.142	0.149	0.156	0.163
11	0.108	0.111	0.114	0.117	0.120	0.127	0.133	0.140	0.147	0.154
12	0.100	0.103	0.107	0.110	0.113	0.119	0.126	0.133	0.140	0.147
13	0.094	0.097	0.100	0.103	0.106	0.113	0.120	0.127	0.134	0.141
14	0.089	0.092	0.095	0.098	0.101	0.108	0.114	0.121	0.128	0.136
15	0.084	0.087	0.090	0.093	0.096	0.103	0.110	0.117	0.124	0.131
20	0.067	0.070	0.074	0.077	0.080	0.087	0.094	0.102	0.110	0.117
25	0.057	0.061	0.064	0.067	0.071	0.078	0.086	0.094	0.102	0.110
30	0.051	0.054	0.058	0.061	0.065	0.073	0.081	0.089	0.097	0.106
35	0.047	0.050	0.054	0.057	0.061	0.069	0.077	0.086	0.095	0.104
40	0.043	0.047	0.051	0.054	0.058	0.066	0.075	0.084	0.093	0.102
45	0.041	0.044	0.048	0.052	0.056	0.065	0.073	0.083	0.092	0.101
50	0.039	0.043	0.047	0.051	0.055	0.063	0.072	0.082	0.091	0.101

Levelised cost of electricity (LCOE)

$$p_E = \frac{I_0}{Q \cdot AF_{i,T}} + oc$$

lifetime costs divided by lifetime electricity output

Lifetime costs: PV of total cost of building and operating

LCOE allows comparison of technologies regardless of lifetime, installed capacity, cost of capital, risk and return.

- initial capital cost*

  * *specific investment costs*: investment costs divided by capacity

- annual operating expenses
- capacity factor
- discount rate
- operational life

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Levelised cost of electricity (LCOE)

Generic formula:

$$NPV = \sum_{t=0}^{T} \frac{CF_t}{(1+i)^t} = -I_0 + \sum_{t=1}^{T} \frac{CF_t}{(1+i)^t}$$

For electricity generation: CF are derived from operating cost and revenues from selling electricity

$$NPV = -I_0 + \sum_{t=1}^{T} \frac{(p_{E,t} - oc_t) \cdot Q_t}{(1+i)^t} = -I_0 + (p_E - oc) \cdot Q \cdot \sum_{t=1}^{T} \frac{1}{(1+i)^t}$$

oc operating cost per unit of energy Q
p_E revenue per unit of energy Q
Q total amount of electricity output over lifetime

Solving for p_E results in levelised cost of electricity (LCOE):

$$p_E = \frac{I_0}{Q \cdot AF_{i,T}} + oc$$

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Levelised cost of electricity (LCOE)

How to calculate the generation costs per unit of electricity?

$$\text{LCOE} = \frac{I_0 \cdot CRF_{i,\,t}}{Q_t} + oc$$

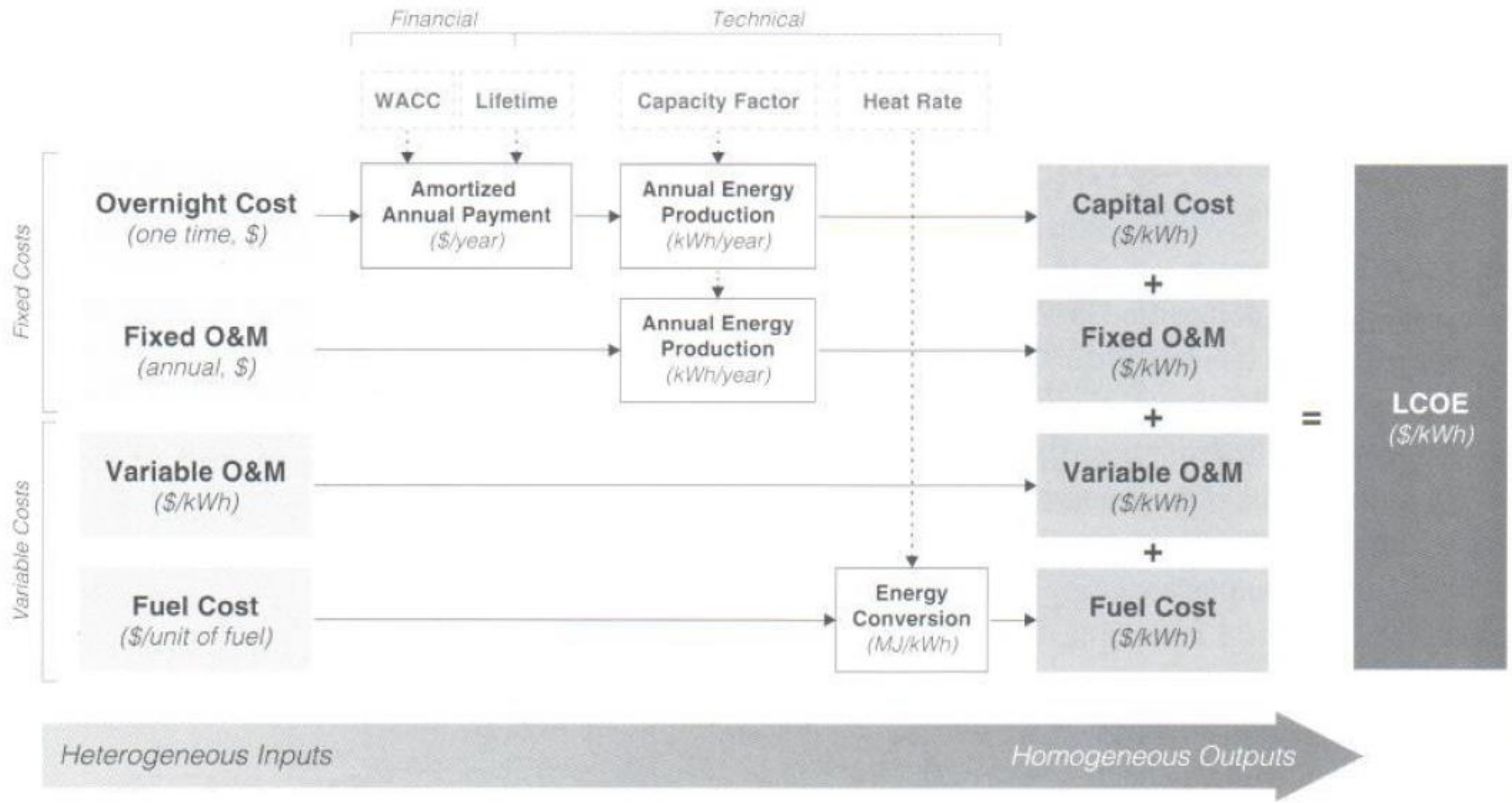
Q_t = Cap * FLH

Q_t	annual electricity output
Cap	installed capacity (rated power)
FLH	full load hours: annual output divided by Cap

$$\text{Capacity factor} = \frac{Q_t\ [\text{kWh}]}{\text{Cap [kW]} * 8.760\text{h}}$$

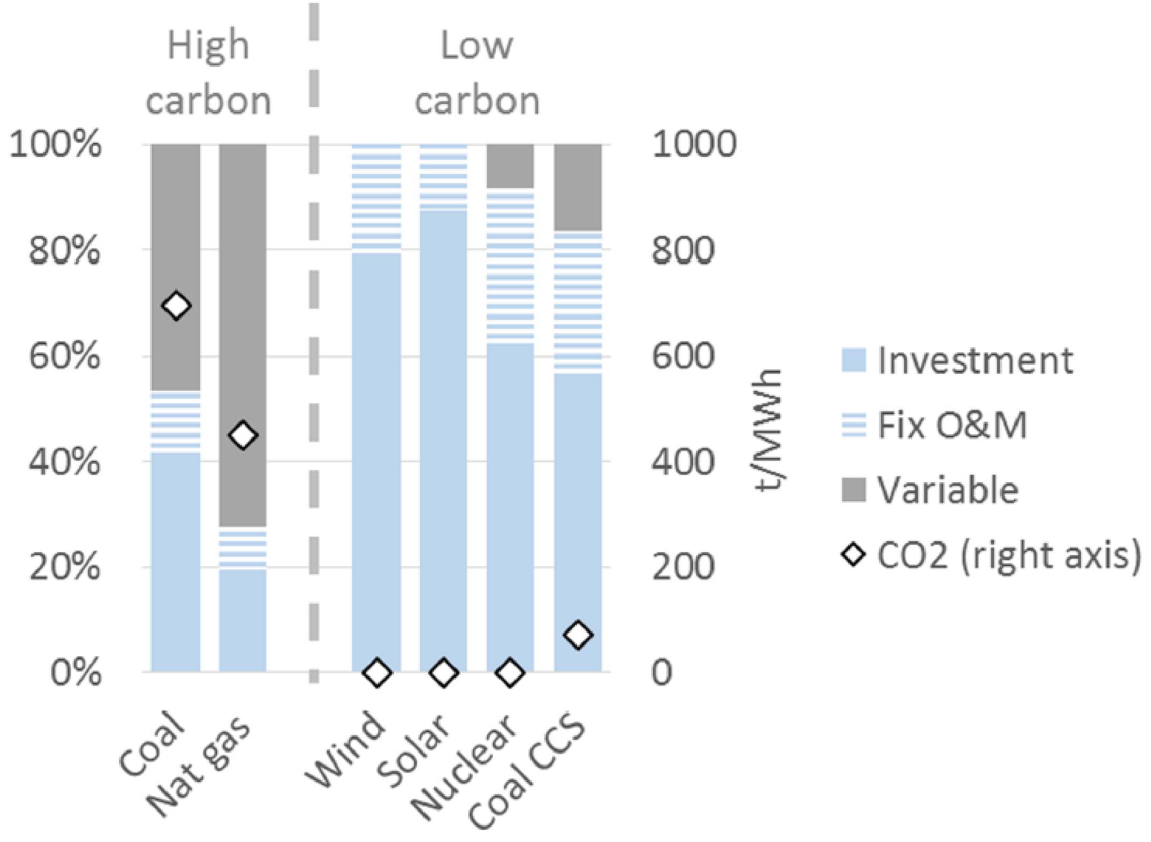
$$\frac{\text{actual annual output}}{\text{max. possible annual output}}$$

LCOE calculation



Source: Bradford, 2018

LCOE composition of generation technologies



Cost composition of different power generation technologies. Typical parameters were used: 7% WACC and capacity factors of 60% for fossil fueled plants, 35% for wind power, 20% for solar power, and 90% for nuclear. A price of USD 30 per t CO_2 was assumed. Under these assumptions, the levelized electricity costs of all technologies are comparable in level (USD 58–84 per MWh).

Source: Hirth and Steckel, 2016

Task 3) NPV and Levelized Cost of Energy (LCOE)

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The table below describes the investment conditions for a 5 kW_{peak} PV system in Germany and in Spain:

Description	***Germany***	***Spain***	***Unit***
Specific investment costs	1 500	1 500	€/kW_{peak}
Operation and maintenance (O&M) costs	9	9	€/kW_{peak}/a
Full load hours	900	1 500	hours/a
Capacity	5	5	kW_{peak}
Lifetime	20	20	a
Interest rate	3	3	%

a) What is the Net Present Value (NPV) of the investment in Spain and in Germany, given a **feed-in tariff (FIT)** of 11.83 ct/kWh?

b) What are the **levelised cost of electricity (LCOE)** of the photovoltaic system in Germany and in Spain (LCOE = electricity generation costs in ct/kWh based on full costing)?

c) Assume that electricity retail prices in Spain and Germany are 29 ct/kWh. What does your result in b) imply for the self-consumption of the generated electricity?

Task 3) NPV and Levelized Cost of Energy (LCOE)

Description	*Germany*	*Spain*	*Unit*
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The table describes the investment conditions for a 5 kW_{peak} PV system in Germany and in Spain:

a) What is the Net Present Value (NPV) of the investment in Spain and in Germany, given a feed-in tariff (FIT) of 11.83 ct/kWh?

$$NPV = -I_0 + \sum_{t=1}^{T} \frac{CF_t}{(1+i)^t}$$

$$I_0 = \text{spec. inv. cost} \cdot Cap$$

$$1500\ €/kW_{peak} \cdot 5\ kW_{peak} = 7.500\ €$$

$$CF_t = (Cap \cdot FLH \cdot FIT) - (Cap \cdot O\&M) = Cap\,(FLH \cdot FIT - O\&M)$$

annual revenue — operating cost p.a.

Spain:

$$g = CF_t = 5\ kW_{peak}\,(1500\ h \cdot 0{,}1183\ € - 9\ €/kW_{peak}/a) =$$

$$= 5 \cdot 168{,}45 = 842{,}25\ €$$

$$PV_{annuity} = g \cdot AF_{3\%,20y}$$

$$= 842{,}25\ € \cdot 14{,}877 = 12.530{,}15\ €$$

$$NPV = -7500\ € + 12530{,}15\ € = 5030{,}15\ €$$

NPV > 0

Task 3) NPV and Levelized Cost of Energy (LCOE)

Description	***Germany***	***Spain***	***Unit***
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Full load hours	900	1 500	hours/a
Capacity	5	5	kW_{peak}
Lifetime	20	20	a
Interest rate	3	3	%

Germany:

$CF_t = 5\,kW_{peak} \cdot (900\,h \cdot 0{,}1183\,€ - 9\,€/(kW_{peak}\,a)) =$

$= 5 \cdot 97{,}47 = 487{,}35\,€$

$PV_{annuity} = 487{,}35\,€ \cdot 14{,}879 = 7250\,€$

$NPV = -7500\,€ + 7250\,€ = \underline{-250\,€}$

$NPV < 0$ → [Project to be rejected]

Task 3) NPV and Levelized Cost of Energy (LCOE)

Description	Germany	Spain	Unit
Specific investment costs	1 500	1 500	€/kW$_{peak}$
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The table describes the investment conditions for a 5 kW$_{peak}$ PV system in Germany and in Spain:

b) What are the **levelised cost of electricity (LCOE)** of the photovoltaic system in Germany and in Spain (LCOE = electricity generation costs in ct/kWh based on full costing)?

$$LCOE = \frac{I_0 + \sum_{t=1}^{20} \frac{O\&M_t}{(1+i)^t}}{\sum_{t=1}^{20} \frac{E_t}{(1+i)^t}}$$

→ O&M [€/(kWh·a)] · Cap

in this case given as annuity. Thus, alternatively we can take annualised view:

$$LCOE = \frac{I_0 \cdot CRF_{3\%,20y} + O\&M \cdot Cap}{E_t}$$

E_t → FLH · Cap

→ OC [€/kWh]

Task 3) NPV and Levelized Cost of Energy (LCOE)

Description	***Germany***	***Spain***	***Unit***
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Full load hours	900	1 500	hours/a
Capacity	5	5	kW_{peak}
Lifetime	20	20	a
Interest rate	3	3	%

Germany:

I

$$LCOE = \frac{7500€ + 9€/kW_{peak}/a \cdot 5\,kW_{peak} \cdot AF_{3\%,20y}}{900h \cdot 5\,kW_{peak} \cdot AF_{3\%,20y}} =$$

($AF_{3\%,20y} \rightarrow 14,877$)

$$= \frac{7500 + 669,465}{66946,5} = 0,122\,€/kWh = 12,2\,ct/kWh$$

II

$$LCOE = \frac{7500€ \cdot CRF_{3\%,20y} + 9\,ct/kW_{peak}\,h \cdot 5\,kW_{peak}}{900h \cdot 5\,kW_{peak}} =$$

($CRF_{3\%,20y} \rightarrow 0,067$)

$$= \frac{502,5 + 45}{4500} = 0,122\,€/kWh = 12,2\,ct/kWh$$

Task 3) NPV and Levelized Cost of Energy (LCOE)

Description	Germany	Spain	Unit
Specific investment costs	1 500	1 500	€/kW$_{peak}$
Operation and maintenance (O&M) costs	9	9	€/kW$_{peak}$/a
Full load hours	900	1 500	hours/a
Capacity	5	5	kW$_{peak}$
Lifetime	20	20	a
Interest rate	3	3	%

Spain:

$$II \; LCOE = \frac{7500\,€ \cdot 0{,}067 + 9\,€/kWpeak/a \cdot 5\,kWpeak}{1500\,h \cdot 5\,kWpeak} =$$

$$= 0{,}073\,€/kWh = 7{,}3\,ct/kWh$$

$$I \; LCOE = \frac{7500\,€ + 9\,€/kWpeak/a \cdot 5\,kWpeak \cdot AF_{3\%,20y}}{1500\,h \cdot 5\,kWpeak \cdot AF_{3\%,20y}} =$$

$$= \frac{7500 + 669{,}465}{111\,577{,}5} = 0{,}073\,€/kWh = 7{,}3\,ct/kWh$$

Task 3) NPV and Levelized Cost of Energy (LCOE)

Description	*Germany*	*Spain*	*Unit*
Specific investment costs	1 500	1 500	€/kW$_{peak}$
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Capacity	5	5	kW$_{peak}$
Lifetime	20	20	a
Interest rate	3	3	%

The table describes the investment conditions for a 5 kW$_{peak}$ PV system in Germany and in Spain:

c) Assume that electricity retail prices in Spain and Germany are 29 ct/kWh. What does your result in b) imply for the self-consumption of the generated electricity?

LCOE < retail price (for both countries)

-> Self-consumption is preferred over buying electricity from the supplier (retail grid parity is reached).

Task 4) Investment appraisal

There are two power plants as investment options. The data is given below:

	Natural gas power plant	***Hard coal power plant***	***Units***
Capacity	900	900	MW
Efficiency	55	43	%
Investment costs	585	900	Million €
Interest rate	8	8	%
Lifetime	20	20	a
Employees	66	140	Number
Labor costs	60 000	60 000	€/a/employee
O&M costs	4	8	Million €/a
Fuel price	22	14	€/MWh_{th}
Emission factor fuel	56	92	kg CO_2 / GJ_{th}
Full load hours	4 000	5 500	hours/a

a) What are the **specific investment costs** in €/kW of the two options?

b) What are the **(short-term) marginal generation costs**?

c) What are the **annual capital costs**?

d) What are the total annual **fixed costs** per MW installed?

e) What are the **levelised cost of electricity (LCOE)**?

f) What must the **full load hours** of the natural gas power plant be so that the long-term marginal generation costs are equal for both technologies?

Task 4) Investment appraisal

	Natural gas power plant	*Hard coal power plant*	*Units*
Capacity (Cap)	900	900	MW
Efficiency (η)	55	43	%
Investment costs (I_0)	585	900	Million €
Interest rate (i)	8	8	%
Lifetime (T)	20	20	a
Employees	66	140	Number
Labor costs	60 000	60 000	€/a/employee
O&M costs (O&M)	4	8	Million €/a
Fuel price	22	14	€/MWh_{th}
Emission factor fuel	56	92	kg CO_2 / GJ_{th}
Full load hours (FLH)	4 000	5 500	hours/a

There are two power plants as investment options.

a) What are the **specific investment costs** in €/kW of the two options?

$$I_{spec} = \frac{I_0}{Cap}$$

$$I_{spec,NG} = \frac{585 \cdot 10^6 €}{900\ MW} = \frac{585\,000\,€}{900\ kW} = 650\ €/kW$$

$$I_{spec,coal} = \frac{900 \cdot 10^6 €}{900\ MW} = \frac{900\,000\,€}{900\ kW} = 1000\ €/kW$$

b) What are the **(short-term) marginal generation costs**?

~~Labour~~ ~~O&M~~ Fuel CO_2 → No CO_2 price is given. Assume 0 €/t for simplification.

$$STMGC = \frac{\text{fuel price}\,[€/MWh_{th}]}{\eta\left[\frac{MWh_{el}}{MWh_{th}}\right]}$$

η → $\frac{\text{energy output}}{\text{energy input}}$

$$STMGC_{NG} = \frac{22\,\frac{€}{MWh_{th}}}{0{,}55\,\frac{MWh_{el}}{MWh_{th}}} = 40\ €/MWh_{el}$$

$$STMGC_{coal} = \frac{14\,\frac{€}{MWh_{th}}}{0{,}43\,\frac{MWh_{el}}{MWh_{th}}} = 32{,}56\ €/MWh_{el}$$

	Natural gas power plant	Hard coal power plant	Units
Capacity (Cap)	900	900	MW
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Full load hours (FLH)	4 000	5 500	hours/a

Task 4) Investment appraisal

There are two power plants as investment options.

c) What are the **annual capital costs**?

$a = I_0 \cdot CRF_{i,T}$

$CRF_{8\%,20} = 0{,}102 \left[\frac{1}{a}\right]$

$a_{NG} = 585 \cdot 10^6 € \cdot 0{,}102 \frac{1}{a} = 59.670.000 €/a = 59{,}67 M€/a$

$a_{coal} = 900 \cdot 10^6 € \cdot 0{,}102 \frac{1}{a} = 91.800.000 €/a = 92{,}8 M€/a$

	Natural gas power plant	*Hard coal power plant*	*Units*
Capacity (Cap)	900	900	MW
Efficiency (η)	55	43	%
Investment costs (I_0)	585	900	Million €
Interest rate (i)	8	8	%
Lifetime (T)	20	20	a
Employees	66	140	Number
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Emission factor fuel	56	92	kg CO_2 / GJ_{th}
Full load hours (FLH)	4 000	5 500	hours/a

Task 4) Investment appraisal

There are two power plants as investment options.

d) What are the total annual **fixed costs** per MW installed?

annual capital costs (fixed) O&M (fixed) labour

$$C_{fix} = \frac{a + \text{no. employees} \cdot \text{labour cost} + O\&M}{Cap}$$

$$C_{fix_{NG}} = \frac{59{,}67 \cdot 10^6 \, €/a + 66 \, \text{empl.} \cdot 60.000 \, \frac{€}{a \cdot \text{empl.}} + 4 \cdot 10^6 \, €/a}{900 \, MW} =$$

$$= \frac{67\,630\,000}{900} = 75\,144 \, €/MW \cdot a$$

$$C_{fix_{coal}} = \frac{92{,}8 \cdot 10^6 \, €/a + 140 \, \text{empl.} \cdot 60.000 \, \frac{€}{a \cdot \text{empl.}} + 8 \cdot 10^6 \, €/a}{900 \, MW} =$$

$$= 121\,333 \, €/MW \cdot a$$