# Energy Economics, Winter Semester 2026-7
# Lecture 6: Financial Management

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# Balance sheet basics

Goal: understand how companies invest in new projects.

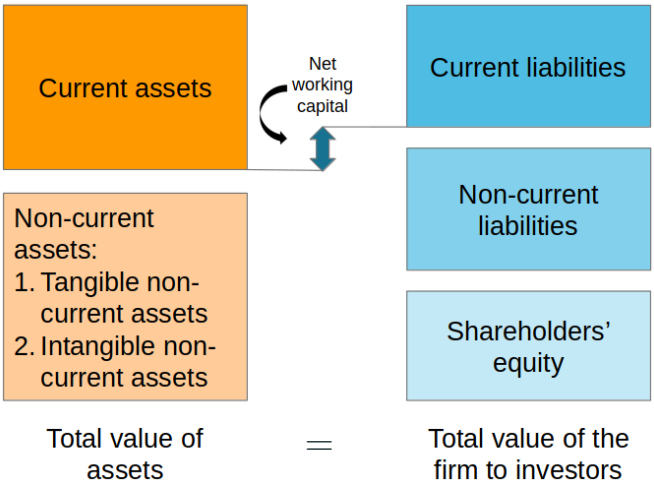
Starting a firm takes investment into **assets**: inventory (raw materials), machinery, land, buildings, and labour.

The value invested into the assets has to be matched by the value raised by **financing**.

By producing and selling products, the firm generates cash – the basis of **value creation** for the firm's owner.

# Balance sheet model of the firm

**Balance sheet**: total assets must equal liabilities owed to others plus equity.



# Balance sheet: examples

## ASSETS

**Current assets**:

- Bank accounts
- Money owed by customers
- Securities

**Non-current assets**:

- Buildings and land
- Machinery
- Intellectual property (e.g. trademarks and patents)

## FINANCING

**Current liabilities**:

- Short-term debt
- Money owed to suppliers

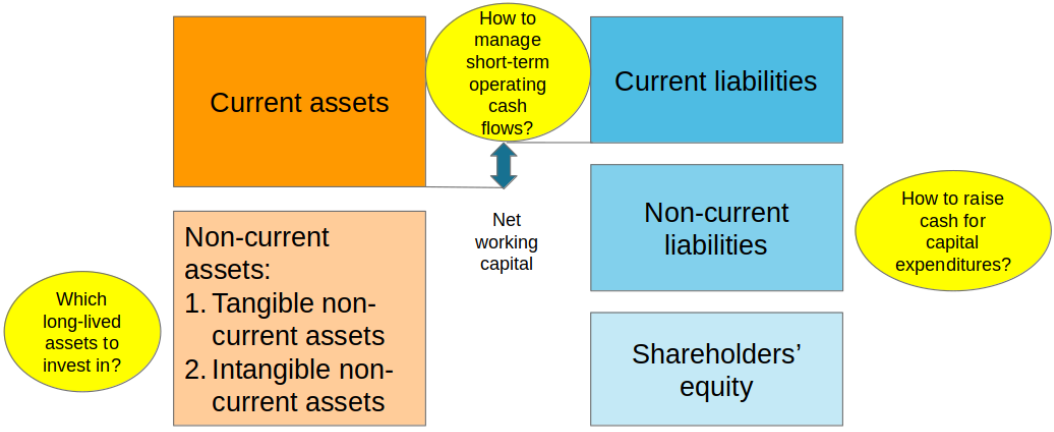
**Non-current liabilities**:

- Long-term debt
- Pension liabilities

**Equity (assets minus liabilities)**:

- Investor equity
- Reserves
- Profit from previous years

# Balance sheet model of the firm




Goal: Maximise the value of a company's equity shares.

# Project evaluation

# Methods of project evaluation

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## Static methods

(single-period)

- **Cost comparison** (e.g. per annum: operating costs plus average annual capital costs plus depreciation per year)
- **Profit comparison** (revenue minus costs)
- **Return on investment** (ROI = EBIT/(average capital employed per year), EBIT = earnings before interest and tax)
- **Payback period** (break-even = investment/(average cash flow per year)

## Dynamic methods

(using time value of money)

- **Net present value** (PV = sum of discounted cash flows; NPV = PV - Investment $> 0$?)
- **Internal rate of return** (IRR = interest rate at which NPV = 0)
- **Equivalent annual annuity** (transformation of cash flow series into annuity)

# Example static method: payback period method

Energy saving project:

New more efficient equipment costs €3,600.

Projected annual energy cost savings: €1,200.

Payback period:

$$\frac{€3,600}{€1,200/a} = 3 \text{ years}$$

Change in annual maintenance costs due to the new equipment has to be considered.

# Present value and discounting

# The value of money depends on time

**Question 1:** What would you prefer: €1000 today, or €1000 in 3 years?

# The value of money depends on time

**Question 1:** What would you prefer: €1000 today, or €1000 in 3 years?

€1000 today can be invested in the bank with an interest rate of 5%.

After 3 years you would have

$$1000 \cdot (1 + 0.05)^3 = 1158$$

**Answer 1:** Best to take the money today and use the opportunity to invest!

**"Money in the future is worth less than money today."**

# The value of money depends on time

**Question 2:** What would you prefer: €1000 today, or €1300 in 5 years?

# The value of money depends on time

**Question 2:** What would you prefer: €1000 today, or €1300 in 5 years?

If you invested €1000 today, after 5 years you would have only

$$1000 \cdot (1 + 0.05)^5 = 1276$$

**Answer 2:** Best to wait for the €1300 in 5 years!

# Present value

To allow comparison between income and outgoings in different years, we need to agree on a particular point in time to evaluate the cash flows.

The simplest and most frequently used time point: today's value, known as the **present value**.

For an **interest rate** $r$ we multiply the income or outgoings in year $t$ by the **discount factor**

$$\frac{1}{(1+r)^t}$$

to calculate the present value. We have **discounted** the future cash flow.

Future income or outgoings are **worth less** from today's point of view (as long as $r$ is positive).

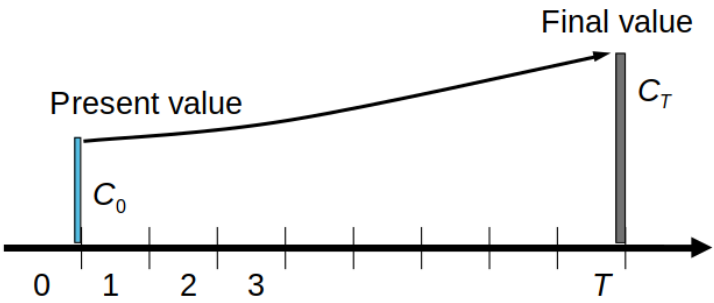
"Money in the future is worth less than money today."

# Cashflow: compounding

**Compounding** takes the present value to the future value.

If the present value is $C_0$, after $T$ periods with interest rate per period $r$ we get the future value $C_T$

$$C_T = C_0 \cdot (1 + r)^T$$

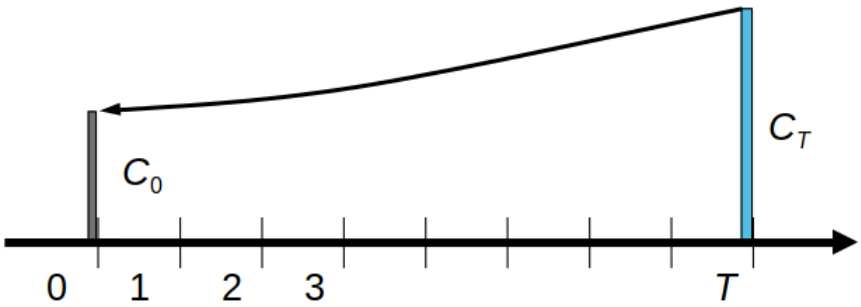


# Cashflow: discounting

**Discounting** takes the future value to the present value.

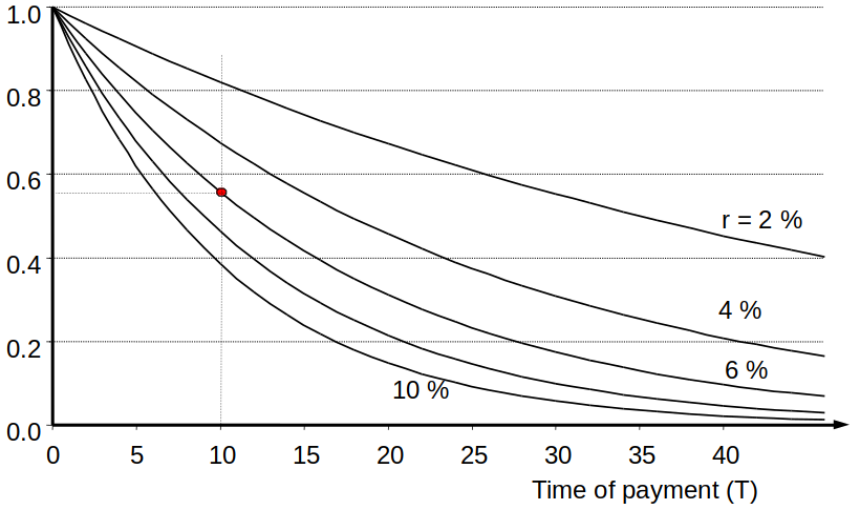
If the future value is $C_T$, the present value is given by

$$C_0 = C_T \cdot \frac{1}{(1+r)^T}$$



# Discount factor

The discount factor $\frac{1}{(1+r)^T}$ can become very small for high $r$ and high $T$:



# Example: present value

For our example with interest rate 5% we can now order the options:

| Income (€) | Year | Present value (€) |
|---|---|---|
| 1000 | 3 | $\frac{1000}{(1+0.05)^3} = 863$ |
| 1000 | 0 | $\frac{1000}{(1+0.05)^0} = 1000$ |
| 1300 | 5 | $\frac{1300}{(1+0.05)^5} = 1019$ |

# Dynamic methods for investment calculations

# Motivation: Power plant investment

A company is considering investing in a photovoltaic plant on its roof. The key figures:

| | |
|---|---|
| Size | 100 kW |
| Investment cost | 800 €kW$^{-1}$ |
| Operating cost | 20 €kW$^{-1}$ a$^{-1}$ |
| Feed-In Tariff | 0.1 €kWh$^{-1}$ |
| Full load hours | 1000 |
| Period of subsidy | 20 years |



The company can invest its money elsewhere for a return of 5%.

**Is it worthwhile to invest in the photovoltaic plant?**

Source: Fraunhofer ISE Stromgestehungskosten 2018, Wikipedia

# Investment calculations

An **investment calculation** quantifies the financial costs and benefits of an investment, assuming that future income and outgoings can be predicted.

It considers

- **Capital costs** - Costs for investments and installation
- **Consumption costs** - Fuel, other materials (e.g. lubricants for wind turbine), etc.
- **Operating costs** - Maintenance, wages, insurance, management, etc.
- **Income** - depends on market price, subsidies, and production

# Dynamic investment calculation: NPV method

For a **dynamic investment calculation** we sum the present values of all **cashflows** $CF_t$ (i.e. income minus outgoings) over the $T$ years of operation taking account of the **hurdle rate** or **required rate of return** $r$ to get the **Net Present Value (NPV)**:

$$NPV = \sum_{t=0}^{T} \frac{CF_t}{(1+r)^t} = \sum_{t=0}^{T} \frac{U_t - I_t - V_t - B_t}{(1+r)^t}$$

where $I_t$ is the capital expenditure in year $t$, $V_t$ the consumption costs (e.g. for fuel cost $o_t$ and annual production $Q_t$, $V_t = o_t \cdot Q_t$), $B_t$ the operating costs und $U_t$ the income (e.g. average market value $p_t$ times annual production $Q_t$, $U_t = p_t \cdot Q_t$).

**Conclusion:** If $NPV > 0$, the investment is worthwhile.

If $NPV < 0$, better to invest with a rate of return of $r$ elsewhere.

For comparisons between different investments, a higher NPV should be preferred.

# Relevant cash flows

Cashflow (CF) from financing activities:

- capital expenditures
- sale of assets

CF from operating activities:

- revenues
- operating expenses
- depreciation
- taxes
- change in working capital

# Relevant cash flows

**Opportunity cost**: potential benefit or income that is foregone as a result of selecting one alternative over another are considered. (E.g. Roof taken by solar PV unit could have been used for solar thermal water heating.)

**Sunk cost**: Cost incurred in the past that cannot be changed by any decision are ignored. (E.g. Once you have bought and installed the PV unit, there is no point taking the purchase of the PV unit into the NPV calculation.)

**Salvation value**: In case of abandonment (divestment), assets, typically, retain a residual value (future revenue). (E.g. Selling the PV unit to a neighbouring firm.)

**Depreciation tax shield**: Yearly depreciation amount is deducted from the income tax base. The resulting tax saving [depreciation amount x tax rate] is added as a positive cash flow.

# Example: Rooftop photovoltaic unit

All cash flows (costs and income) in €:

| year $t$ | 0 | 1 | 2 | $\cdots$ | 20 |
|---|---|---|---|---|---|
| Capital costs $I_t$ | 80,000 | 0 | 0 | | 0 |
| Operating costs $B_t$ | 0 | 2,000 | 2,000 | | 2,000 |
| Income $U_t$ | 0 | 10,000 | 10,000 | | 10,000 |
| Net cash flow $U_t - I_t - B_t$ | -80,000 | 8,000 | 8,000 | | 8,000 |
| Discount factor $\frac{1}{(1+r)^t}$ | 1 | $\frac{1}{(1+r)}$ | $\frac{1}{(1+r)^2}$ | | $\frac{1}{(1+r)^{20}}$ |

# NPV simplification

If investments only occur in the first year, and the costs and income for the following years are constant, we can simplify the NPV formula:

$$NPV = -I_0 + (U - V - B) \sum_{t=1}^{T} \frac{1}{(1+r)^t}$$

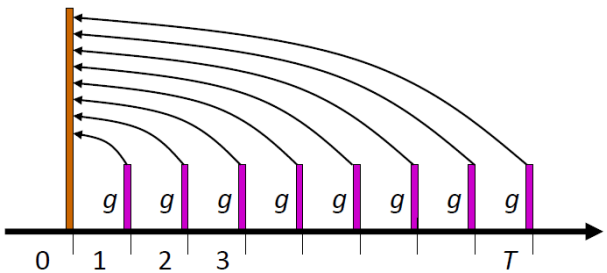
The sum $\sum$ is called the **Present Value Factor** $PVF(r, T)$.

For a geometric series with $|q| < 1$ we have $\sum_{n=0}^{\infty} q^n = \frac{1}{1-q}$. For $q = (1+r)^{-1}$ we can simplify the formula

$$\begin{aligned} PVF(r,T) &= \sum_{t=1}^{T} \frac{1}{(1+r)^t} \\ &= \left[\frac{1}{(1+r)} - \frac{1}{(1+r)^{T+1}}\right] \sum_{t=0}^{\infty} \frac{1}{(1+r)^t} = \left[\frac{1}{(1+r)} - \frac{1}{(1+r)^{T+1}}\right] \frac{1}{1-(1+r)^{-1}} \\ &= \left[\frac{1}{(1+r)} - \frac{1}{(1+r)^{T+1}}\right] \frac{1+r}{1+r-1} = \frac{1}{r}\left[1 - \frac{1}{(1+r)^T}\right] \end{aligned}$$

# Present Value Factor

The Present Value Factor $PVF(r, T)$ brings a series of equal payments $g = U - V - B$ to the present value (orange) so that they can be compared with the initial investment $I_0$.



# Present Value Factor: Table

The **Present Value Factor** $PVF(r,T) = \sum_{t=1}^{T} \frac{1}{(1+r)^t} = \frac{1}{r}\left[1 - \frac{1}{(1+r)^T}\right]$.

| | Interest rate [%] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Years | 3.0 | 3.5 | 4.0 | 4.5 | 5.0 | 6.0 | 7.0 | 8.0 | 9.0 | 10.0 |
| 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 |

# Example: Rooftop photovoltaic unit

For our example with $r = 0.05$

$$\begin{aligned} NPV &= -80,000 + (10,000 - 2,000) \cdot \frac{1}{r}\left[1 - \frac{1}{(1+r)^T}\right] \\ &= -80,000 + 8,000 * 12.5 \\ &= 19,698 \end{aligned}$$

**Conclusion:** It's worthwhile to invest in the photovoltaic unit!

# Example: Rooftop photovoltaic unit

For our example with $r = 0.05$

$$\begin{aligned} NPV &= -80,000 + (10,000 - 2,000) \cdot \frac{1}{r}\left[1 - \frac{1}{(1+r)^T}\right] \\ &= -80,000 + 8,000 * 12.5 \\ &= 19,698 \end{aligned}$$

**Conclusion:** It's worthwhile to invest in the photovoltaic unit!

NB: The calculation is very sensitive to the hurdle rate, e.g. with $r = 0.08$

$$\begin{aligned} NPV &= -80,000 + 8,000 * 9.8 \\ &= -1,454 \end{aligned}$$

**Conclusion:** The investment is not worthwhile.

# Internal rate of return (IRR) method

The **Internal Rate of Return (IRR)** is the required hurdle rate to reach the point $NPV = 0$.

In our example you can either experiment or use the Newton-Raphson algorithm to determine the IRR $r$ by solving

$$0 = NPV = -I_0 + (U - V - B) \sum_{t=1}^{T} \frac{1}{(1+r)^t}$$

We must solve:

$$PVF(r, T) = \frac{I_0}{U - V - B}$$

In our example we have $PVF(r, 20) = \frac{80{,}000}{8{,}000} = 10$ and find an IRR of $r = 7.75\%$.

This is higher than alternative investment opportunity of only 5% $\Rightarrow$ invest in the solar plant!

**Projects with similar risk profile but higher IRR should be preferred!**

# Internal rate of return (IRR): another example

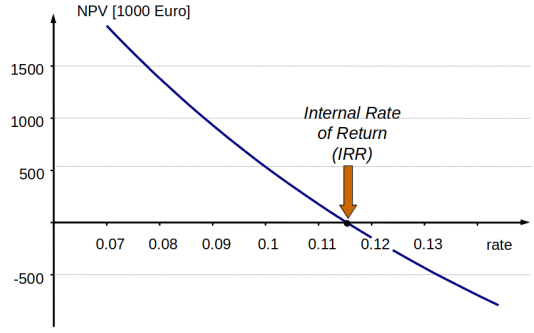
| | |
|---|---|
| $I_0$ | 5,000,000 EUR |
| $T$ | 20 years |
| $B_t$ | 200,000 EUR |
| $Q$ | 500,000 units |
| $p$ | 1.70 EUR/unit |
| $U_t = p \cdot Q$ | 850,000 EUR |
| $U_t - B_t$ | 650,000 EUR |

Solve for $r$:

$$0 = NPV = -I_0 + (U - B)PVF(r, T)$$

i.e. find $r$ such that:

$$PVF(r, T) = \frac{I_0}{U - B}$$




In this case $PVF(r, 20) = \frac{5{,}000{,}000}{650{,}000} = 7.7$.
$\Rightarrow r \sim 11.6\%$.

# Annuity method

For the **annuity method**, instead of bringing all cashflow ($CF = U - V - B$) to the present value, we convert the initial investment to identical annual payments to compare them with the cashflow.

The NPV method asks: is $NPV = CF \cdot PVF(r, T) - I_0 > 0$?

The annuity method asks: is $CF - \frac{I_0}{PVF(r,T)} > 0$?

By dividing $I_0$ by $PVF(r, T)$ we get the **annuity**, i.e. the annualised investment cost $a = \frac{I_0}{PVF(r,T)}$. The factor $a(r, T) = \frac{1}{PVF(r,T)}$ is the **annuity factor**, which spreads the capital costs $I_0$ evenly over the operational years of the investment while taking account of the rate $r$ (like a mortgage for a house).

The formula for the annuity factor is derived from that for the PVF:

$$a(r, T) = \frac{1}{PVF(r, T)} = \frac{r}{1 - (1 + r)^{-T}}$$

# Annuity Factor: Table

The **Annuity Factor** $a(r,T) = \frac{1}{PVF(r,T)} = \frac{r}{1-(1+r)^{-T}}$.

| | Interest rate [%] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Years | 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 |

# Examples of annuity factor

AF = Annuity Factor, $a(r, T)$

| Lifetime $T$ years | Discount Rate $r$ % | AF $a(r, T)$ per unit |
|---|---|---|
| 20 | 0 | 0.05 |
| 20 | 5 | 0.08 |
| 20 | 10 | 0.12 |
| 20 | 20 | 0.21 |
| 40 | 0 | 0.025 |
| 40 | 5 | 0.06 |
| 40 | 10 | 0.10 |
| 40 | 20 | 0.20 |

Things to notice:

- AF reduce to $1/T$ in limit $r \to 0$
- AF climbs steeply with $r$
- For long lifetimes, AF is similar to short lifetimes for high $r$ - in reality investors try to pay off investments faster than lifetime

# Annuity method applied to PV plant example

For our PV plant the cashflow per year over the 20 year lifetime is:

$$CF = U - B = 10,000€/a - 2,000€/a = 8,000€/a$$

The annuity is for $r = 5\%$ and $T = 20a$:

$$a = I_0 \cdot a(5\%, 20a) = 80,000€ \cdot 0.08/a = 6,400€/a$$

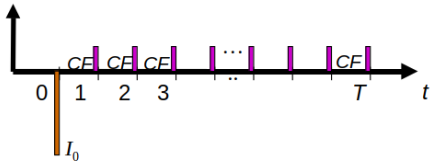
Since $CF - a = 8,000€/a - 6,400€/a = 1,600€/a > 0$, we should invest in the project!

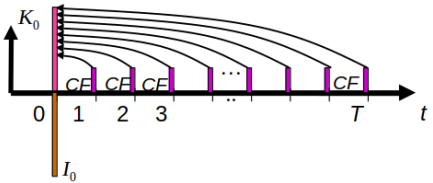
# Comparison of dynamic methods

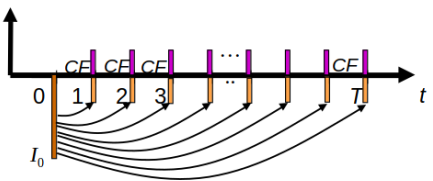
Investment $I_0$ is period 0, identical cashflows (CF) in periods 1 to $T$.

**NPV method**: discount all cashflows to the present (period 0) and construct net present value (NPV).

**Annuity method**: Convert investment into identical annual payments, so that they're comparable with the cashflows.



# Hurdle rate and sources of capital

The hurdle rate represents **cost of capital** and **project risk**.

Hurdle rate = risk-free interest rate (e.g. from government bonds) + risk premium

**How to raise cash for capital expenditures?**

**Equity** (own capital) - raised from shareholders

- rewarded by dividends + the difference in the market price of shares (if positive)
- right to share in assets remaining after liabilities in case of liquidation
- participate in managing the firm

**Debt** (borrowed capital) - borrowed from creditors / debtholders

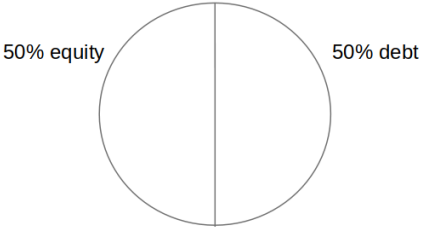
- rewarded through interest
- preferred over shareholders (incl. in case of bankruptcy)

# Weighted Average Cost of Capital

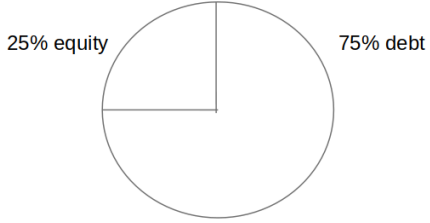
**Weighted Average Cost of Capital** is the cost of capital weighted by its source:

$$WACC = \frac{E}{E+D} r_e + \frac{D}{E+D} r_d (1-t) \tag{1}$$

where $E$ is market value of equity, $D$ is market value of debt, $r_e$ is the return on equity, $r_d$ is the debt interest rate and $t$ is the corporate tax rate. (The amount of interest paid on debt is deducted from the taxable income. This reduces the income tax paid by the company.)




Capital structure 1




Capital structure 2

# German example figures for electricity production technologies in 2018

Technische Universität Berlin

WACC is the **Weighted Average Cost of Capital** over the bank interest rate for borrowed capital (Fremdkapital) and the investor's return on their own equity (Eigenkapital).

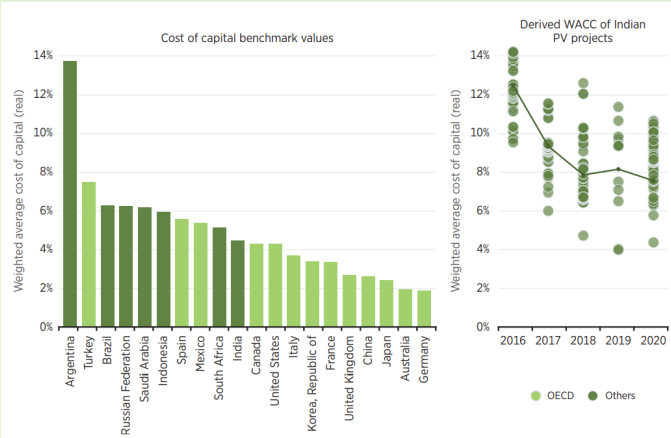
| | PV Dach Klein-anlagen (5-15 kWp) | PV Dach Großanlgen (100-1000 kWp) | PV Frei-fläche (ab 2000 kWp) | Wind Onshore | Wind Offshore | Biogas | Braun-kohle | Stein-kohle | GuD | GT |
|---|---|---|---|---|---|---|---|---|---|---|
| Lebensdauer in Jahren | 25 | 25 | 25 | 25 | 25 | 30 | 40 | 40 | 30 | 30 |
| Anteil Fremdkapital | 80% | 80% | 80% | 80% | 70% | 80% | 60% | 60% | 60% | 60% |
| Anteil Eigenkapital | 20% | 20% | 20% | 20% | 30% | 20% | 40% | 40% | 40% | 40% |
| Zinssatz Fremdkapital | 3,5% | 3,5% | 3,5% | 4,0% | 5,5% | 4,0% | 5,5% | 5,5% | 5,5% | 5,5% |
| Rendite Eigenkapital | 5,0% | 6,5% | 6,5% | 7,0% | 10,0% | 8,0% | 11,0% | 11,0% | 10,0% | 10,0% |
| WACC nominal | 3,8% | 4,1% | 4,1% | 4,6% | 6,9% | 4,8% | 7,7% | 7,7% | 7,3% | 7,3% |
| WACC real | 1,8% | 2,1% | 2,1% | 2,5% | 4,8% | 2,7% | 5,6% | 5,6% | 5,2% | 5,2% |
| OPEX fix [EUR/kW] | 2,5% von CAPEX | 2,5% von CAPEX | 2,5% von CAPEX | 30 | 100 | 4,0% von CAPEX | 36 | 32 | 22 | 20 |
| OPEX var [EUR/kWh] | 0 | 0 | 0 | 0,005 | 0,005 | 0 | 0,005 | 0,005 | 0,004 | 0,003 |

Source: Fraunhofer ISE Stromgestehungskosten 2018

# WACC in different countries

WACC also depends on each country's risk profile and the experience of local investors with the technology, which can improve as the technology becomes established (see Indian PV on right).

**Figure B1.1** Benchmark real WACC estimates for utility-scale solar PV projects in the G20, 2021




Source: IRENA 2021

# Debt-to-equity ratio and leverage

In the photovoltaic plant example, the project had an internal rate of return of $r_{total} = 7.75\%$.

How is the return on equity $r_e$ affected by the debt interest rate $r_d$ and the debt-to-equity ratio?

Consider the total rate of return, which is equal to the weighted average cost of capital (for this example we will ignore tax):

$$r_{total} = \frac{E}{E+D} r_e + \frac{D}{E+D} r_d$$

Now solve for $r_e$:

$$r_e = r_{total} + \frac{D}{E}(r_{total} - r_d)$$

Conclusion: assuming $r_d < r_{total}$, the higher the **debt-to-equity ratio** $\frac{D}{E}$, the greater the return on equity will be. This is the **leverage effect**. We use debt to leverage our equity to get a higher return on equity.

# Debt-to-equity ratio and leverage

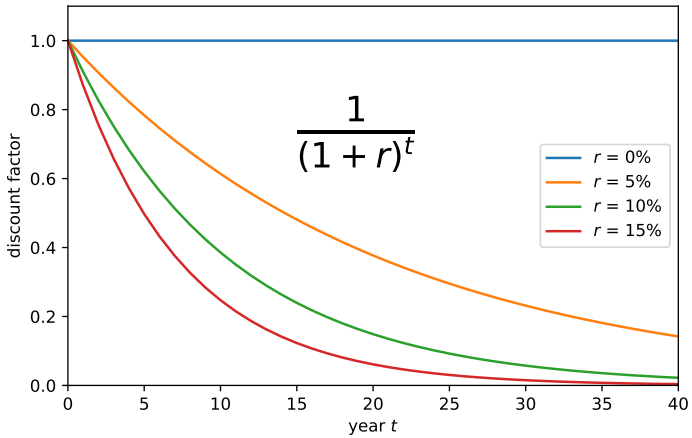
Consider now different debt-to-equity ratios for the photovoltaic plant example with $r_{total} = 7.75\%$ and $r_d = 5\%$.

| debt-capital ratio $\frac{D}{D+E}$ | equity-capital ratio $\frac{E}{D+E}$ | debt-equity ratio $\frac{D}{E}$ | $r_e$ [%] |
|---:|---:|---:|---:|
| 0 | 1 | 0 | 7.75 |
| 0.25 | 0.75 | 0.33 | 8.33 |
| 0.5 | 0.5 | 1 | 10 |
| 0.75 | 0.25 | 3 | 15 |
| 0.9 | 0.1 | 9 | 30 |
| 0.99 | 0.01 | 99 | 255 |

We have used debt to leverage our return of equity to a higher rate. But no bank is likely to agree to such a small debt-equity ratio as 99!

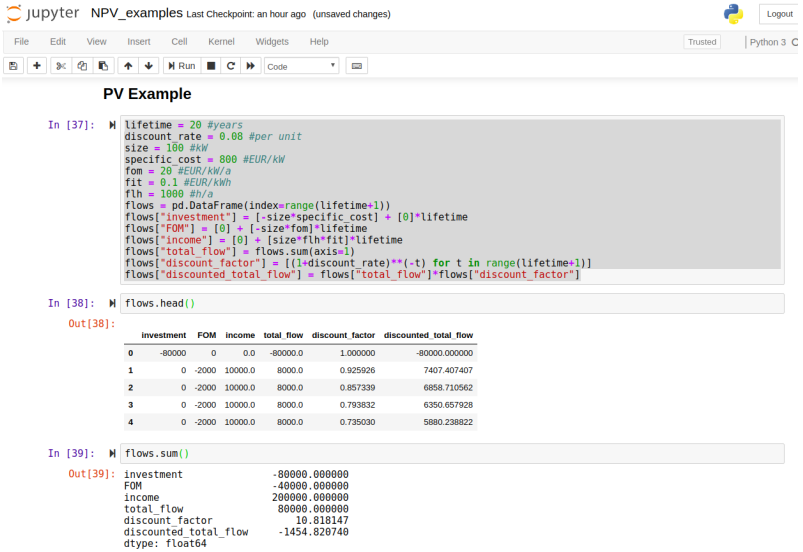
# Warning: Discounting over long time periods

Over long time periods the discounting can have a very large effect....



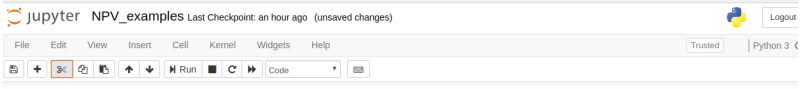

- Long-term benefits aren't seen, e.g. long production life of nuclear power plants or benefits of long-lived efficiency measures
- Long-term costs are also suppressed, e.g. decommissioning, waste disposal, climate damages
- This is a **controversial topic!**

# Programming example: photovoltaic plant




| | investment | FOM | income | total_flow | discount_factor | discounted_total_flow |
|---|---|---|---|---|---|---|
| 0 | -80000 | 0 | 0.0 | -80000.0 | 1.000000 | -80000.000000 |
| 1 | 0 | -2000 | 10000.0 | 8000.0 | 0.925926 | 7407.407407 |
| 2 | 0 | -2000 | 10000.0 | 8000.0 | 0.857339 | 6858.710562 |
| 3 | 0 | -2000 | 10000.0 | 8000.0 | 0.793832 | 6350.657928 |
| 4 | 0 | -2000 | 10000.0 | 8000.0 | 0.735030 | 5880.238822 |

# Programming example: nuclear plant




## Nuclear Example

In [56]:
```
lifetime = 40 #years
discount_rate = 0.05 #per unit
size = 3e6 #kW
specific_cost = 5000 #EUR/kW
decommissioning_cost = 1000 #EUR/kW
fom = 20 #EUR/kW/a
fuel = 10 #EUR/MWh
market_value = 50 #EUR/MWh
flh = 8000 #h/a
flows = pd.DataFrame(index=range(lifetime+1))
flows["investment"] = [-size*specific_cost] + [0]*(lifetime-1) + [-size*decommissioning_cost]
flows["FOM"] = [0] + [-size*fom]*lifetime
flows["income"] = [0] + [size*flh*market_value/1000]*lifetime
flows["total_flow"] = flows.sum(axis=1)
flows["discount_factor"] = [(1+discount_rate)**(-t) for t in range(lifetime+1)]
flows["discounted_total_flow"] = flows["total_flow"]*flows["discount_factor"]
```

In [57]:
```
flows.head()
```

Out[57]:

| | investment | FOM | income | total_flow | discount_factor | discounted_total_flow |
|---|---|---|---|---|---|---|
| 0 | -1.500000e+10 | 0.0 | 0.000000e+00 | -1.500000e+10 | 1.000000 | -1.500000e+10 |
| 1 | 0.000000e+00 | -60000000.0 | 1.200000e+09 | 1.140000e+09 | 0.952381 | 1.085714e+09 |
| 2 | 0.000000e+00 | -60000000.0 | 1.200000e+09 | 1.140000e+09 | 0.907029 | 1.034014e+09 |
| 3 | 0.000000e+00 | -60000000.0 | 1.200000e+09 | 1.140000e+09 | 0.863838 | 9.847749e+08 |
| 4 | 0.000000e+00 | -60000000.0 | 1.200000e+09 | 1.140000e+09 | 0.822702 | 9.378808e+08 |

In [59]:
```
flows.sum()
```

Out[59]:
```
investment               -1.800000e+10
FOM                      -2.400000e+09
income                    4.800000e+10
total_flow                2.760000e+10
discount_factor           1.815909e+01
discounted_total_flow     4.135221e+09
dtype: float64
```

# Interest rates and inflation

A bank offers a one-year **nominal interest rate** of 10% per year.

E.g. An individual who deposits €1,000 will have €1,100 in a year.

Suppose the **rate of inflation** is 6% per year.

E.g. A restaurant that charges €10 for a meal today will be charging €10.60 for the same meal in a year.

Today, the individual could buy €1,000 / €10 = 100 meals.

In a year, they will be able to buy €1,100 / €10.60 = 103.8 meals.

The resulting increase in consumption is 3.8% (and not 10%). 3.8% is the **real interest rate**, i.e. the nominal interest rate corrected by inflation.

$$1 + \text{nominal interest rate} = (1 + \text{real interest rate}) \cdot (1 + \text{inflation rate})$$

From

$$1 + \text{nominal interest rate} = (1 + \text{real interest rate}) \cdot (1 + \text{inflation rate})$$

we can derive

$$\begin{aligned}
\text{real interest rate} &= \frac{1 + \text{nominal interest rate}}{1 + \text{inflation rate}} - 1 \\
&= (1 + \text{nominal interest rate}) \cdot (1 - \text{inflation rate} + (\text{inflation rate})^2 - \cdots) - 1 \\
&= \text{nominal interest rate} - \text{inflation rate} + \text{higher terms}
\end{aligned}$$

$\Rightarrow$ subtracting inflation from the nominal interest rate gives an approximation of the real interest rate.

# Cash flow and inflation

For future cash flows we can choose either **real** or **nominal** values.

**Nominal cash flow**: actual money in cash to be received / paid.

**Real cash flow**: the cash flow's purchasing power.

Nominal cash flows must be discounted at the nominal rate.

Real cash flows must be discounted at the real rate.

# Dynamic Investment Calculation Summary

- Future income or costs are worth less from today's point of view
- To calculate the **present value** give the **interest rate** $r$, multiply the cash flow in year $t$ by the **discount factor** $\frac{1}{(1+r)^t}$
- To calculate the **net present value (NPV)** for an investment, sum the present values of all cashflows (income minus costs)
- If $NPV > 0$, the investment is worthwhile compared to investing with interest rate $r$
- For two different investments, a higher NPV should be preferred
- Alternative dynamic methods: **internal rate of return method** and **annuity method**
- **Long-term** costs or benefits are **suppressed** by discounting

# Levelised Cost Of Electricity (LCOE)

# Levelised Cost Of Energy (LCOE)

You can also solve for the market value or feed-in tariff that's necessary to cover all the costs of the investment, i.e. the point where the present value of all income balances the present value of all costs. You solve for the price $p$ such that

$$0 = NPV = -I_0 + (pQ - oQ - B)PVF(r, T)$$

where $V = oQ$, $Q$ is the annual production and $o$ is the variable cost (e.g. fuel). We find:

$$p = \frac{1}{Q}\left(\frac{I_0}{PVF(r, T)} + B + oQ\right) = \frac{1}{Q}\left(I_0 \cdot a(r, T) + B\right) + o$$

For the PV plant we find a price of $p = 89$ €/MWh for $r = 0.05$.

This value corresponds to the average long-term costs of the unit, since we've divided the total yearly costs by the total production $Q$. It is called the the **Levelised Cost Of Energy (LCOE)**.

It is also called the **Long-Run Marginal Cost (LMRC)**, since we've added to the short-run marginal cost $o$ an annualised fixed contribution to the capital and operating costs.

Check: The higher $I_0$ or $B$ are, the higher the LCOE. The higher $Q$ is, the lower the LCOE.

# Parameters for different generation technologies

Here are some typical investment and operational parameters projected for 2020:

| Source | Lifetime years | Capital Cost €kW$^{-1}$ | Fix O&M €kW$^{-1}$a$^{-1}$ | Var O&M €MWh$_{\mathrm{el}}^{-1}$ | $\eta$ [%] | Fuel Cost €/MWh$_{\mathrm{th}}$ | Marg. Cost €/MWh$_{\mathrm{el}}$ |
|---|---|---|---|---|---|---|---|
| Hard Coal | 40 | 1200 | 30 | 6 | 39 | 10 | 32 |
| Gas OCGT | 30 | 400 | 15 | 3 | 39 | 20 | 54 |
| Gas CCGT | 30 | 800 | 20 | 4 | 60 | 20 | 37 |
| Nuclear | 40-60 | 6000 | 0 | 6 | 33 | 3.3 | 16 |
| Wind Onshore | 25 | 1240 | 35 | 0 | | 0 | 0 |
| Solar PV | 25 | 750 | 25 | 0 | | 0 | 0 |

O&M = Operation and Maintenance, Var. = Variable, Fix. = Fixed, $\eta$ = efficiency

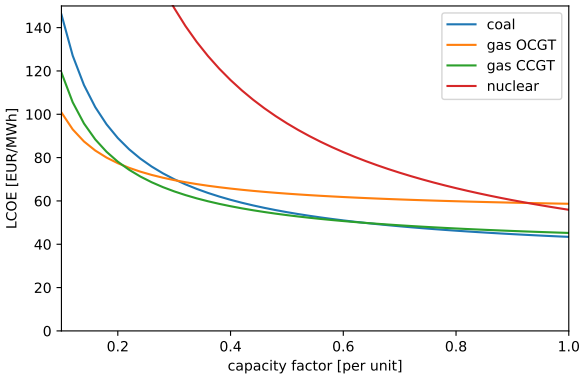
For a plant with capacity $G_s$ in MW and yearly production $Q$ in MWh$_{\mathrm{el}}$, we have $I_0 = 1000 \cdot G_s \cdot (\text{Capital Cost})$, $B = 1000 \cdot G_s \cdot (\text{Fix O\&M})$, $V = Q \cdot o$ where o is the marginal cost $o = (\text{Marg. Cost}) = (\text{Var O\&M}) + (\text{Fuel Cost})/\eta$.



Source: DIW Data Documentation, 2013

# LCOE for dispatchable generators depends on capacity factor

The LCOE had the form (Marg. Cost) + (Yearly Fixed Costs)/(Yearly Production). Therefore it decreases with increasing capacity factor:



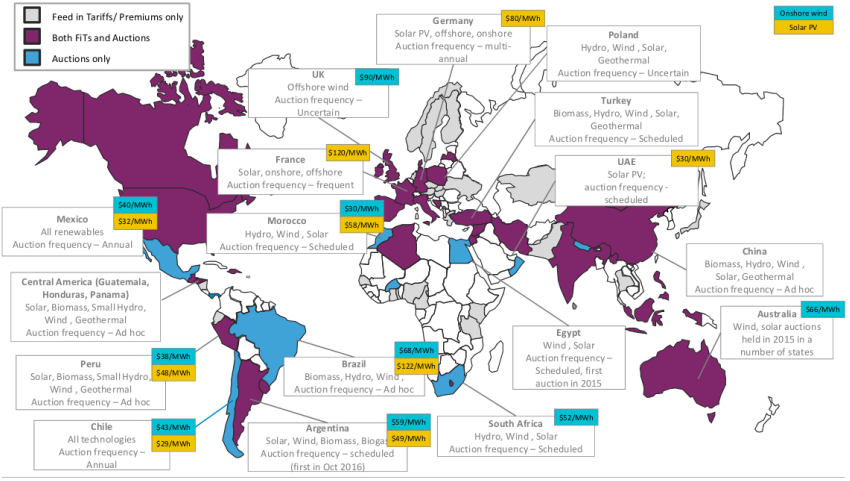

- LCOE $>$ marginal cost
- LCOE starts high then reduces as fixed costs are spread over more hours
- There are **crossing points** where some types of generators become cheaper for a given capacity factor
- NB: All generators need downtime for regular maintenance, so cf $< 0.9$
- NB: Carbon pricing would alter this graphic by adding to the marginal cost

# LCOE for wind and solar depends on location: auction results 2017

## A selection of recent global auction results

Baringa

Renewable auction prices are reducing globally, and these inform our cost input assumptions




*Source: Baringa analysis; IRENA (https://www.irena.org/DocumentDownloads/Publications/IRENA_Renewable_energy_auctions_in_developing_countries.pdf); all prices are stated in USD*

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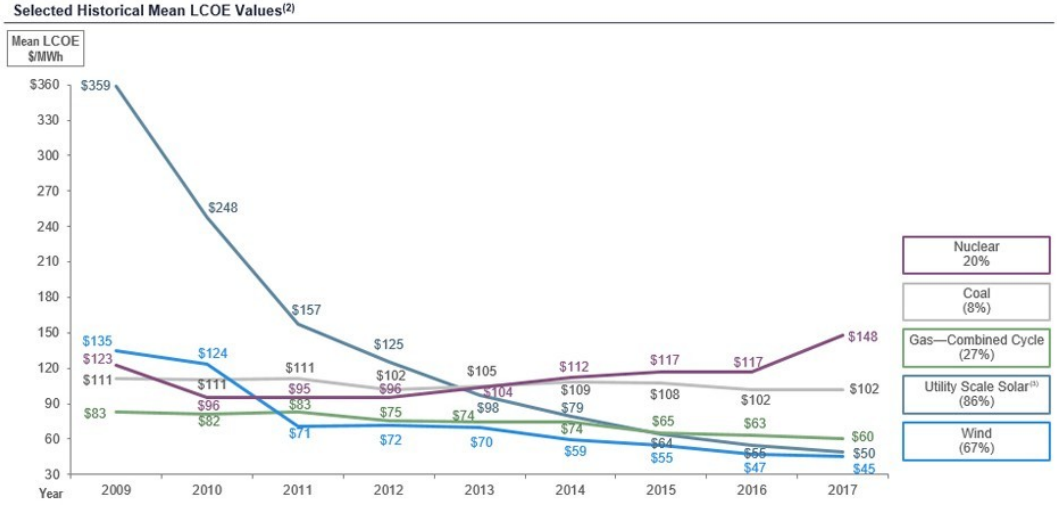
Source: **Baringa Partners LLP 2017**

# Levelised Cost of Electricity Since 2009 in US

NB: Treat with care since LCOE doesn't take account of time or place of generation!




Source: Lazard's LCOE Analysis V11

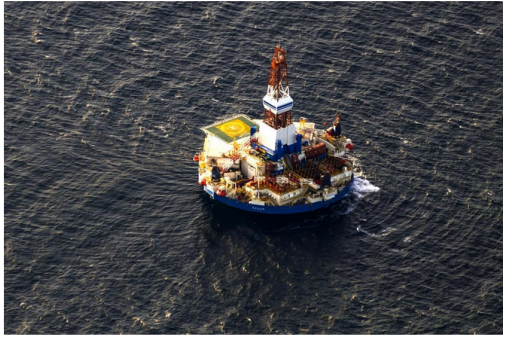
# Real options

# Shell abandons Alaska oil field

## Shell puts its $9bn Arctic drilling project on ice

Robin Pagnamenta

September 28 2015, 10:25am,
The Times



Shell said that exploratory results had been disappointing
GARY BRAASCH/CORBIS

Royal Dutch Shell ordered a retreat from the Arctic yesterday, as it abandoned plans to drill for oil in Alaska's Chukchi Sea, despite forfeiting nearly $9 billion in total costs.

From Foreign Policy magazine — David Francis — 28th Sep 2015:

"The decision to abandon oil exploration at the top of the world is at once both surprising and to be expected. It comes just two months after President Barack Obama signed off on Shell's operations off the coast of Alaska, and after the company defended its actions to environmental groups."



Source: Foreign Policy, 2015

# Shell abandons Alaska oil field

"Shell today provides an update on the Burger J exploration well, located in Alaska's Chukchi Sea. The Burger J well is approximately 150 miles from Barrow, Alaska, in about 150 feet of water. Shell safely drilled the well to a total depth of 6800 feet this summer in a basin that demonstrates many of the key attributes of a major petroleum basin. For an area equivalent to half the size of the Gulf of Mexico, this basin remains substantially under-explored."

"Shell has found indications of oil and gas in the Burger J well, but these are not sufficient to warrant further exploration in the Burger prospect. The well will be sealed and abandoned in accordance with U.S. regulations."

"[. . . ]Shell continues to see important exploration potential in the basin, and the area is likely to ultimately be of strategic importance to Alaska and the US. However, this is a clearly disappointing exploration outcome for this part of the basin"

"Shell will now cease further exploration activity in offshore Alaska for the foreseeable future. This decision reflects both the Burger J well result, the high costs associated with the project, and the challenging and unpredictable federal regulatory environment in offshore Alaska."



Source: Shell.com, 28th Sep 2015

# Real options

Cash flows used for calculation under NPV method are future projections and, thus, estimated values.

Uncertainty determining the risk of a project may be resolved during its lifetime.

Flexibility to **react to changes** is part of investment evaluation.

Financial options theory has been applied to physical investments.

Option is the right to buy [or sell] the underlying asset at a specified price during [or at] a specified time. Option holder pays option premium to option writer.

**Real options** are physical investments that allow the owner the option to do something (e.g. sell or buy a commodity) in the future.

# Real options: valuing project flexibility

"A **real option** is a right, but not an obligation, to do something for a certain cost within or at a specific time." (Source: He, 2007)

Options to make adjustments to the project once it is accepted based on new information:

- delay investment until an uncertainty disappears (**timing option**)
- expand or reduce the scale of the project
- change the input or output of the project
- abandon the project if a pessimistic scenario materialises

Example: oil or gas field with production costs exceeding the current oil/gas price but still valuable with a view to a potential future rise in the price.

Example: buy land next to power plant that gives option to expand later, depending on market conditions.

# Real options versus NPV method

**NPV method**: more uncertain assets have relatively less economic value $\Rightarrow$ riskier investments are penalised by higher discount rates.

**Real options theory**: uncertainty means not only possibility of future loss but also opportunity to create value from flexibilities by adapting the project to evolving conditions.

Energy projects are characterised by:

- long time horizons
- large amounts of capital
- high uncertainty

$\Rightarrow$ real options theory can be helpful.

Must weigh valuation complexity vs. helpful way of thinking.

# Oil drilling problem: Bayesian decision theory

Consider the problem faced by an oil company that is trying to decide whether to drill an exploratory oil well on a given site. Drilling costs are $200,000 regardless of whether oil is found.

If oil is found, i.e. the well is 'wet', it is worth $800,000. If the well is 'dry', it is worth nothing.

Suppose that the oil company estimates that the probability that the site has oil ('wet') is 40%.

| Decision | State of nature | |
|---|---|---|
| | Wet | Dry |
| Drill | 600T | -200T |
| Do not drill | 0 | 0 |
| Prior probability | 0.4 | 0.6 |



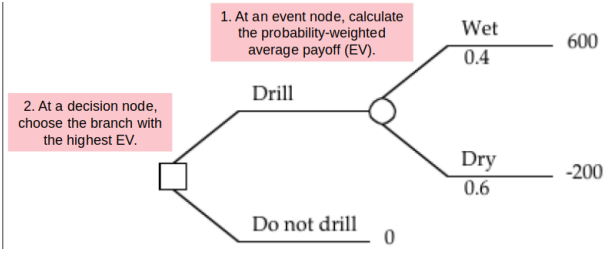
Source: M. Hillier

# Decision tree method

**Decision tree method** is used for modelling sequential decision problems under uncertainty.

- **Decisions**: mutually exclusive and collectively exhaustive set of possible alternatives of courses of action
- **Events**: mutually exclusive and collectively exhaustive set of possible outcomes (states of nature) with assigned probabilities. The sum of probabilities in a set of events is equal to one.
- **Payoffs**: sum of costs and revenues associated with an alternative

# Oil drilling problem: Decision tree solved (rolled-back)




If drilling is done, expected payoff is

$$\mathbb{E}(\text{payoff}) = 0.4 * (800,000 - 200,000) + 0.6 * (-200,000) = 120,000$$

If no drilling:

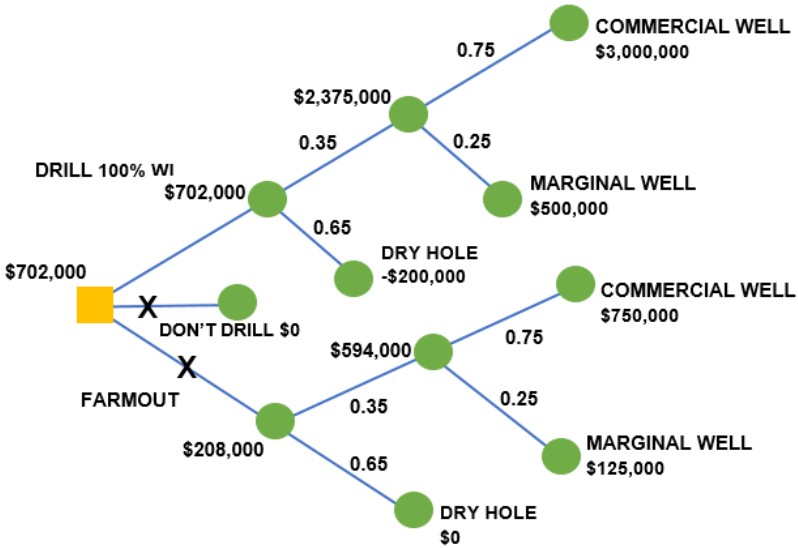
$$\mathbb{E}(\text{payoff}) = 0$$

$\Rightarrow$ **Drill!**



Source: M. Hillier

# Oil drilling problem: Advanced decision tree

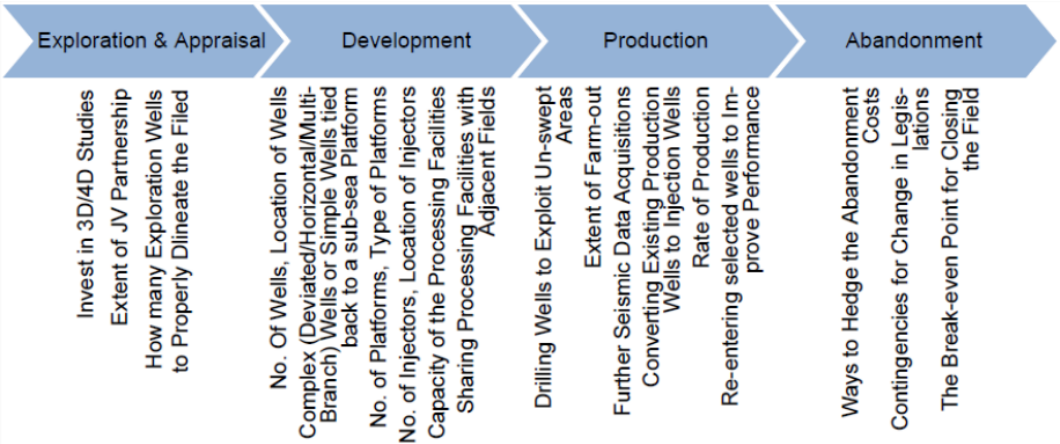





Source: Seba 2008

# Example of drilling uncertainties

Oil and gas upstream industry is characterised by sequential investments.






Source: Jafarizadeh, Bratvold, 2009

# Real options: Application examples

- Oil and gas exploration and production projects
- Developing a new technology $\Rightarrow$ high R&D cost and risk
- Change in regulation, e.g. climate policies $\Rightarrow$ future CO2 price

# Creating real options for technology development

In 2021 Microsoft founder Bill Gates announced the Breakthrough Energy Catalyst programme, which " is designed to get governments, companies, innovators, and philanthropists to work together to play their unique role in commercializing clean technology fast. We intend to directly invest up to $3 billion over 5 years to advance vetted projects in four key areas: direct air capture, green hydrogen, long-duration energy storage, and sustainable jet fuel."

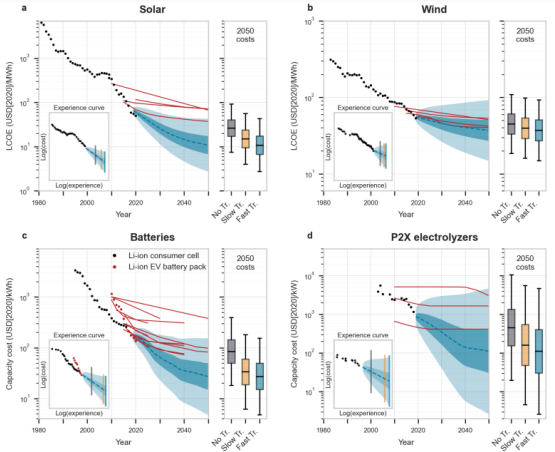
Why do you think he chose these technologies?



Source: Financing the Clean Industrial Revolution, 2021

# Creating real options for technology development

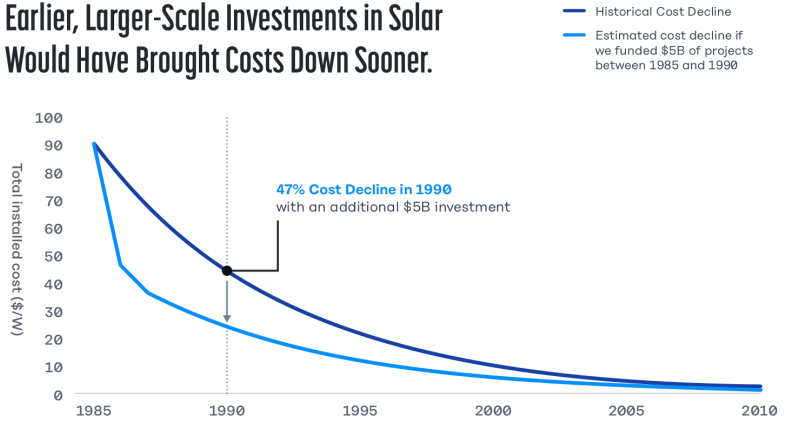
Direct air capture, green hydrogen (using electrolysers), long-duration storage (possible with green hydrogen) and sustainable jet fuel (possible with green hydrogen) all are just at the start of their experience curves. **High levels of uncertainty** - 50% and 95% confidence intervals:




Source: Way et al, 2021

# Analogy to solar PV

Consider hypothetical what-if question. When would the best time have been to invest $5 billion in solar? Benefits of early investment: shows us options early, resolves uncertainty, have biggest impact on cost reduction, reducing **green premium** of clean technology.




Source: Breakthrough Energy analysis; data from MIT and IRENA

Source: **Financing the Clean Industrial Revolution, 2021**