Integrated course „Energy Economics“
- Exam Preparation: Key Theories Revisited

Chair of Energy Systems
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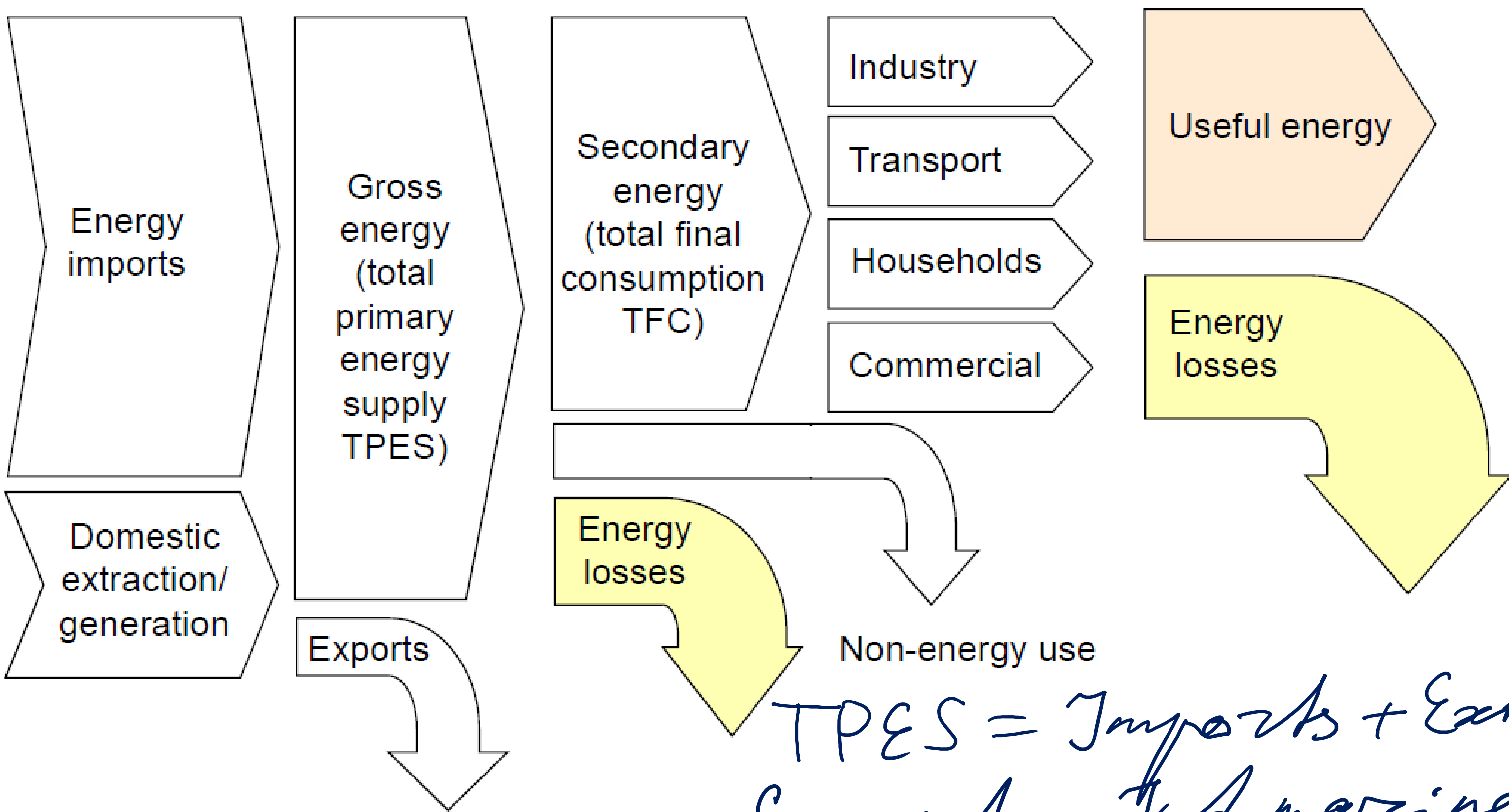
Outline

- Energy balances
- Economics fundamentals
- Financial management
- Electricity markets
  - Market structure
  - Electricity generation
  - Energy trading
  - Renewables support
- Emissions
- Resources and sustainability
- Oil and gas markets

Energy Balances: Energy flow chart



Source: Zweifel / Praktiknjo / Erdmann, 2017

TPES = Imports + Extraction
− Exports − Int. marine/aircraft bunkers
± Stock changes

Terms and definitions

- **Gross energy** / Primary energy: Aggregate energy supply from domestic sources and imports minus energy exports
- **Final energy supply** (intermediate good): Energy sold by energy companies to end users for energetic use
- Treatment of **non-energy use** (raw material in chemistry)
- **Useful energy**: Energy that is supplied from heaters, radiators, coolers, motors, light bulps etc. to end users
- **Energy Services**: Not the energy from radiators matters but the well being of people in a well tempered room …

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Energy Balances: Energy sources

Primary energy sources are in the form as found in nature and have not undergone any transformation.

- oil, coal, natural gas, nuclear, wind, solar, biomass, geothermal, hydropower

Secondary energy sources are forms of energy after conversion, either chemical or physical.

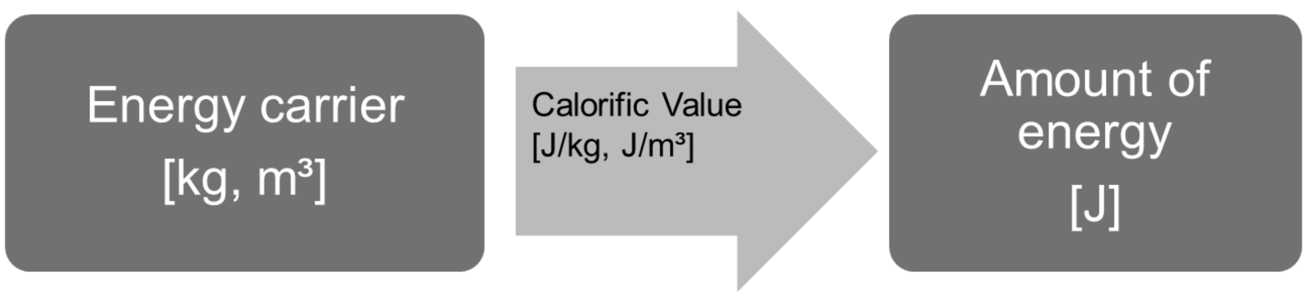
- electricity, refined fuels (e.g. gasoline), synthetic fuels (e.g. hydrogen)
- easily usable form

Energy Balances: Measuring primary energy

Primary energy sources are originally measured in units corresponding to their natural form: volume, mass etc.

Original units can be converted into energy units.

Calorific value is used for energy sources that can be converted into heat through combustion: coal, gas, oil, biomass.



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Energy Balances: Lower calorific value of energy fuels

	Density	Energy [10^9 J]	Remarks
1 t Crude oil	0.86 g/cm³	39–43	Mean: 41.9·10^9 J
1 Barrel (bbl) crude oil		5.7	=159 l (ca. 50/365 t.o.e.)
1 t Heating oil el.	0.84 g/cm³	42.5	at 15–20 ºC
1 t Gasoline	0.75 g/cm³	43.1	at 15–20 ºC
1 t Methanol (CH_3OH)	0.80 g/cm³	19.7	
1 t Ethanol (C_2H_5OH)	0.80 g/cm³	26.9	
1 t Liquefied Petroleum Gas LPG	0.53 g/cm³	45.9	at 2–18 bar
1 t Liquefied Natural Gas LNG	0.47 g/cm³	47.2	at –164 ºC
1 t Hydrogen (LH_2)	0.071 g/cm³	120.4	at –252 ºC
1000 m³ Natural gas L	0.82 kg/m³	33.4	Mean: 35.6·10^9 J
1000 m³ Natural gas H	0.79 kg/m³	36.6	
1000 m³ Compressed gas CNG	156 kg/m³	7000	at 200 bar
1000 m³ Petroleum gas		40.7	
1000 m³ Methane (CH_4)	0.65 kg/m³	35.8	
1000 m³ Propane (C_3H_8)	1.87 kg/m³	86.7	
1000 m³ hydrogen (H_2)	0.09 kg/m³	10.8	
1000 m³ Liquefied hydrogen (H_2)	15.6 kg/m³	1950	at 200 bar
1 t Hard coal		29–35	Mean 29.3· 10^9 J
1 t Lignite		7.5–13	
1 t Wood	0.6 g/cm³	14.6	3.5 · 10^6 kcal
1 t Uranium oxide (U_3O_8)		414’000	Light Water Reactor LWR

Energy Balances: Units of energy

Energy unit conversion						
	MJ	kcal	kWh	t.o.e.	Barrel	t.c.e.
1 MJ	1	238,8	0,2778	23,88 E^{-6}	175 E^{-6}	34,14 E^{-6}
1 kcal	0,0042	1	0,00116	0,1 E^{-6}	0,73 E^{-6}	0,143 E^{-6}
1 kWh	3,6	860	1	86 E^{-6}	630 E^{-6}	123 E^{-6}
1 t.o.e.	41.880	10 E^{+6}	11.630	1	7,33	1,430
1 Barrel	5.713	1,36 E^{+6}	1.587	0,1364	1	0,195
1 t.c.e.	29.290	6,995 E^{+6}	8.136	0,6995	5,127	1

Source: Zweifel / Praktiknjo / Erdmann, 2017

Tonne of oil equivalent (t.o.e.): energy generated by burning one metric ton (7,4 barrels) of oil, or 1270 m^3 of natural gas, or 1,4 metric tons of coal.

Energy Balances: Measuring RES

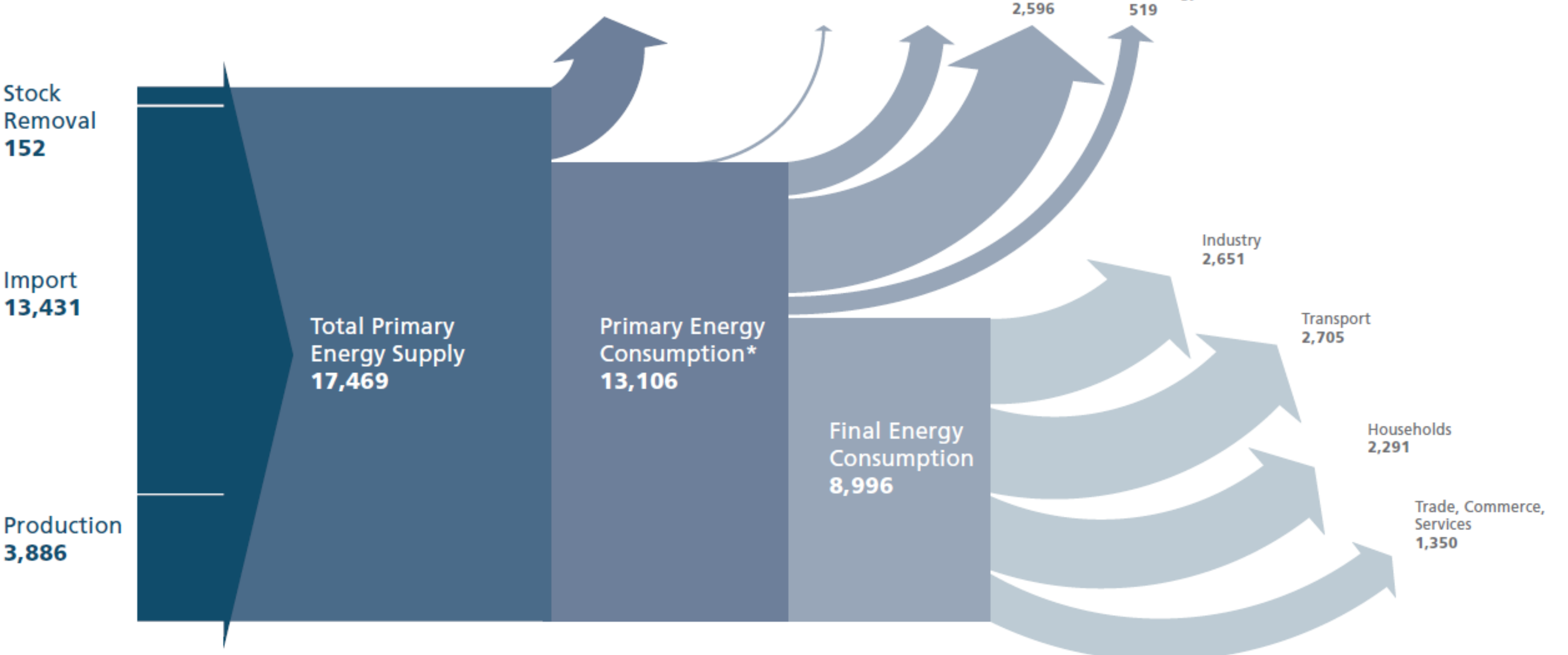
How to value energy carriers which do not have a calorific value, e.g. wind, PV, nuclear energy, water, geothermal heat?

electricity imports?

- Substitution Principle: amount of fuel that would be necessary to produce that amount of electricity in a thermal powerplant (35-40%)
- Efficiency Principle: actual efficiency of respective technology (hydro 80-90%, wind 30-55%, solar 10-25%)
- Fictive Efficiency Principle (IEA): 100% for wind, solar, hydro (underestimated RES share)

Energy Balances: Energy flow chart for Germany in 2018

Petajoule (PJ)



Source: AGEB, 2019

Energy Balance: Simplified structure

EU-28, 2014 (ktoe)	Total (all products)	Solid fossil fuels	Crude oil & petroleum products	Gas	Nuclear heat	Renewable energies	Non-renewable wastes	Electricity	Derived heat
+ Primary production	770 722	149 335	70 030	117 019	226 132	195 814	12 392		
+ Primary production receipt	9 370		9 370						
+ Other sources (recovered products)	4 909	685	3 968	256					
+ Recycled products	1 125		1 125						
+ Imports	1 411 681	159 831	882 362	320 253		15 704	255	33 270	
+ Stock changes	- 9 349	- 4 041	358	- 5 451		- 220	6		
- Exports	530 788	37 293	362 306	89 161		10 057	29	31 937	
- Bunkers	41 622		41 622						
- Direct use	10 116		10 116						
Gross inland consumption	1 605 931	268 517	553 168	342 917	226 132	201 241	12 624	1 332	
Transformation input	1 277 176	253 214	627 959	102 222	226 132	57 134	9 297	192	1 02
+ Conventional thermal power stations	357 010	190 639	12 879	92 227		51 703	8 536		1 02
+ Nuclear power stations	226 132				226 132				
+ District heating plants	19 484	3 816	1 048	8 521		5 146	761	192	
+ Coke ovens	39 002	38 367	624	11					
+ Blast furnaces	13 421	13 421							
+ Gas works	736	710	1	25					
+ Refineries	613 159		613 159						
+ Patent fuel plants	245	171	74						
+ BKB/PB plants	4 958	4 958							
+ Charcoal production plants	227					227			
+ Coal liquefaction plants	839	839							
+ For blended natural gas	231		175			56			
+ Gas-To-Liquids (GTL) plants									
+ Non-specified Transformation Input	1 734	293		1 439		2			
Transformation output	932 177	33 008	612 716	21 162		69		209 643	55 57
+ Conventional thermal power stations	173 718							134 296	39 42
+ Nuclear power stations	75 437							75 348	8
+ District heating plants	16 068								16 06
+ Coke ovens	35 927	28 712		7 214					
+ Blast furnaces	13 421			13 421					
+ Gas works	526			526					
+ Refineries	612 716		612 716						
+ Patent fuel plants	207	207							
+ BKB/PB plants	4 089	4 089							
+ Charcoal production plants	69					69			
Exchanges, transfers and returns	2 428		2 428			- 61 990		61 990	
Consumption of the energy branch	77 518	669	31 050	18 131		912	62	22 536	4 15
Distribution losses	24 960	48	47	2 810		25	0	17 505	4 52
Available for final consumption	1 160 881	47 595	509 255	240 915		81 249	3 264	232 733	45 87
Statistical difference	*- 191*	*- 499*	*2 277*	*- 2 198*		*- 129*	*- 0*	*32*	*32*
Final non-energy consumption	99 387	1 518	84 020	13 849					
Final energy consumption	1 061 684	46 576	422 957	229 264		81 378	3 264	232 701	45 54

+ Industry
+ Transport
+ Other sectors

Source: Eurostat

Fuels

Supply TPES

Transformation

TFC Consumption

Flows

Energy Balance: Cumulated energy requirement

Cumulated energy requirement is total primary energy amount required for production, use and disposal of a product over its lifetime.

$$CER = CER_P + CER_U + CER_D$$

CER is used in life-cycle assessment to account for all environmental impacts of an industrial process.

'Grey energy' → imported goods
→ disposal of goods abroad

Energy required for production/recycling is not reflected in the national energy balances in this case.

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- Energy balances
- **Economics fundamentals**
- Financial management
- Electricity markets
- Emissions
- Resources and sustainability
- Oil and gas markets

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Market structures

Market is a group of sellers and a group of buyers of a particular good or service.

Perfect competition:

Sellers are price takers.

- many buyers and many sellers > cannot influence the price
- goods at exactly the same (homogeneous)
- consumers have perfect information
- no entry or exit barriers

Monopoly:

- seller is the sole producer and can influence the price of its output

Sellers are price setters.

Market power is the ability to maintain a price above the price under competition.

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Market structures

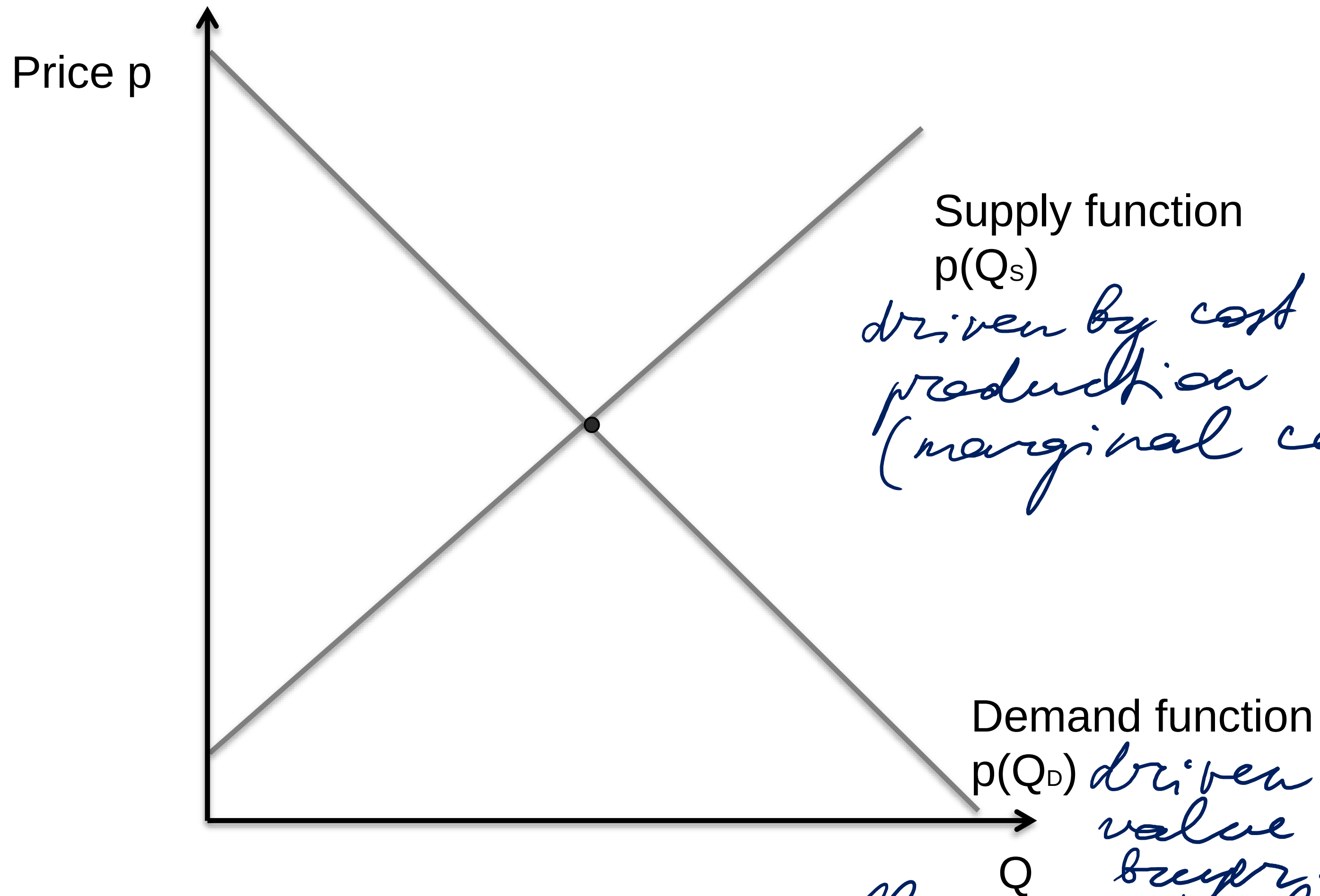
	one seller	few sellers	many sellers
one buyer	Bilateral monopoly		Monopsony (buyer's monopoly)
few buyers		Oligopolistic market structures	
many buyers	Seller's monopoly		Perfect competition

e.g. labour market

Oligopoly: a few sellers offer a similar or identical product.

Monopolistic competition: many sellers offer products that are similar but not identical.

Demand and Supply

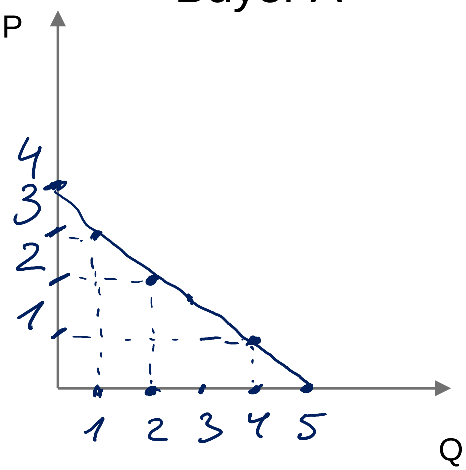


driven by cost of production (marginal cost)

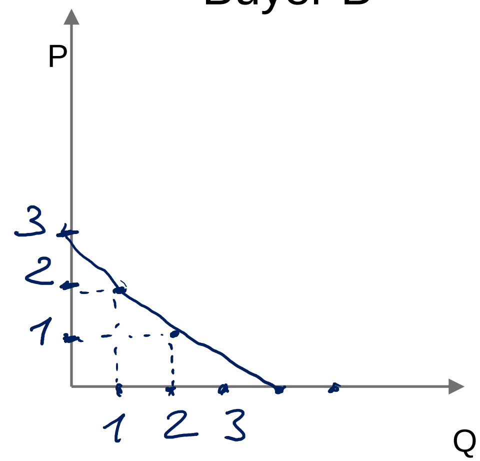
driven by value to buyer: willingness & ability to pay

Demand and Supply

Buyer A



Buyer B

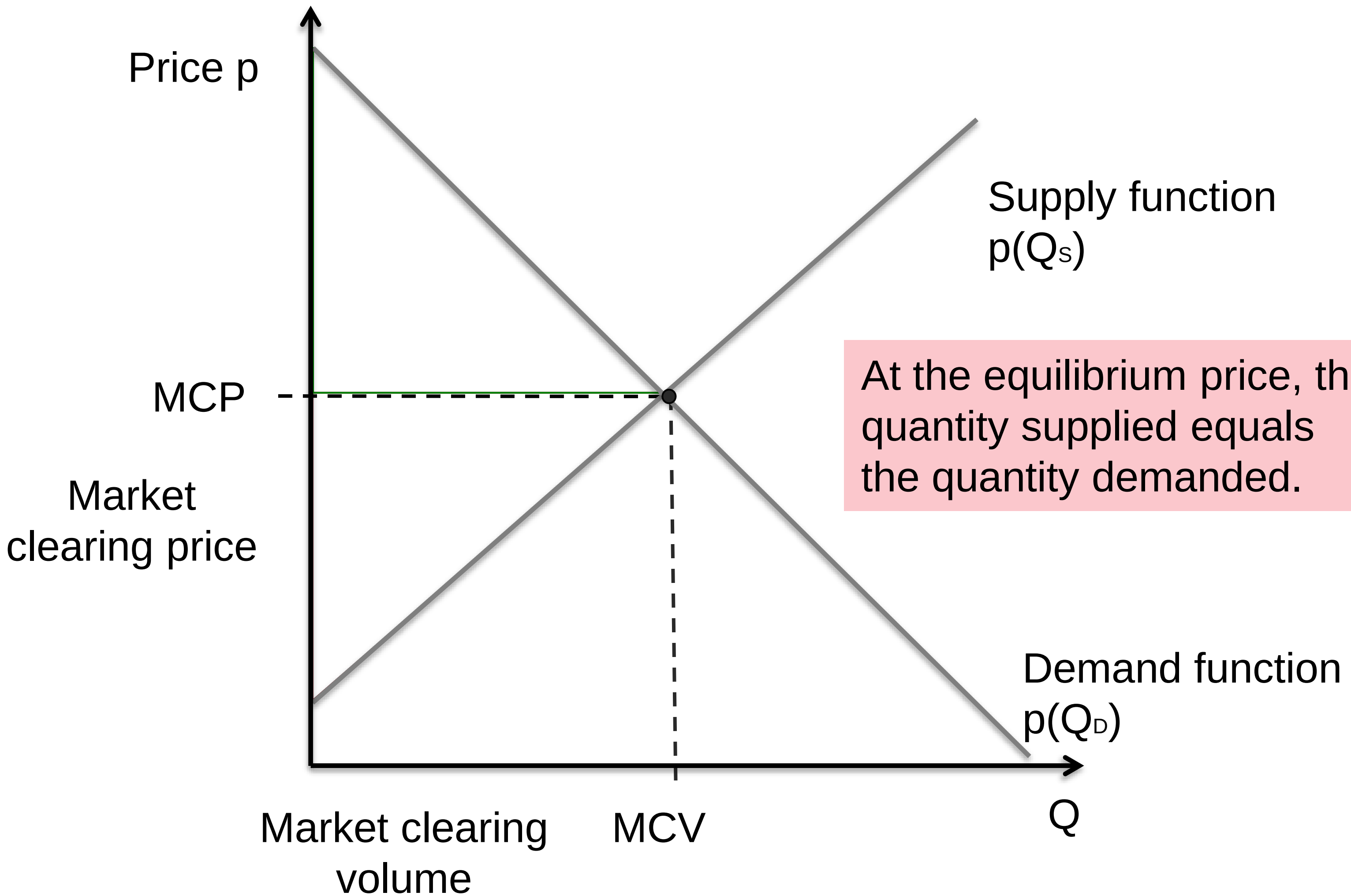


Market demand

(Buyer A + Buyer B)

For each price, add up the quantities demanded by each buyer at that price.

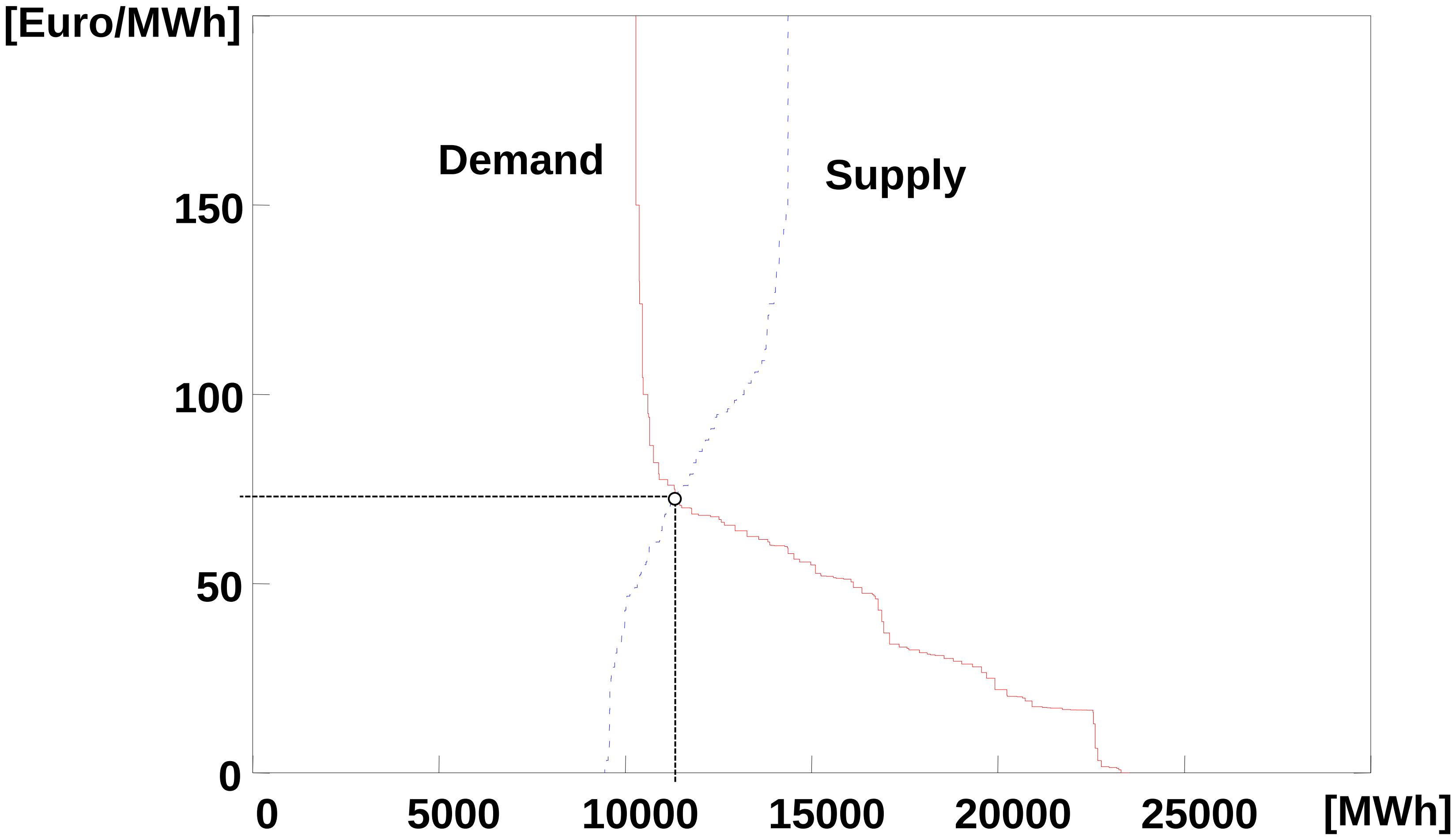
Demand and Supply



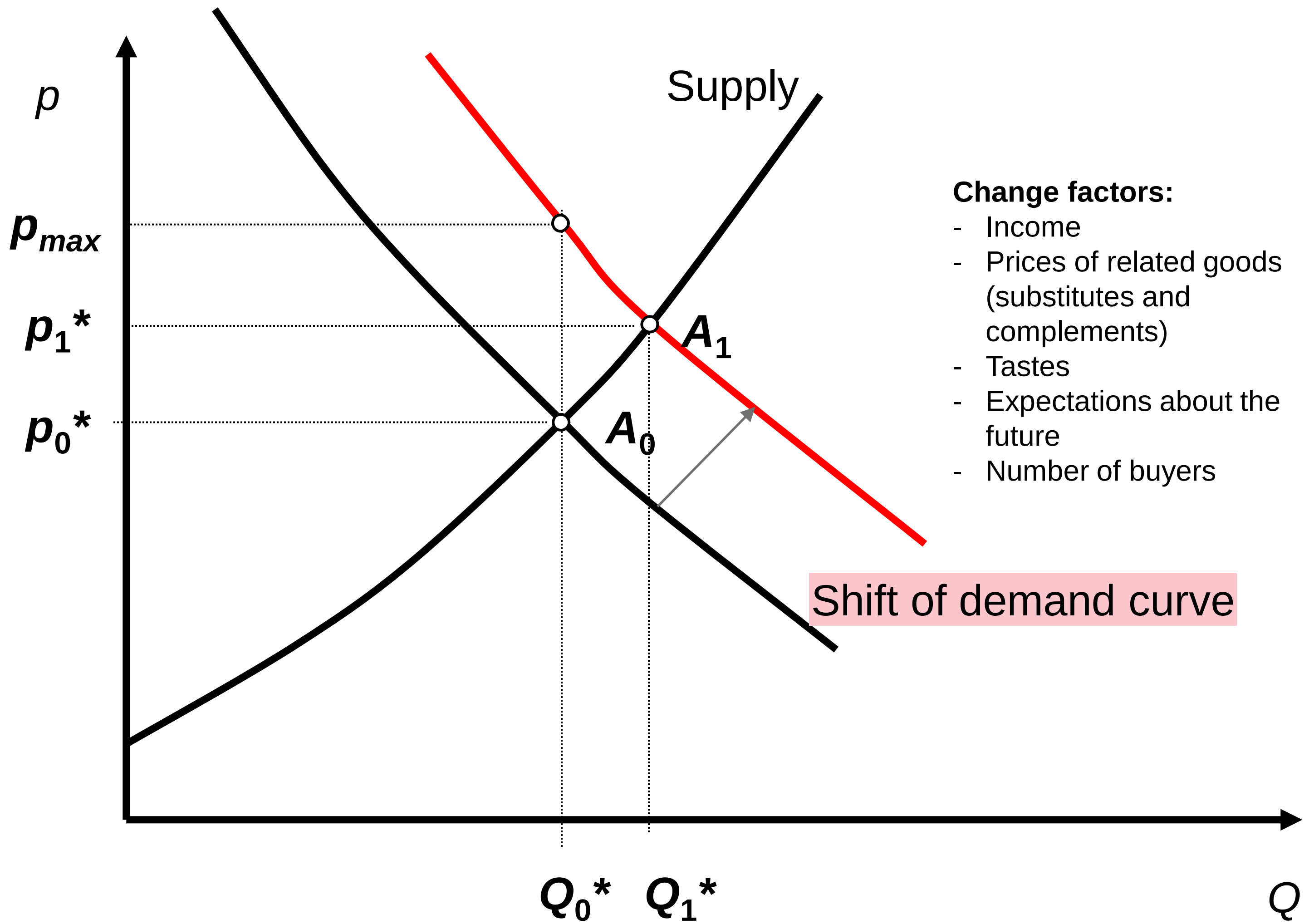
At the equilibrium price, the quantity supplied equals the quantity demanded.

Bidding curves at EEX

[delivery period Monday, 6.11.2006, 8-9 h]

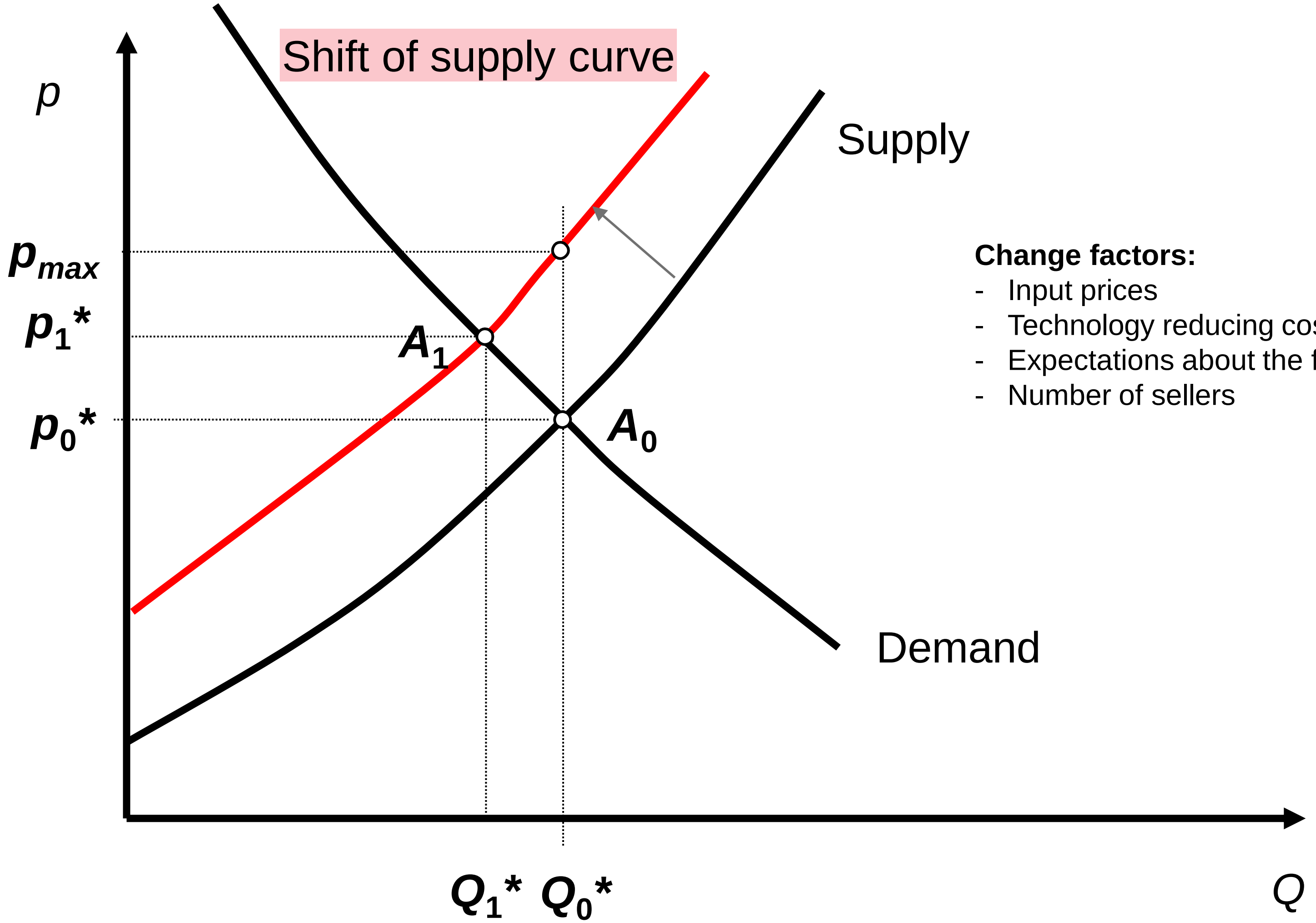


Price reaction to change in demand



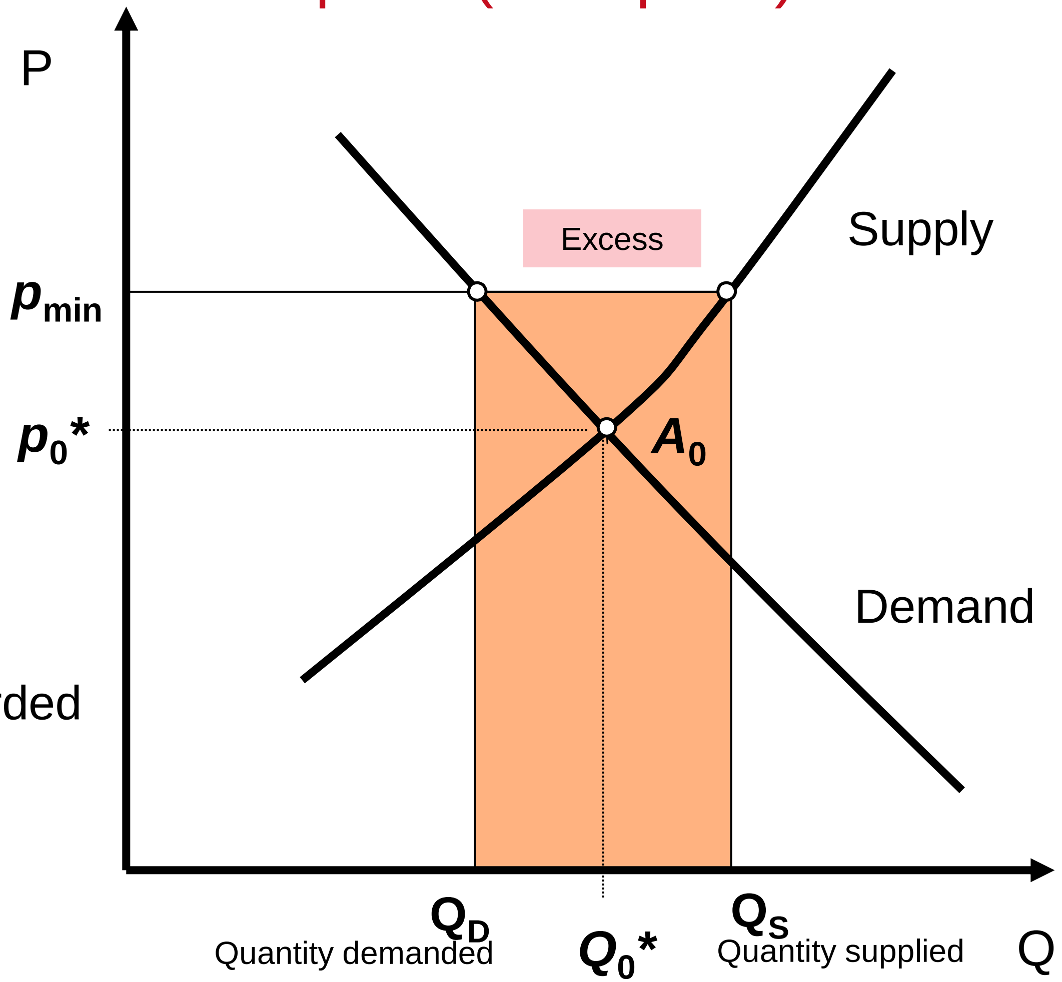
Change factors:
- Income
- Prices of related goods (substitutes and complements)
- Tastes
- Expectations about the future
- Number of buyers

Price reaction to change in supply



Change factors:
- Input prices
- Technology reducing costs
- Expectations about the future
- Number of sellers

State regulation: Minimum price (floor price)

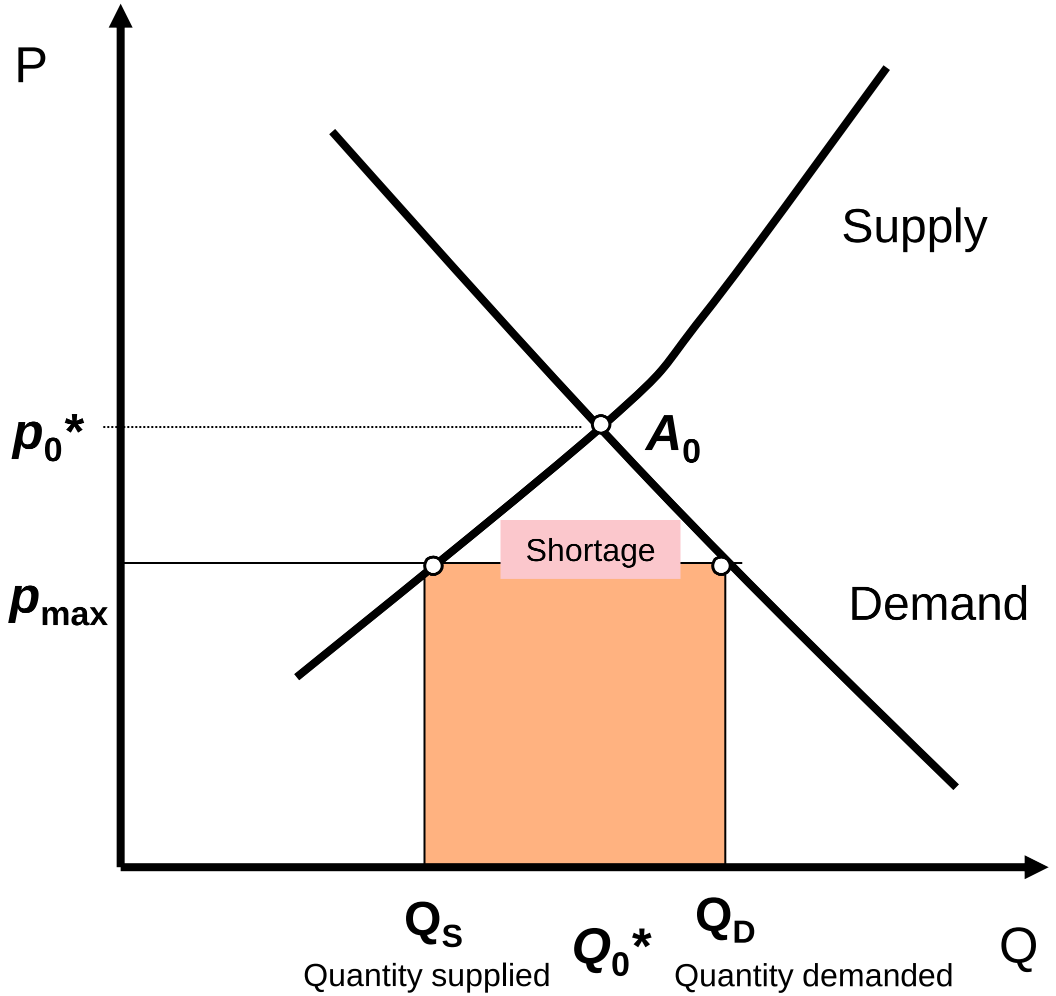


Examples:

EU agriculture politics:
milk overproduction discarded

Minimum wages

State regulation: Maximum price (price cap)

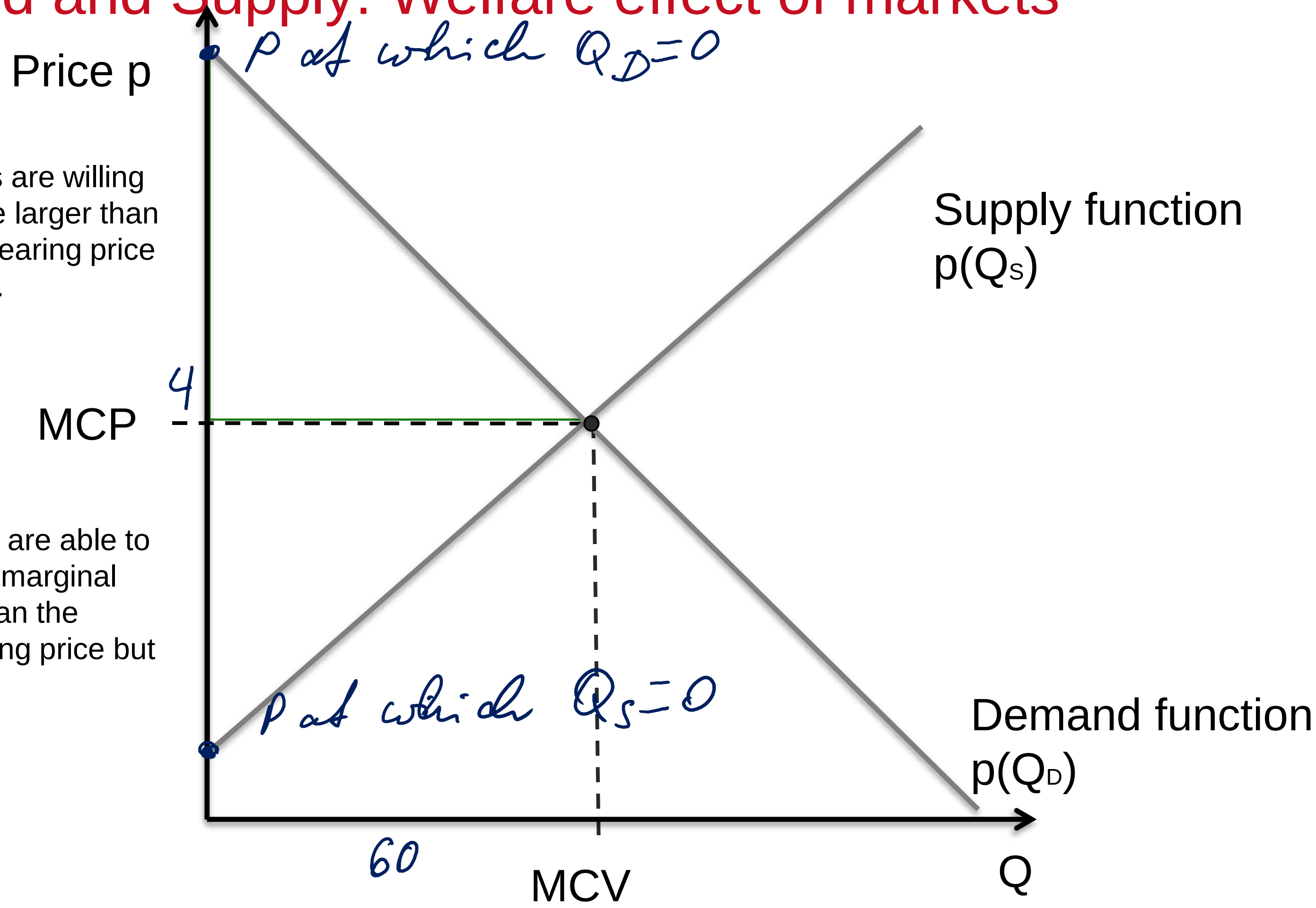


Examples:

apparment rent,
bread/staples,
energy products

Demand and Supply: Welfare effect of markets

Some buyers are willing to pay a price larger than the market clearing price but pay MCP.



Some sellers are able to produce at a marginal cost lower than the market clearing price but sell at MCP.

Demand and Supply: Welfare effect of markets

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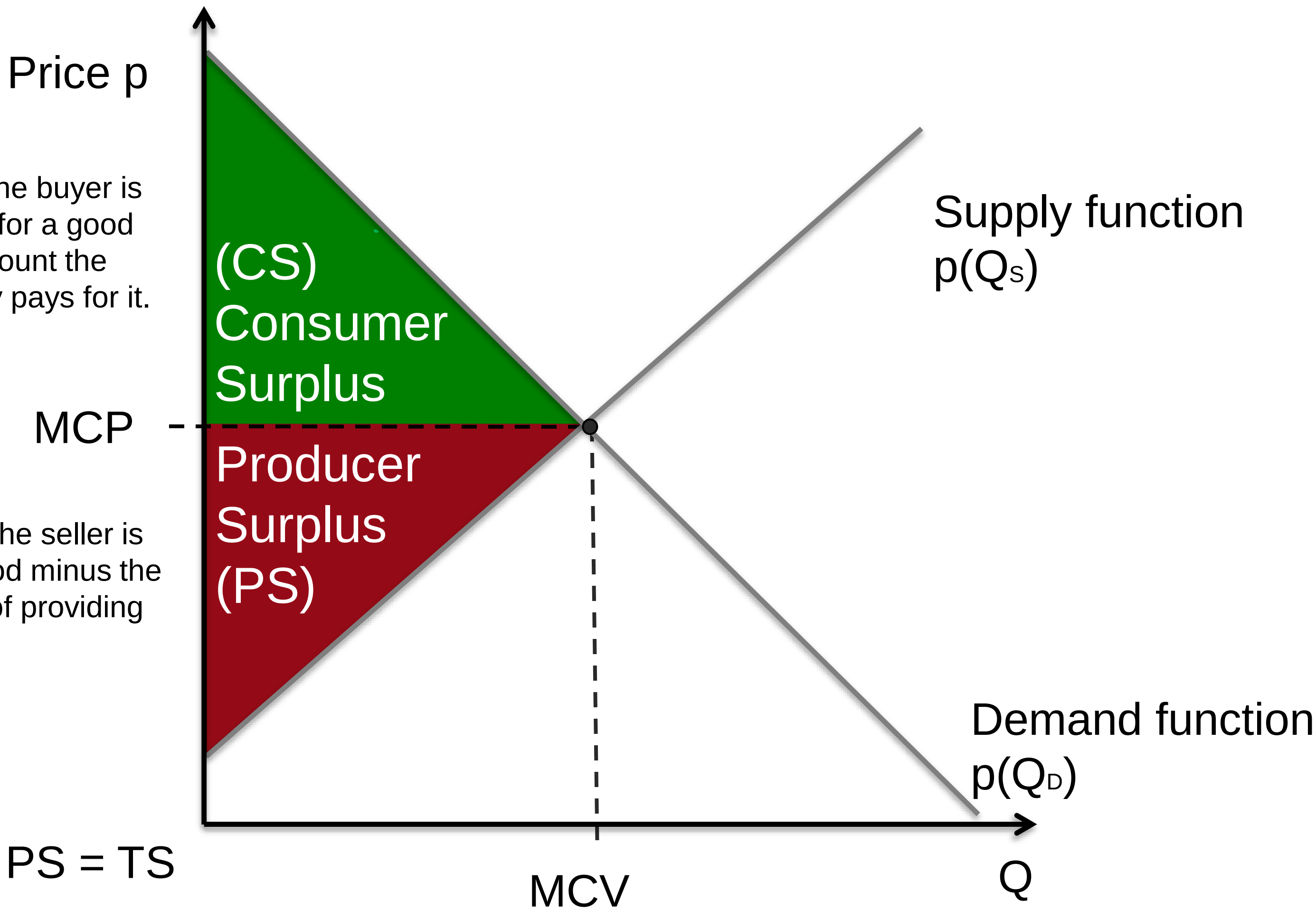
The amount the buyer is willing to pay for a good minus the amount the buyer actually pays for it.



The amount the seller is paid for a good minus the seller's cost of providing it.

CS + PS = TS

Total surplus indicates the degree of efficiency of resource allocation.

Price elasticity

Elasticity is a measure of how much buyers and sellers respond to changes in market conditions (e.g. prices – price elasticity).

Price elasticity of demand is a measure of how much the quantity demanded of a good responds to a change in the price of that good.

$$\text{Price elasticity of demand} = \frac{\text{\% change in quantity demanded}}{\text{\% change in price}}$$

$$\eta_{P,Q} = \frac{dQ}{dP} \cdot \frac{P}{Q}$$

Price elasticity (continued)

$-1 < \eta_{p,Q} \leq 0$	inelastic demand
$-\infty < \eta_{p,Q} \leq -1$	elastic demand
$\eta_{p,Q} = -1$	if price increases by 1%, demand decreases by 1%

Convention to operate with absolute values $|\eta_{p,Q}|$:

$\eta_{p,Q} > 1$	elastic demand
$0 \leq \eta_{p,Q} \leq 1$	inelastic demand

Price elasticity of demand: Electricity

Demand for electricity is largely inelastic.

General reasons for inelastic demand (0 – 1):

- Buyers do not perceive the price changes
- Switching to alternative products (substitutes) is cumbersome
- Lack of substitutes

- Time:

Goods tend to have more elastic demand over longer time horizons.

A more narrowly defined market has a more elastic demand than a broader market.

Supply side: Cost of production

The price at which a seller is willing to sell their goods is determined by their cost of production:

- explicit cost: out-of-pocket expenses - money actually paid
- opportunity cost: potential benefit or income that is foregone as a result of selecting one alternative over another

Terms and definitions of cost accounting

- **Fixed Costs** are the share of the total costs that do not change with a variation of the produced quantity

- **Variable Costs** are the share of the total costs that do change with a variation of the produced quantity

- **Total Costs** are the sum of fixed and variable costs

Terms and definitions of cost accounting (continued)

- **Average costs** are total cost per unit: TC divided by the produced quantity Q.
- **Marginal costs** are costs incurred for producing one additional unit of production volume.
- **Contribution margin** is selling price minus variable cost per unit.

Total cost consideration

	A	B	C
Turnover	800	500	700
Variable Cost	350	150	400
Fixed Cost	150	150	500
Total Cost	500	300	900
Operating income	300	200	- 200
Overall outcome		**300**	

Total cost consideration without product C

	A	B	C
Turnover	800	500	0
Variable Cost	350	150	0
Fixed Cost	150	150	500
Total Cost	500	300	500
Operating income	300	200	- 500
Overall outcome		**0**	

Variable cost

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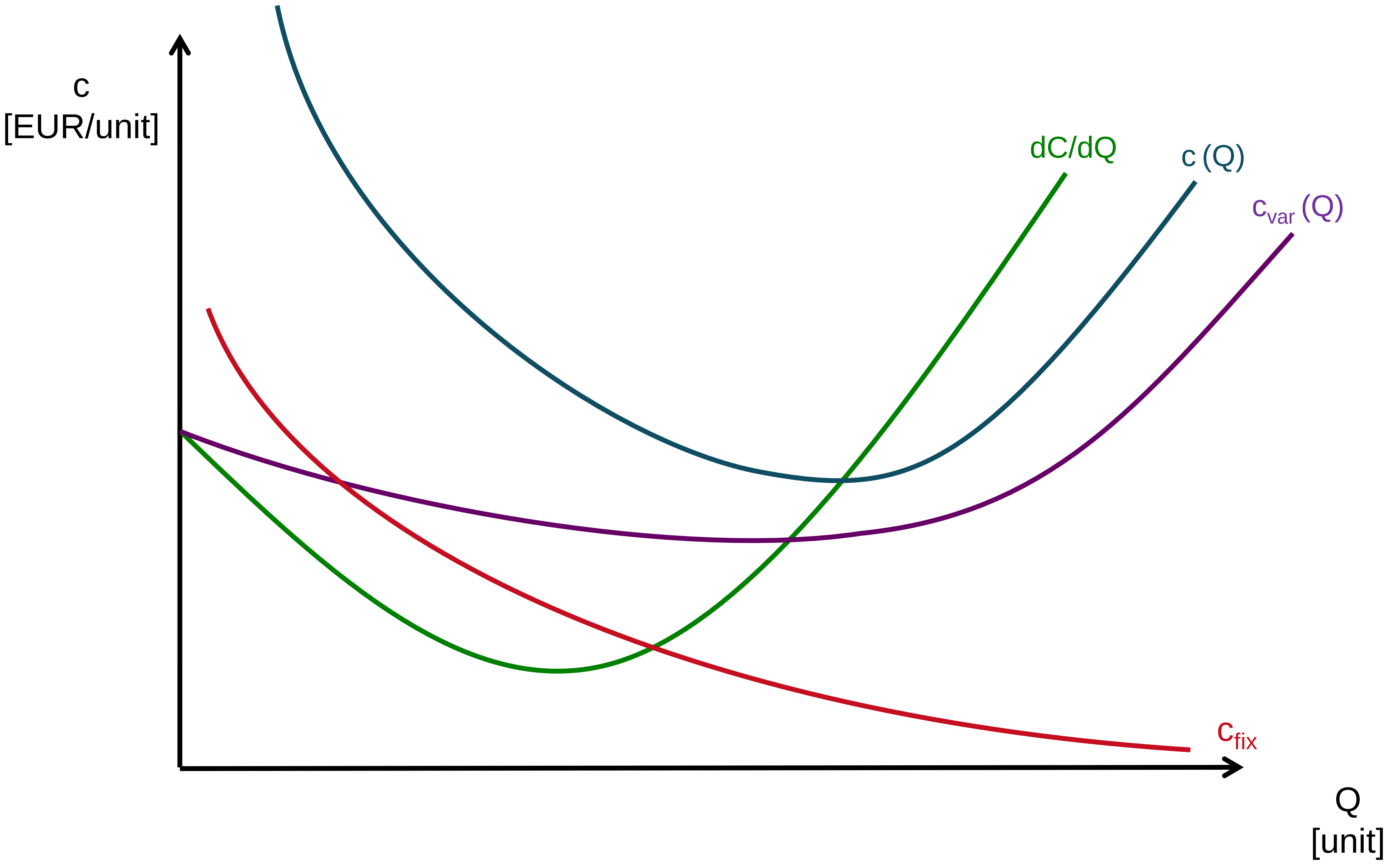
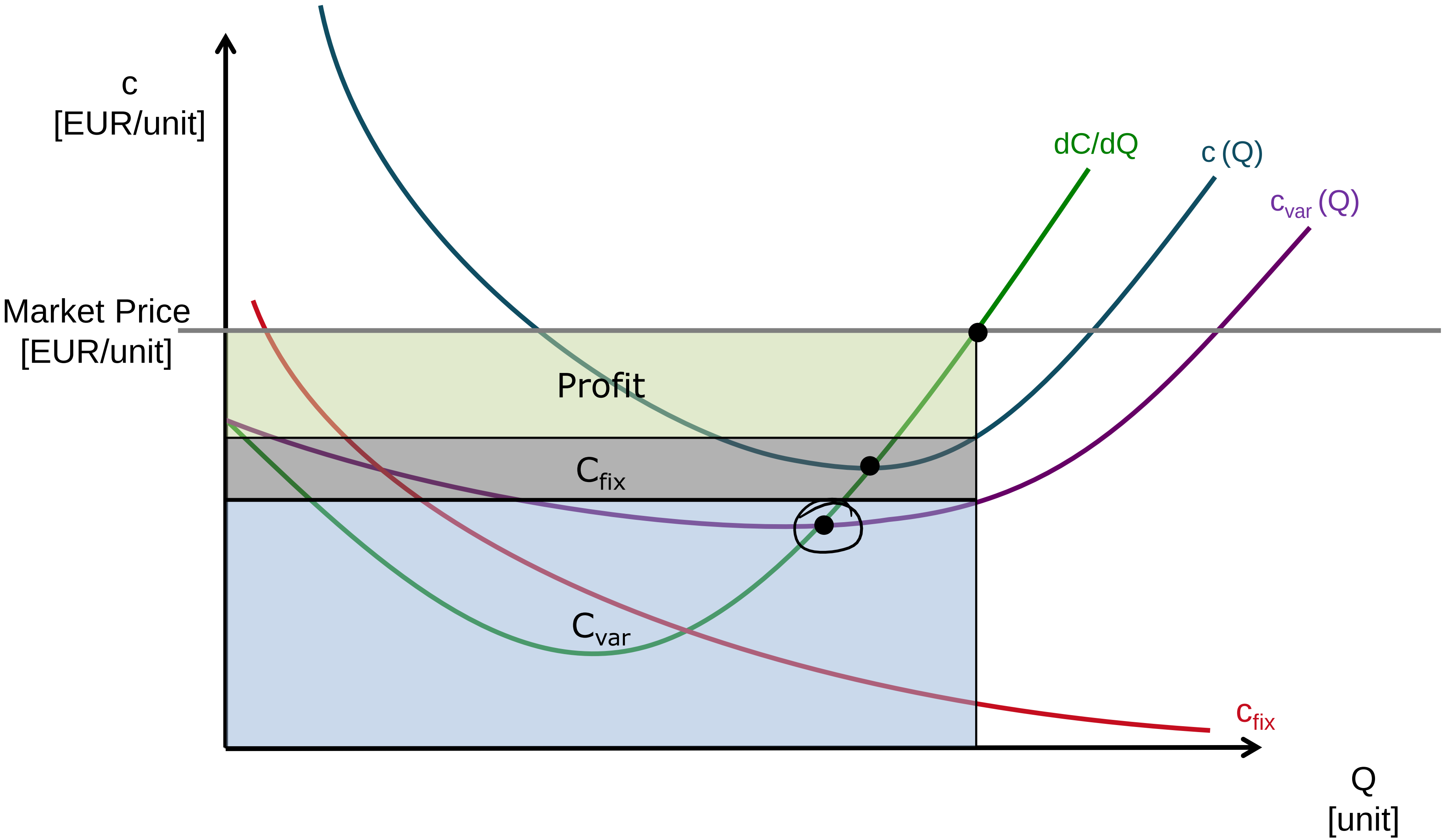
	A	B	C
Turnover	800	500	700
Variable Cost	350	150	400
Contribution margin	450	350	300
Total contribution margin	1100		
Fixed cost	800		
Overall outcome	**300**		

Cubic cost structure – cost structure



Cubic cost structure – conclusions for a price taker



Market structures - 1

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Market is a group of sellers and a group of buyers of a particular good or service.

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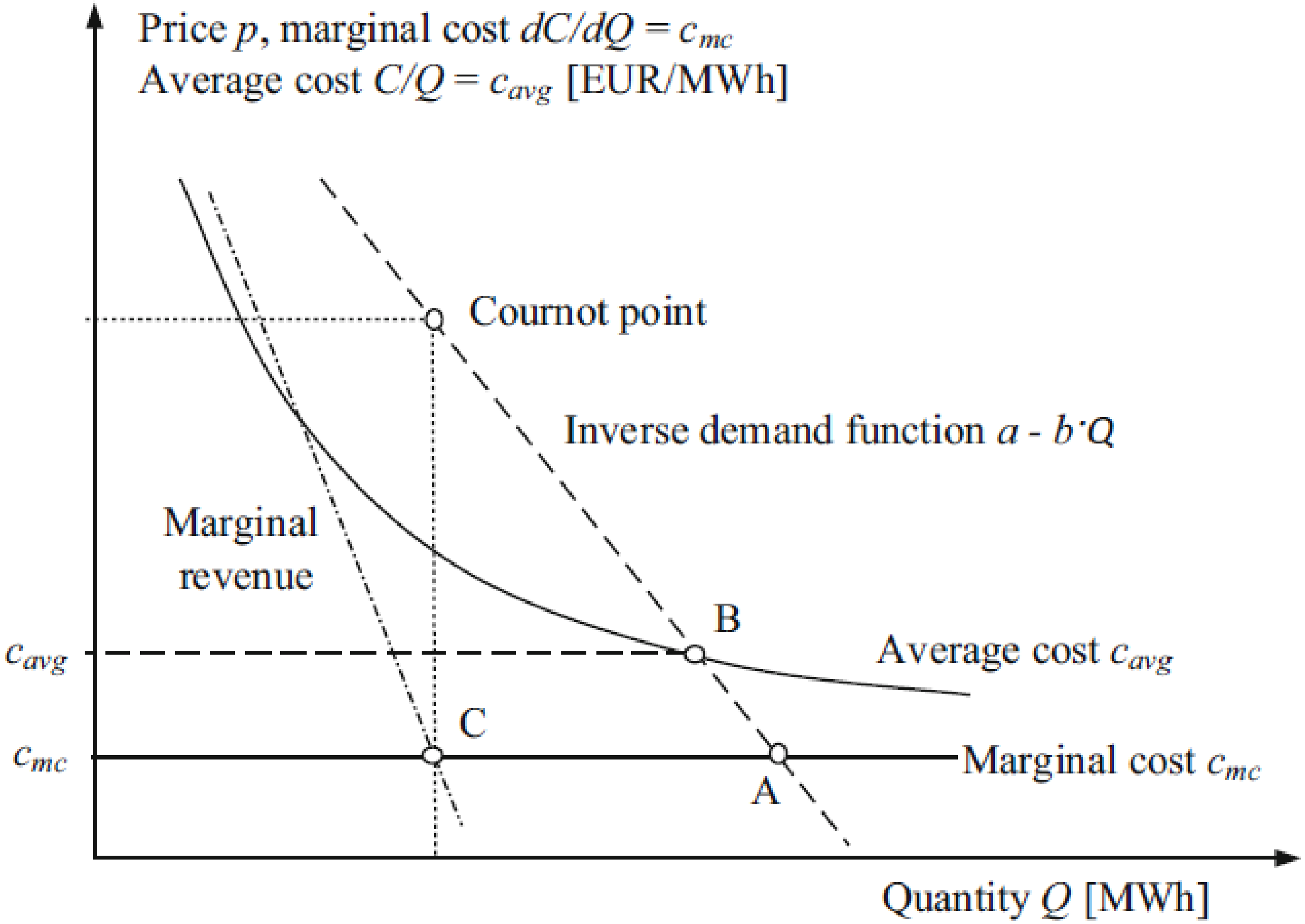
- consumers have perfect information
- no entry or exit barriers

Monopoly:

- seller is the sole producer and can influence the price of its output

Market power is the ability to maintain a price above the price under competition.

Monopoly Pricing



Supply and pricing

$\Pi = p \cdot Q - C$

$C = C_{var} \cdot Q + C_{fix}$

$$\frac{d\Pi}{dQ} = \frac{d(p \cdot Q)}{dQ} - \frac{dC}{dQ} = 0$$

Π	Profit (per period)
p	Sales price
Q	Output (Quantity)
C	Production costs

<u>Competitive markets</u>

$p = \frac{dC}{dQ}$ ⟶ „Marginal cost = Price rule“

<u>Monopoly markets</u>

$\frac{dC}{dQ} = \frac{d(p \cdot Q)}{dQ}$ ⟶ „Marginal costs = marginal revenue rule“

Market structures - 2

Cournot oligopoly:

- More than one firm
- All firms produce one homogeneous product (no product differentiation)
- No cooperation among firms (no collusion)
- Firms have market power - each firm's output decision affects the good's price
- Fixed number of firms
- Firms compete in quantities, and choose them simultaneously
- Economically rational and strategically acting firms, seeking to maximize profit given their competitors' decisions

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Introduction to corporate finance

Understanding how companies invest in new projects

Starting a firm takes investment into **assets**:

inventory (raw materials), machinery, land, and labour.

The amount of cash invested into the assets has to be matched by the amount of cash 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

Current assets

How to manage short-term operating cash flows?

↑ match amounts and timing of cash inflows & outflows → short-term liquidity

Current liabilities

Net working capital

Non-current liabilities

How to raise cash for capital expenditures?

↓ sell bonds and shares that raise more cash than they cost

Which long-lived assets to invest in?

↓ buy assets that generate more cash than they cost

Non-current assets:

1. Tangible non-current assets
2. Intangible non-current assets

Shareholders' equity

Total value of assets

Total value of the firm to investors

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

Source: Hillier, Ross, Westerfield, Jaffe, Jordan, 2016

Methods of project valuation

Static methods

(single-period)

- Cost comparison statement

+ operating costs p.a.
+ average capital costs p.a.
+ depreciation p.a.
annual costs

- Profit comparison

revenues ./. annual costs

- Return on investment

EBIT = earnings before interest and tax + interest on debt

ROI = *EBIT* / avg. capital employed p.a.

- Pay-back period

Break even = investment / avg. cash flow p.a.

Dynamic methods

(*time value of money*)

- Net present value

PV = sum of discounted cash flows

NPV = *PV* - Investition > 0?

- Equivalent annual annuity

transformation of cash flow series into annuity

- Internal rate of return

IRR = discount rate at which [*NPV*=0]

Time value of money

Value of an investment depends on the timing of cash flows.

Cash flow is an amount of money paid or received (revenue or expenditure).

Cash flows are characterised by the amount (+/-) and due date.

Time value of money: value of a cash flow at the time it becomes due.

Present value: value of a cash flow at present.

For a cash flow due and payable today:

present value = time value

For a cash flow due and payable at a future time:

present value = time value – interest

Cashflows: Discounting and compounding

To be able to compare cashflows, they have to be discounted or compounded to the same reference period.

Choice between spending a sum of money or lending it.

Interest rate is the price for obtaining funds for a specified time.

It reflects the opportunity cost in view of other investment options and risk of credit default.

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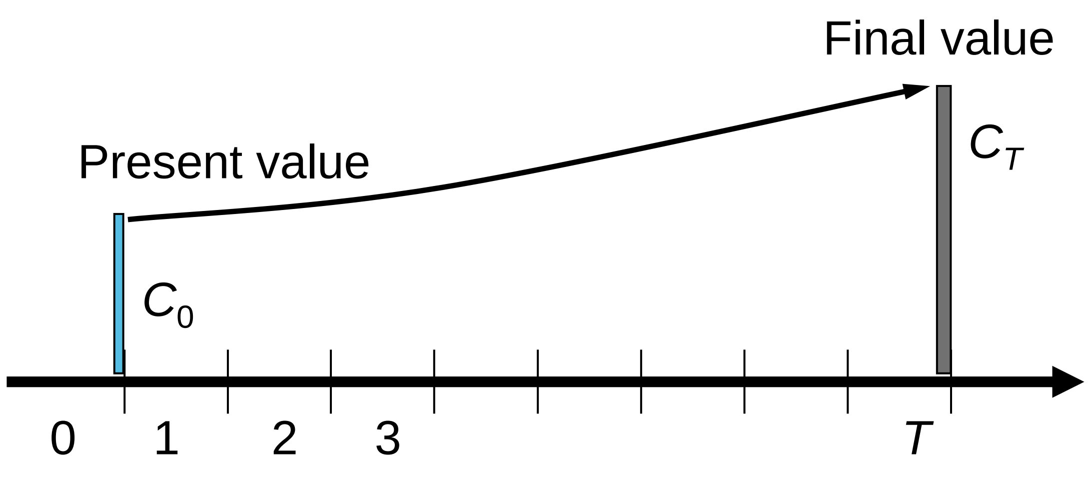
Cash flows: Compounding

- **Compounding:** Present value → future value

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

C_0 = the cash flow at date 0 (today) = present value
i = interest rate per period
T = number of periods (time horizon)
C_T = value of the cash flow at time T = future value

Compound interest:
$C_0 \cdot (1+i)$ lended again after 1 period
$(C_0(1+i)) \cdot (1+i)$ lended again after 1 period
etc.

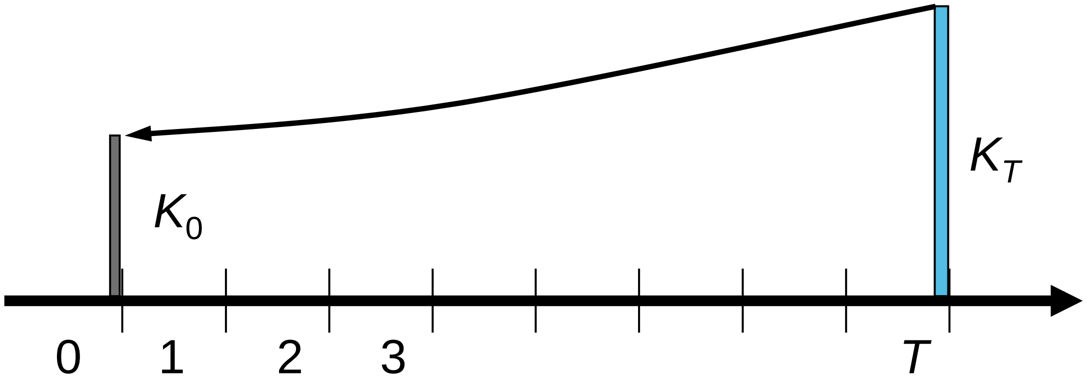


Cash flows: Discounting

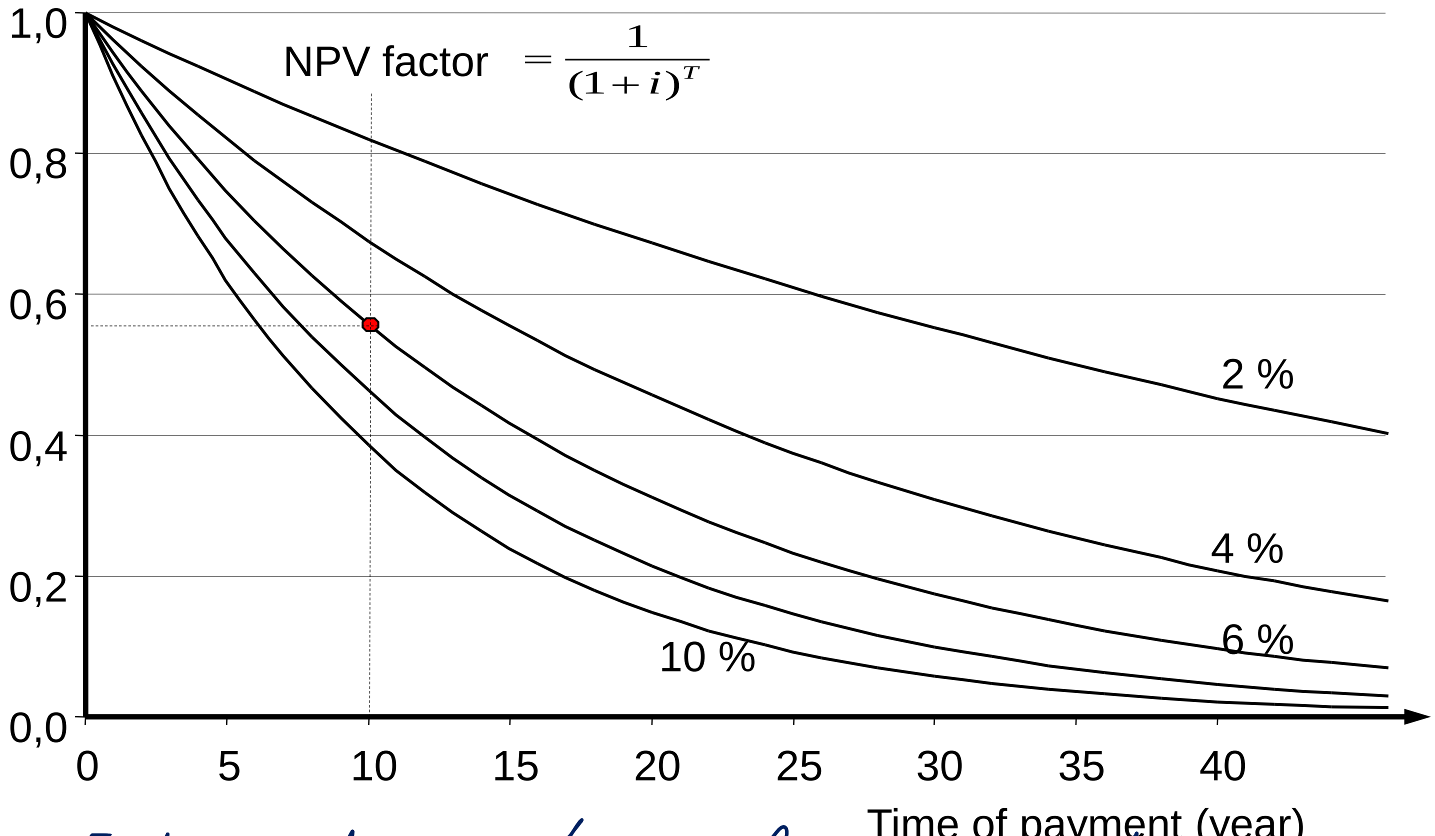
- **Discounting:** Future value → present value

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

C_0 = value of the cash flow at date 0 (today) = present value
i = interest rate per period
T = number of periods (time horizon)
C_T = the cash flow at time T = future value



Present value of a future cash flow

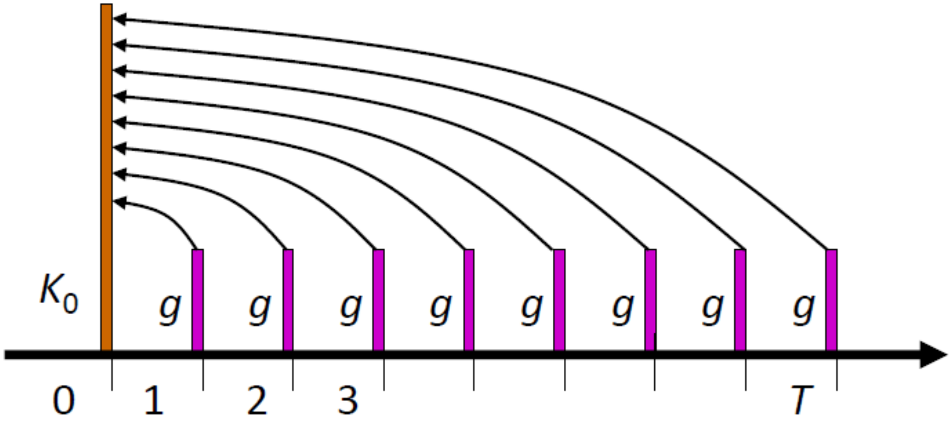


PV depends on time of payment (the sooner, the higher PV) and on the interest rate (the lower the interest rate, the higher PV).

Annuity: NPV with constant cash flows

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

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

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

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

Annuity 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	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

A fixed periodical payment multiplied with applicable ANF returns the present value of the annuity.

Capital recovery factor

$CRF = \frac{1}{AF}$

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

A loan amount multiplied with applicable CRF returns a constant annual amount needed to repay the loan.

Capital structure

The discount rate represents cost of capital and project risk.

Risk-free interest rate + 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)

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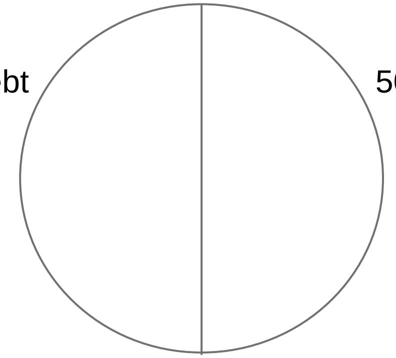
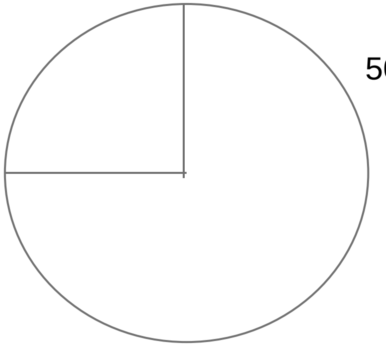
Capital structure: Weighted average cost of capital



Capital structure 1



Capital structure 2

$$\text{WACC} = \frac{E}{D+E}(r_e) + \frac{D}{D+E}(r_d)$$

Where:

E = market value of equity

D = market value of debt

r_e = cost of equity

r_d = cost of debt

Capital budgeting: NPV (DCF) method

The value of a project is measured by its net present value (NPV):

present value of the future cash flows minus the initial investment outlay.

1. Identify forecast all cash flows (revenues and costs) associated with a project (forecast).
2. Map the cashflows on a cash flow time chart.
3. Discount each cashflow using an applicable interest rate.
4. Sum up all the discounted cashflows (DCF) to obtain NPV
5. Invest only if NPV > 0 [NPV = 0 indifferent]

Capital budgeting: NPV (DCF) method

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

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

Relevant cash flows

CF from financing activities:

- capital expenditures
- sale of assets

CF from operating activities:

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

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Relevant cash flows (continued)

e.g. unused storage facility (as alternatively, it can be used for another purpose)

Opportunity cost: potential benefit or income that is foregone as a result of selecting one alternative over another are considered.

Sunk cost: Cost incurred in the past that cannot be changed by any decision are ignored.

Salvation value: In case of abandonment (divestment), assets, typically, retain a residual value (future revenue).

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.

NPV method: Calculation example

Discount rate: 7%

Period t	Investment [1000 EURO]	Cash flow [1000 EURO]	Discount factor $(1+i)^{-t}$	PV [1000 EURO]
0	-3000	0	1,000	-3000,0
1	0	160	0,935	149,5
2	0	400	0,873	349,4
3	0	400	0,816	326,5
4	0	400	0,763	305,2
5	0	400	0,713	285,2
6	0	400	0,666	266,5
7	0	400	0,623	249,1
8	0	400	0,582	232,8
9	0	400	0,544	217,6
10	0	400	0,508	203,3
11	0	400	0,475	190,0
12	0	400	0,444	177,6
13	0	400	0,415	166,0
14	0	400	0,388	155,1
15	0	400	0,362	145,0
Total (NPV)				**418,9**

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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

$$p_E - oc = \frac{I_0}{Q \cdot \sum_{t=1}^{T} \frac{1}{(1+i)^t}}$$

$$\sum_{t=1}^{T} \frac{1}{(1+i)^t} = AF_{i,T}$$

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

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

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

Levelised cost of electricity (LCOE)

How to calculate the generation costs per unit of electricity?

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

E_t = Cap * FLH

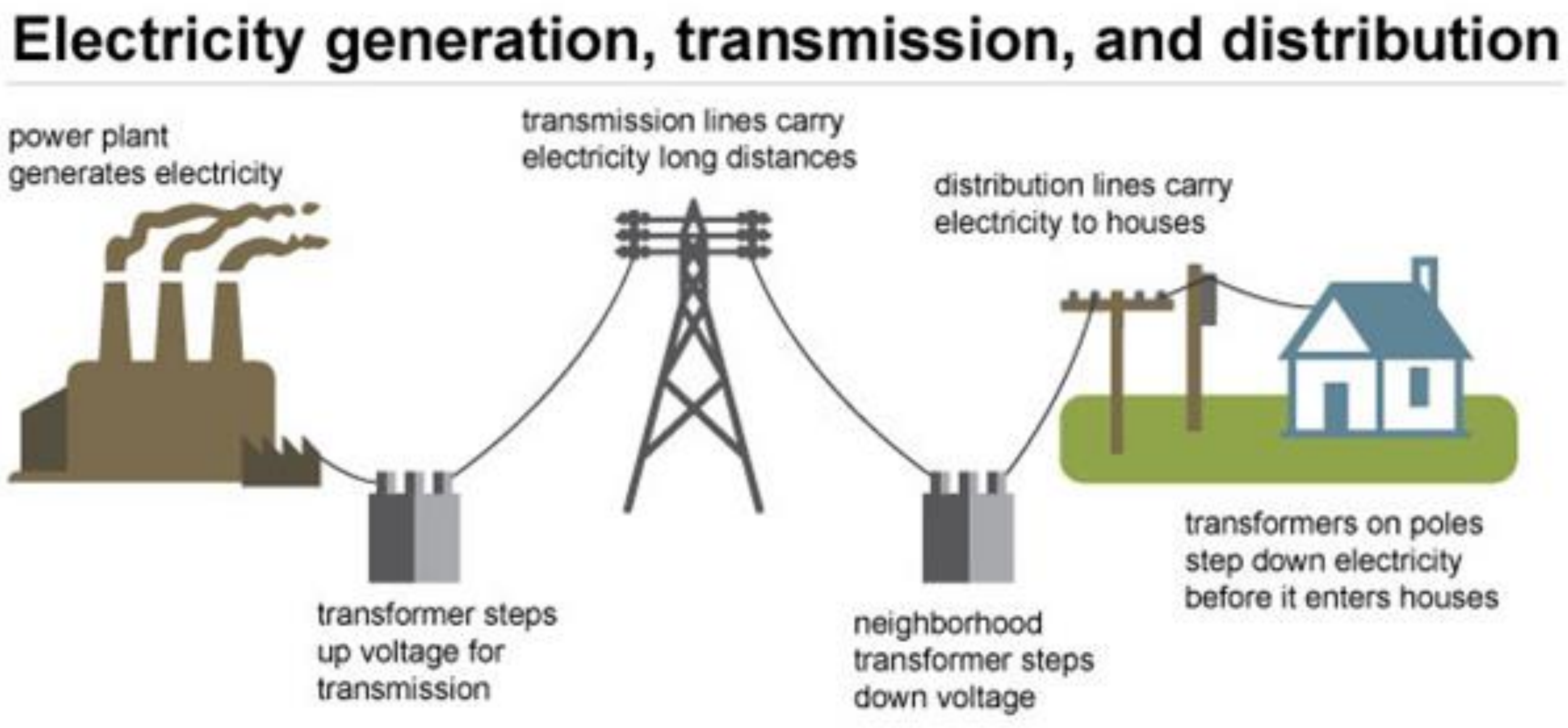
E_t	annual electricity output
Cap	installed capacity (rated power)
FLH	full load hours: annual output divided by Cap

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

Outline

- Energy balances
- Economics fundamentals
- Financial management
- **Electricity markets: Market structure**
- Emissions
- Resources and sustainability
- Oil and gas markets

Electricity market: Technical view



Source: U.S. EAI

Electricity market: Economic view

Commercial infrastructure

Electricity is produced in power plants.

Technical infrastructure

Produced electricity is offered/traded in the wholesale market.

Produced electricity is transported to final consumers via transmission and distribution grid.

Electricity retailers procure electricity in the wholesale market for supplying final consumers.

Final consumers buy electricity from retailers.

Electricity market: Natural monopoly

Natural monopolies occur in industries for which it is only economically efficient to have a single provider due to economies of scale (decreasing average costs with increasing scale of production).

Electricity transmission and distribution is a decreasing cost industry: Duplicating the grid is economically inefficient.

Yet, natural monopolies – like monopolies in general – tend to overcharge and underserve.

Electricity market: Unbundling

Competitive conditions for electricity generation and retail can be created by state regulation aiming at:

- Costs transparency

  → prevent cross-subsidies*

  ** allocating costs from competitive activities to grid operation*

- Non-discriminatory access to the grid

  → grid connection and transmission/distribution services

Unbundling is a set of organisational measures to separate transmission and distribution networks from generation and retail activities.

The goal is to ensure independence of a grid operator from other activities in a vertically integrated company and to prevent discrimination of other market participants.

Competitive and natural monopoly activities

Generation	Wholesale	Transmission incl. dispatch	Distribution and metering	Retail
Primary energy is transformed into electricity and injected into the grid	Energy is sold/traded on the wholesale market	Electricity is transmitted via high voltage grid until the local distribution grid	Electricity is transformed from high to medium/low voltage and distributed to final customers	Electricity is supplied to final consumers based on their demand
Power plant operators	Energy traders	Transmission system operators (TSO)	Distribution system operators (DSO)	Retailers
Competition	Competition	Regulated	Regulated	Competition
		Natural monopoly		

Outline

- Energy balances
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- **Electricity markets: Electricity generation**
- Emissions
- Resources and sustainability
- Oil markets
- Gas markets

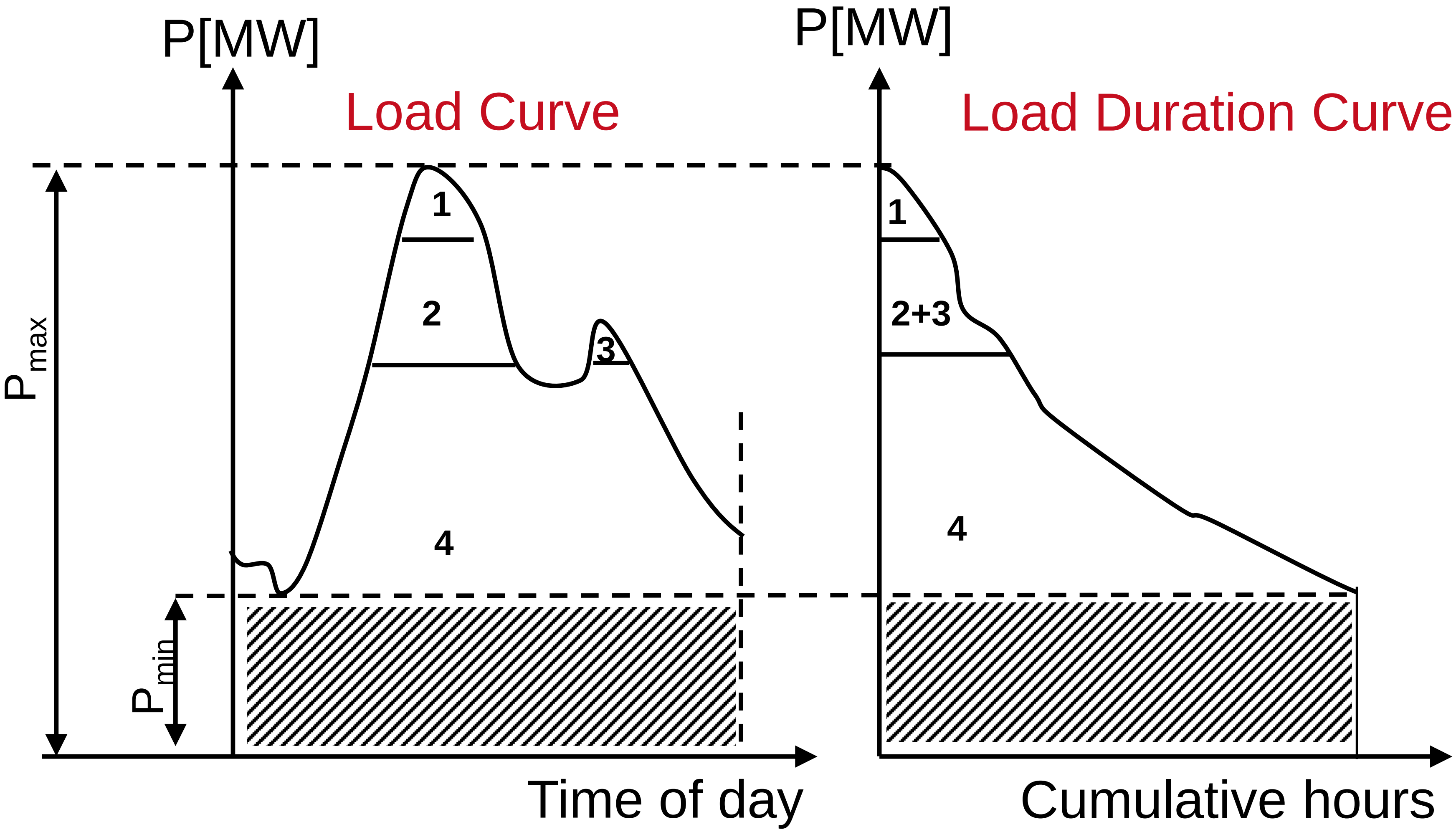
Matching supply and demand

Electricity is virtually non-storable.

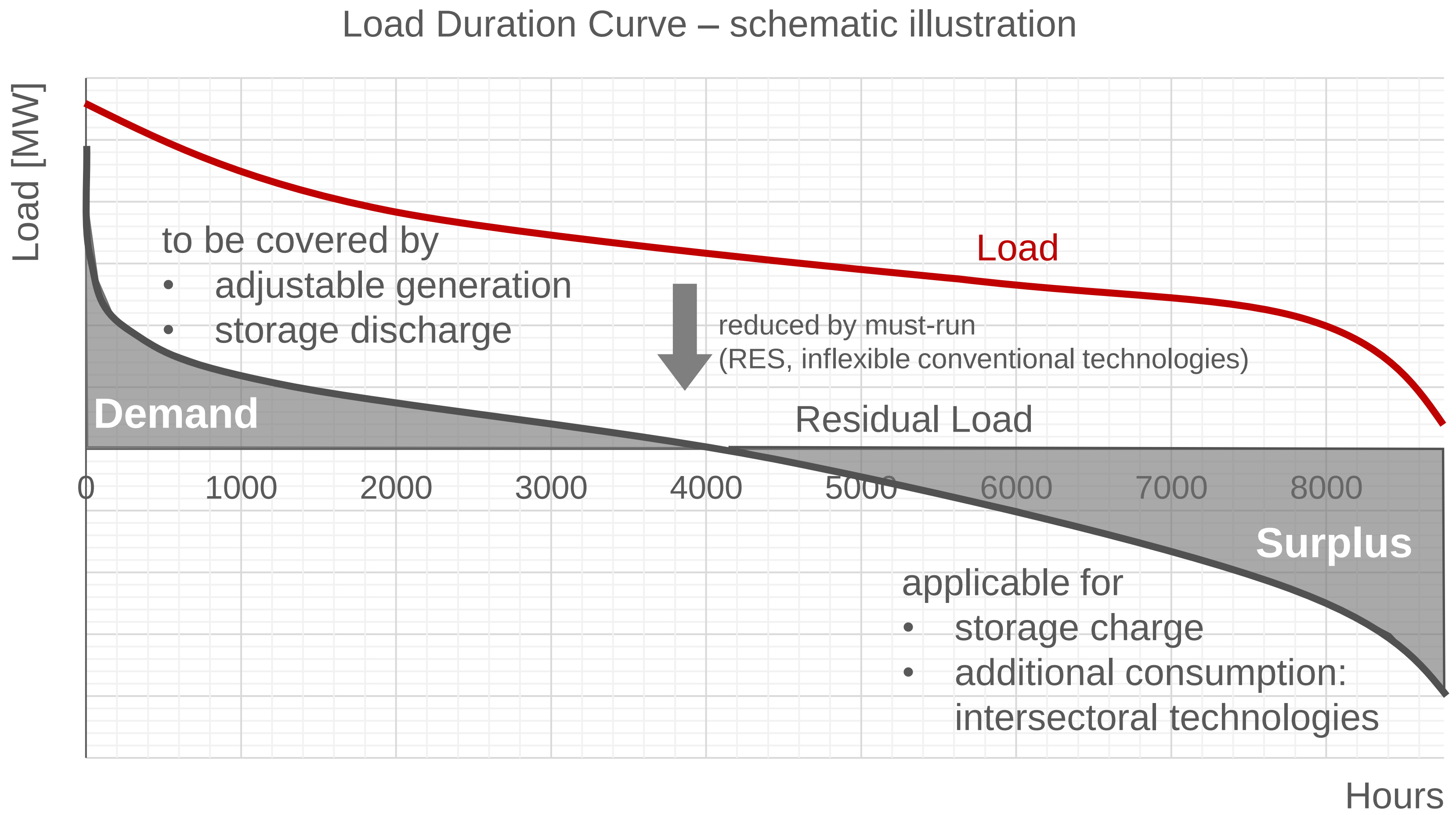
Demand is barely responsive to wholesale price fluctuations.

Thus, electricity supply and demand are balanced by continuous adjustment of generation.

Load Curve and Load Duration Curve



Load and Residual Load



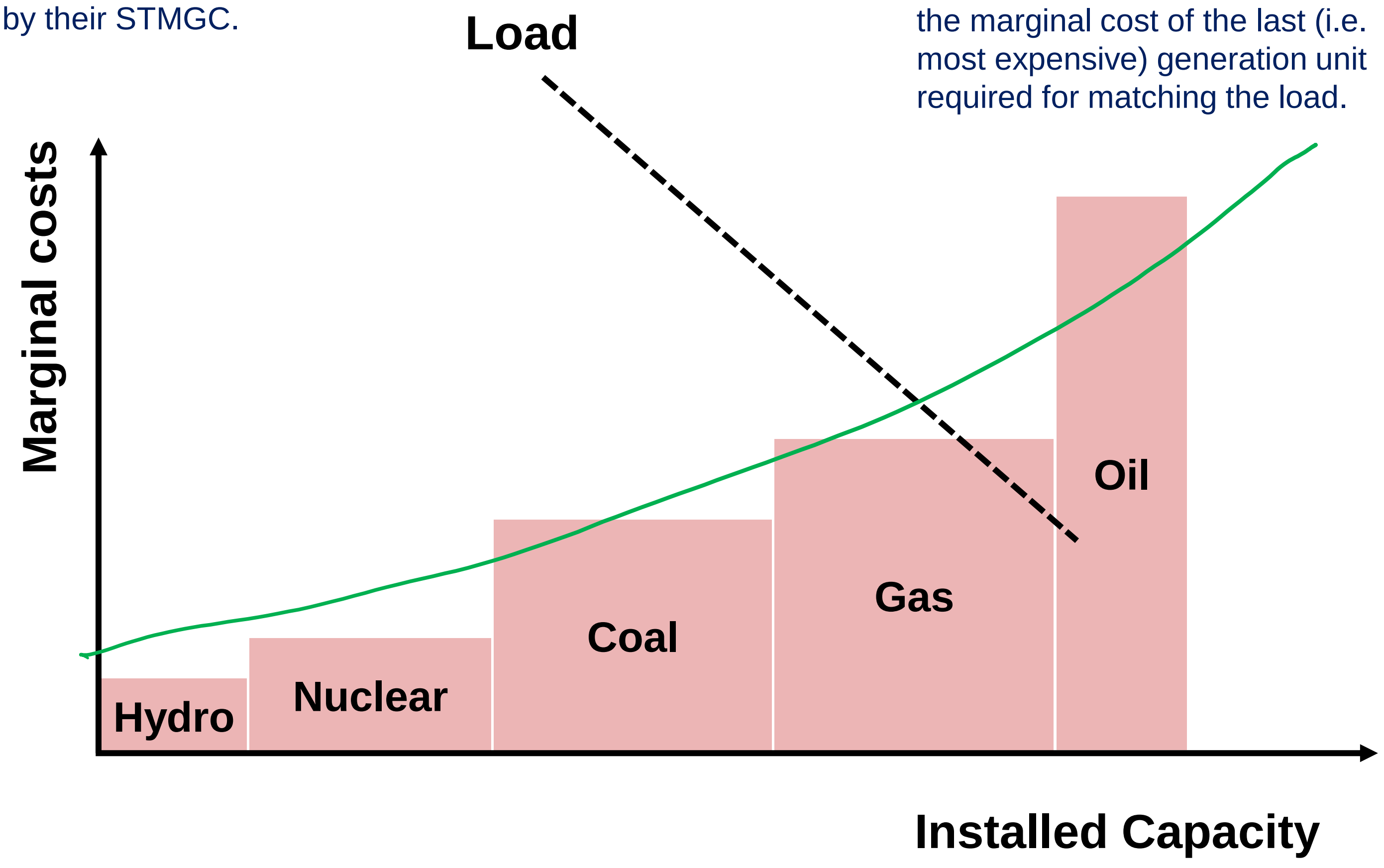
Categories of costs in power production

	Relevance for		
	Operational Decisions	Decommissioning Decisions	Investment and Expansion Decisions
Costs depending on capacity	[€/MW]		
• Capital costs (annuity) • Labour costs • Fixed O&M costs		 X X	X X X
Costs depending on operation	[€/MWh]		
• Fuel costs • CO_2 costs • Other variable costs (e.g variable O&M costs, ramping costs, start-up costs)	X X X	X X X	X X X

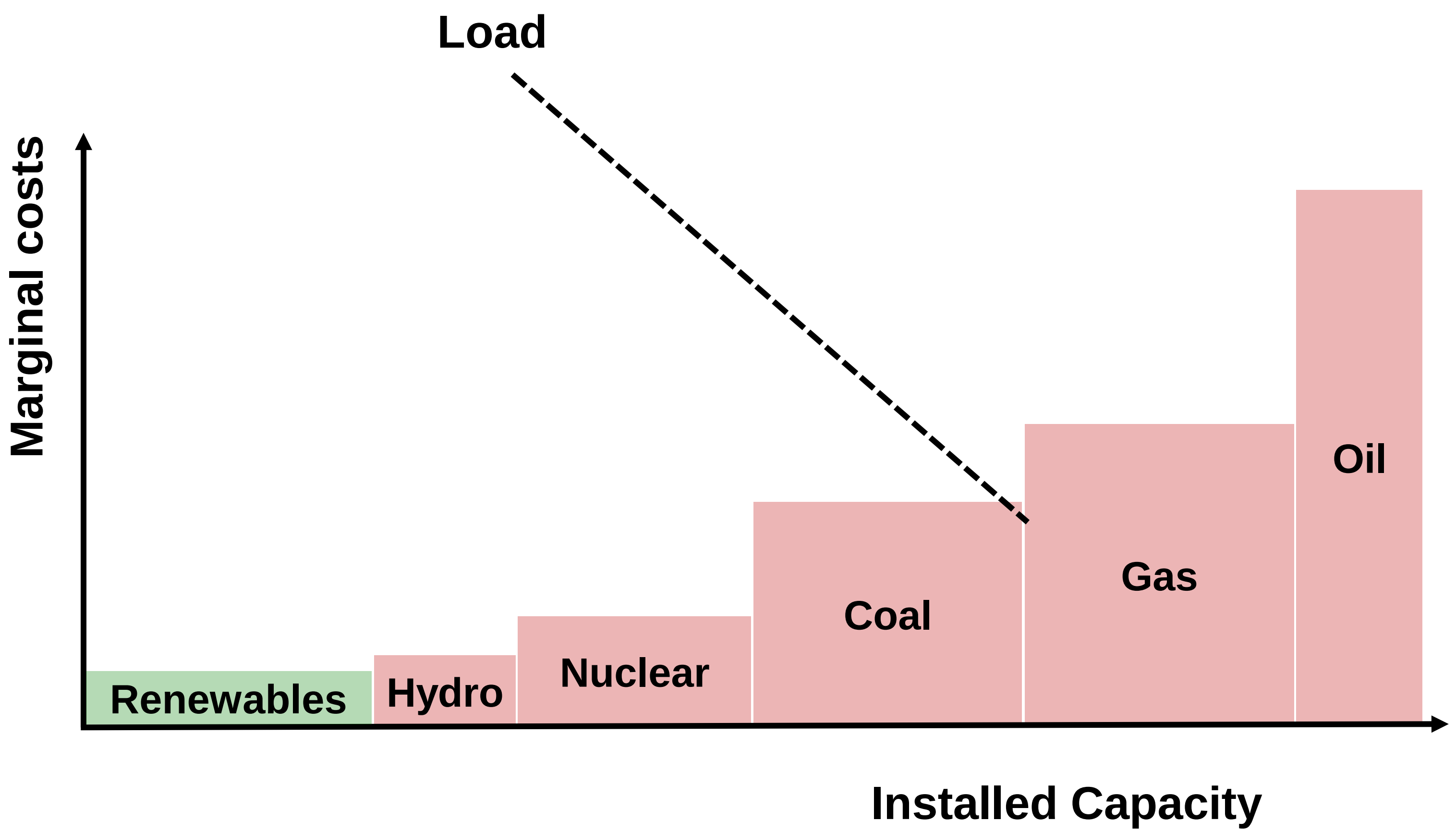
Merit Order

Available generation capacities arranged by their STMGC.

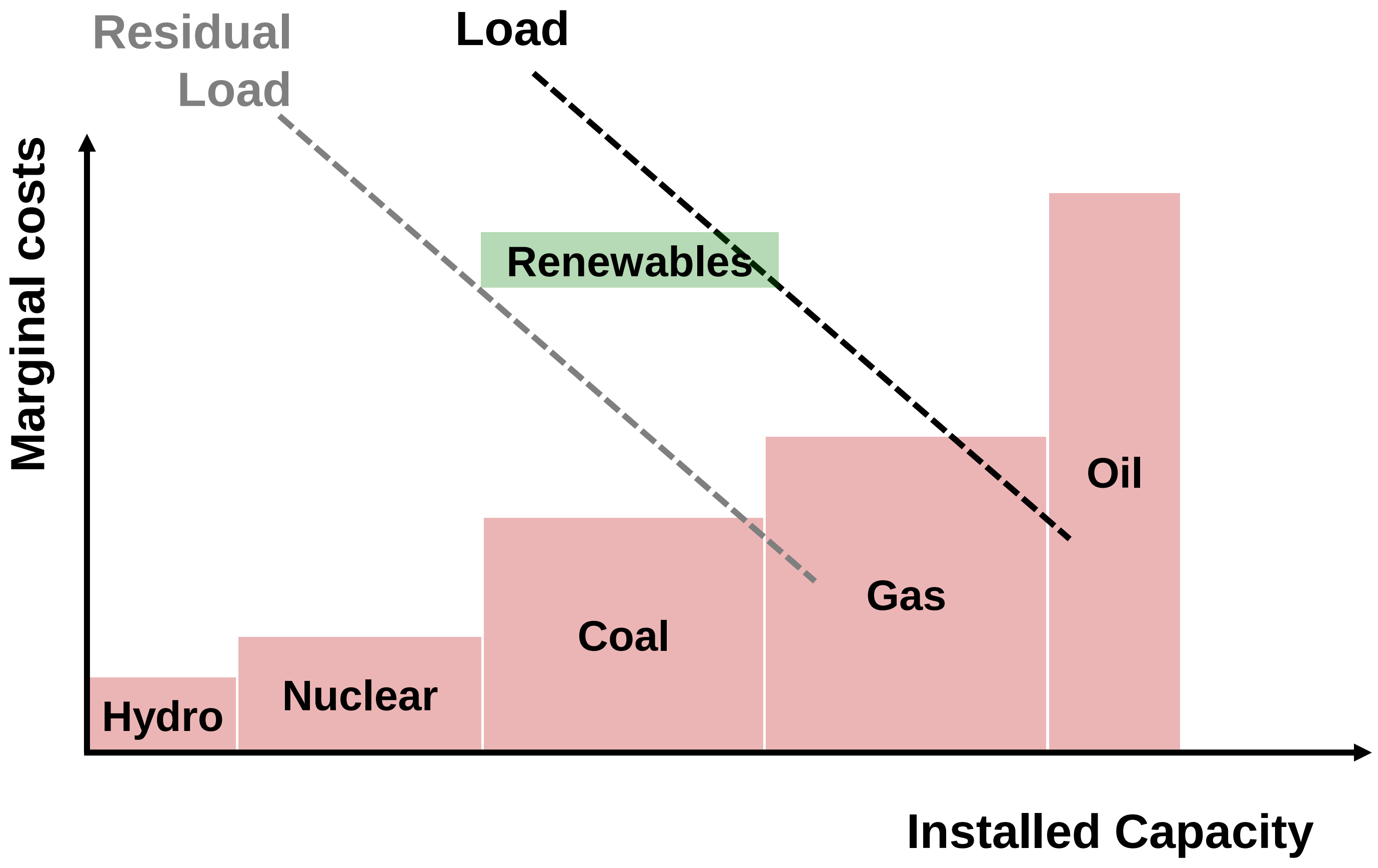
The market clearing price equals the marginal cost of the last (i.e. most expensive) generation unit required for matching the load.



Merit Order Effect of Renewables

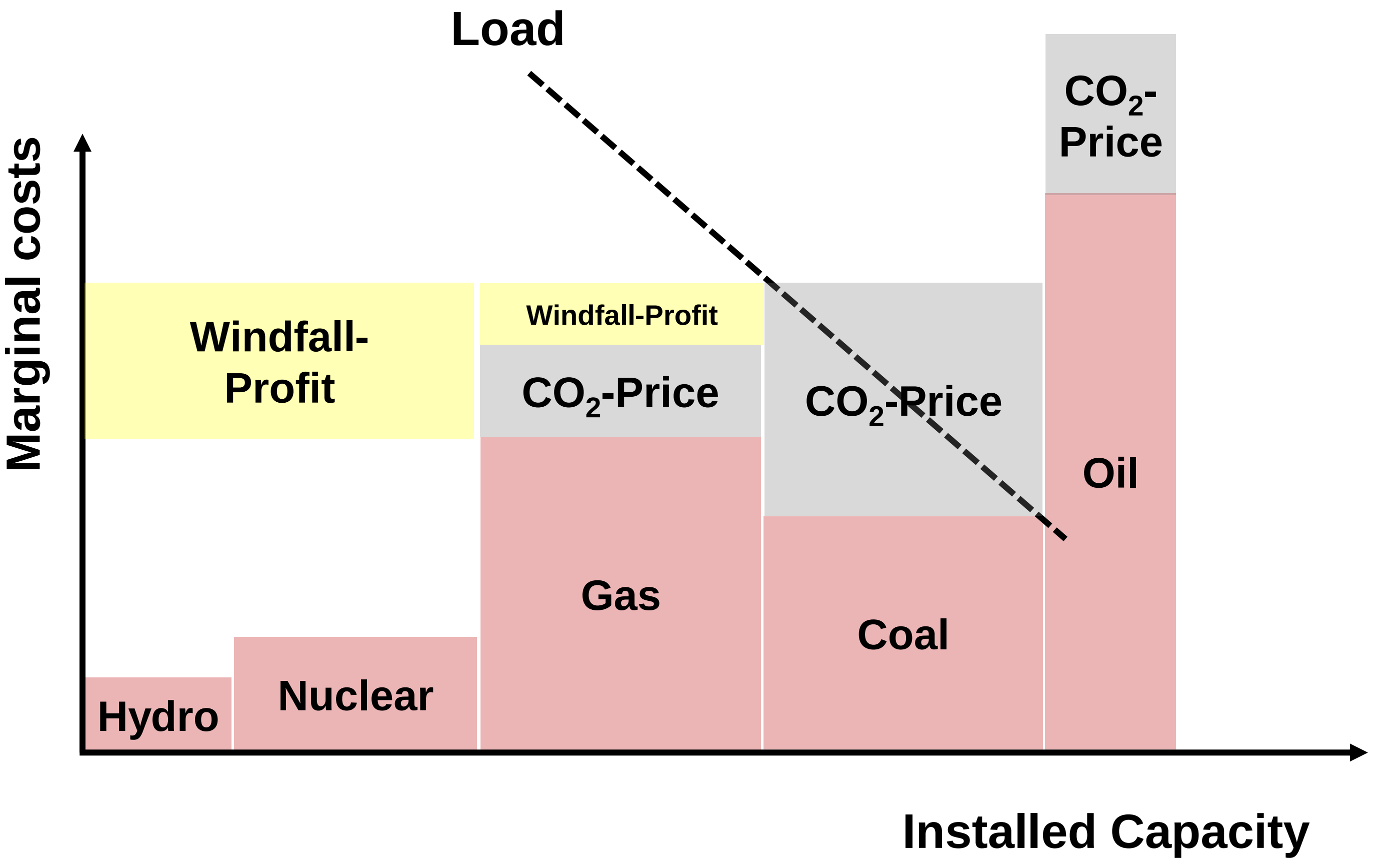


Merit Order



Residual Load
Load
Marginal costs
Renewables
Oil
Gas
Coal
Nuclear
Hydro
Installed Capacity

Merit Order - Impact of CO_2 – Prices



Levelised cost of electricity (LCOE)

How to calculate the generation costs per unit of electricity?

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

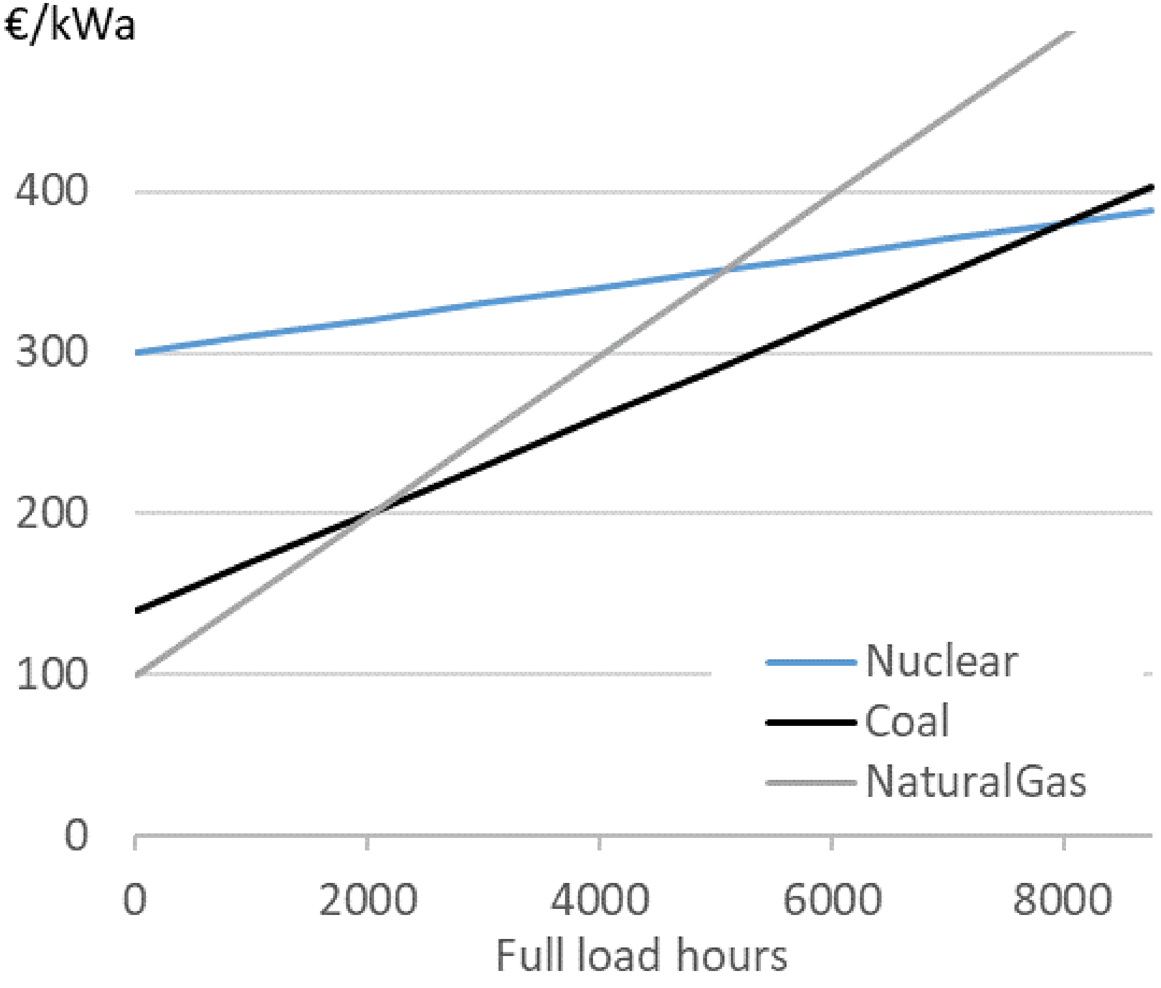
$E_t = Cap * FLH$

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

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

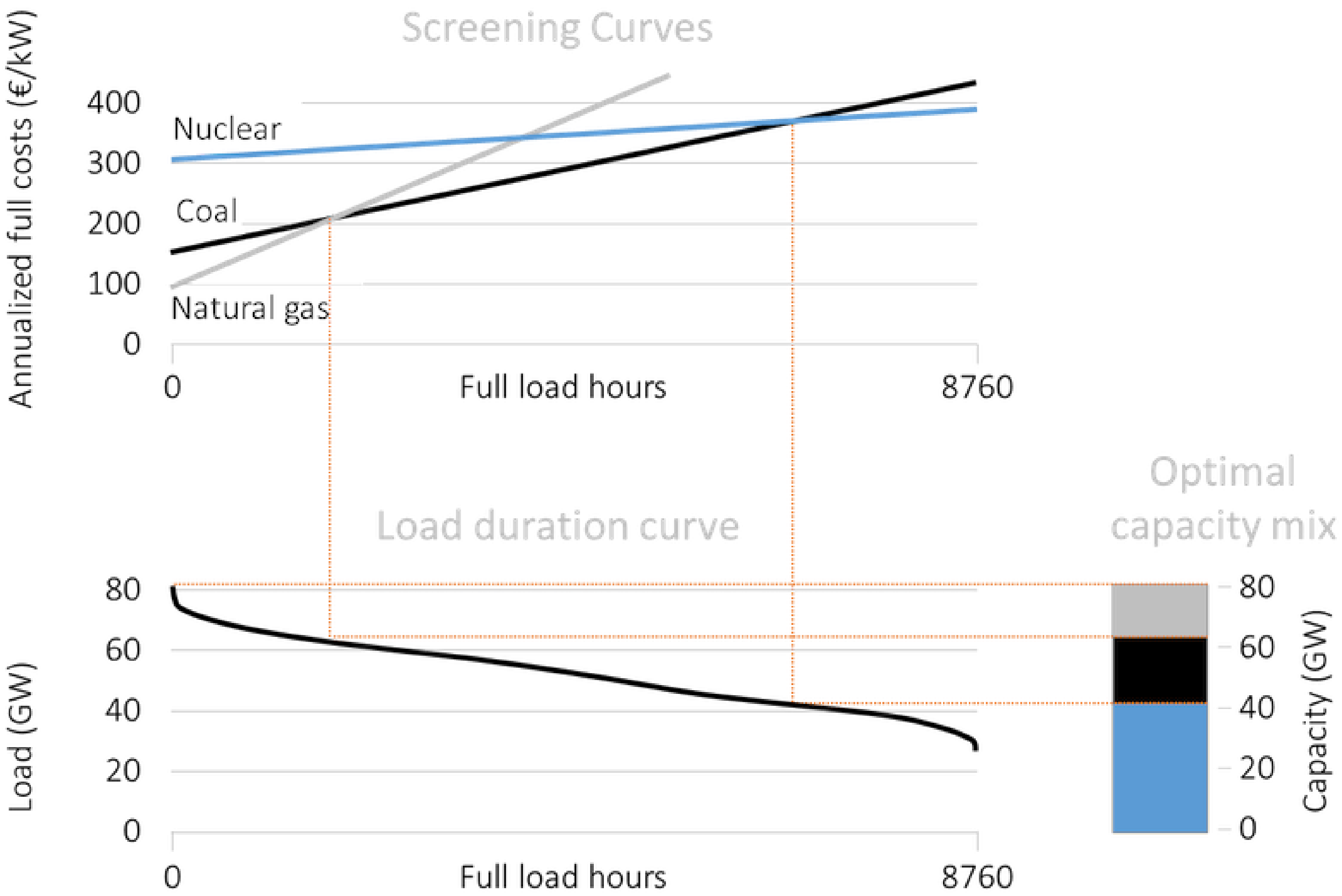
Screening Curves

Total cost p. a.
per unit of capacity



Hirth & Steckel (2016)

Cost-optimal mix of thermal technologies



Source: OEE

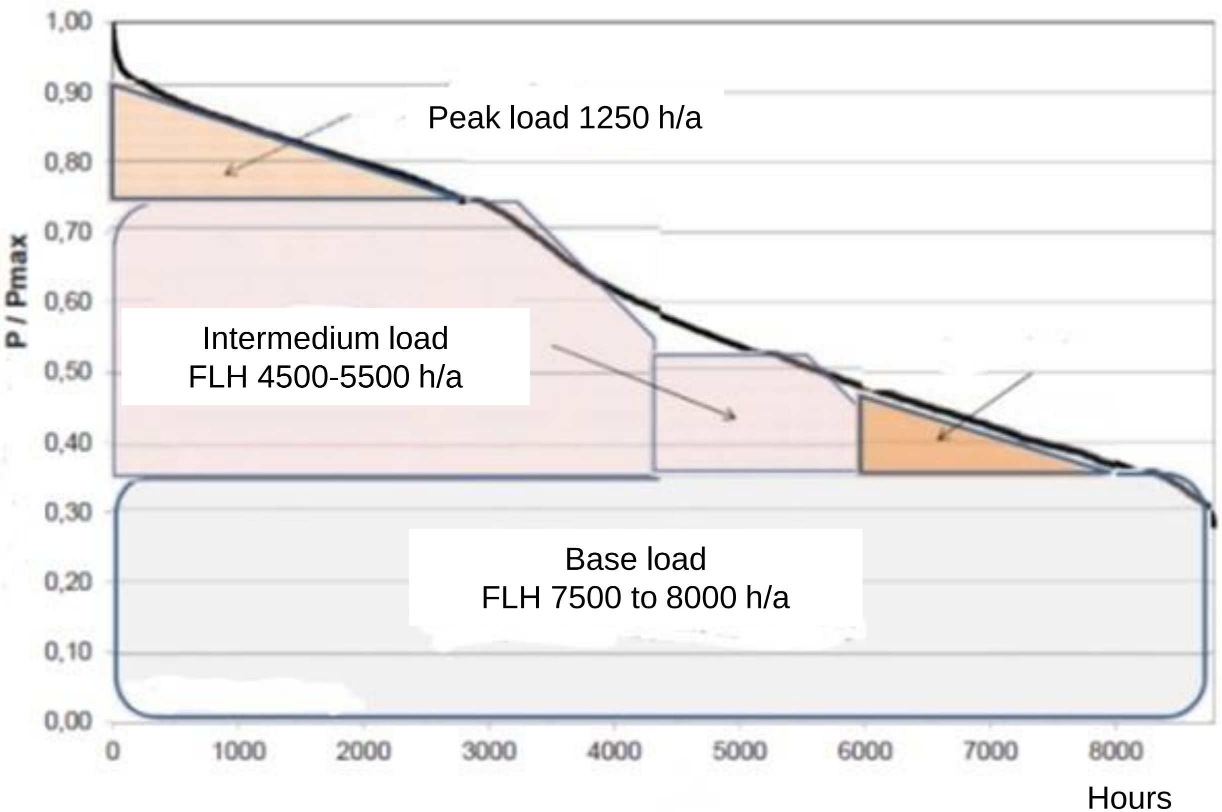
Power plants in the merit order

Power plant types based on their place in merit order:

Power plant type	FLH [h/a]	Operation features	Technologies
Baseload	> 7.000	continuous	lignite
Intermedium load	4.500 – 5.500	during peak hours (wd 8-8)	hard coal
Peak load	< 1.250	at times of peak demand	pumped-storage hydro, gas
Reserve		during power plant shut-downs	old power plants

Source: Konstantin, 2017

Power plants in the merit order



Source: Konstantin, 2017

Outline

- Energy balances
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Trading forms: Exchange vs. OTC

Mediated trading: power pool or power exchange

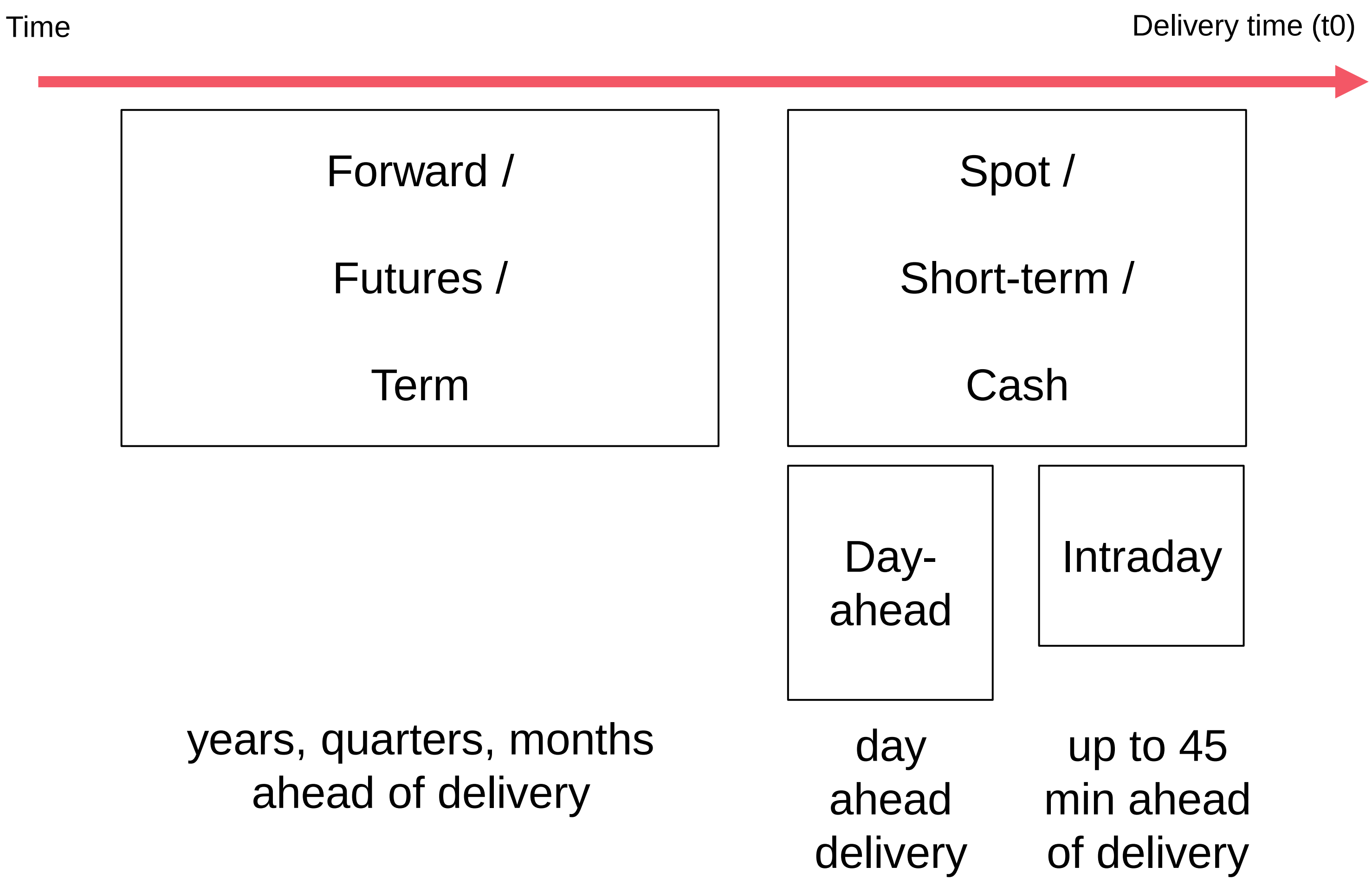
- organised auction resulting in a uniform price
- highly standardised products; no room for negotiation
- transparency
- regulated
- clearing and colateral costs

Bilateral trading: over-the-counter (OTC)

- intermediation cost (opportunity cost or broker fee)
- individual prices agreed between pairs of buyers and sellers
- (≈pay-as-bid principle)
- standard framework agreements: EFET/GTMA; ISDA; DRV etc.
- unregulated

Typically: Combination of exchange and OTC trading.

Energy trading: Submarkets



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Energy Trading: Submarkets

Time → Delivery time (t0)

Exchange

EEX Futures	Day-Ahead Auction EXAA	Day-Ahead Auction EPEX Spot	Intraday Auction EPEX Spot	Intraday continuous EPEX Spot
until 24:00 on the last day of M-2	until 10:12	until 12:00 on D-1	until 15:00 on D-1	from 15:00 on D-1 until 5 min before t0
Mo-Fr (no trading on weekend and public holidays)	hours and 15 min	hours and blocks	15 min	15 min [16:00 D-1 until 5 min before t0)
	Mo-Fr (no trading on weekend and public holidays)			

Bilateral

Forward / Term	Spot / Short-term

until 15 min before t0 across control areas; immediately before t0 for trades within the same control area. Forward and spot All products are negotiated bilaterally.

Control power

Primary reserve	Secondary reserve	Minute reserve
until Tue 15:00 for Mo from 00:00	daily until 8:00 for following day from 00:00	daily until 8:00 for following day from 00:00
Time blocks: one week	Time blocks: six 4-hour blocks	Time blocks: six 4-hour blocks

Source: Adapted from Next Kraftwerke

What is a trading product

Trading product is combination of transaction features:

- Underlying asset — *electricity*
- Delivery point — *TSO control area*
- Delivery period — *start date / end date*

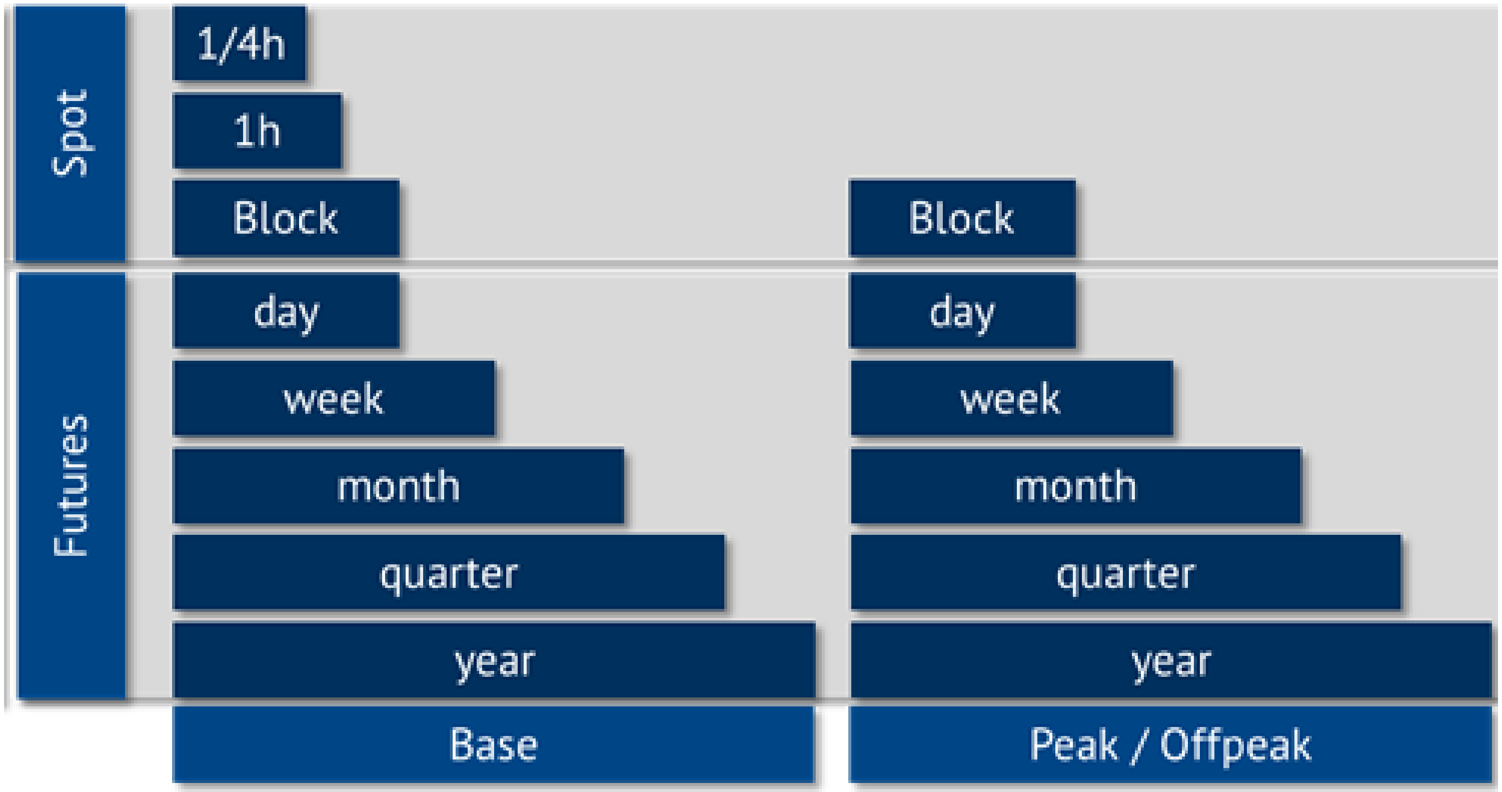
- Delivery amount — *contract capacity [MW]*
  Price — *contract quantity [MWh]*

A certain amount of product is traded at a certain price.

A bid (offer to buy) or ask (offer to sell) is characterised by: product, price, trading day and time.

→ different market price of the same product at different times

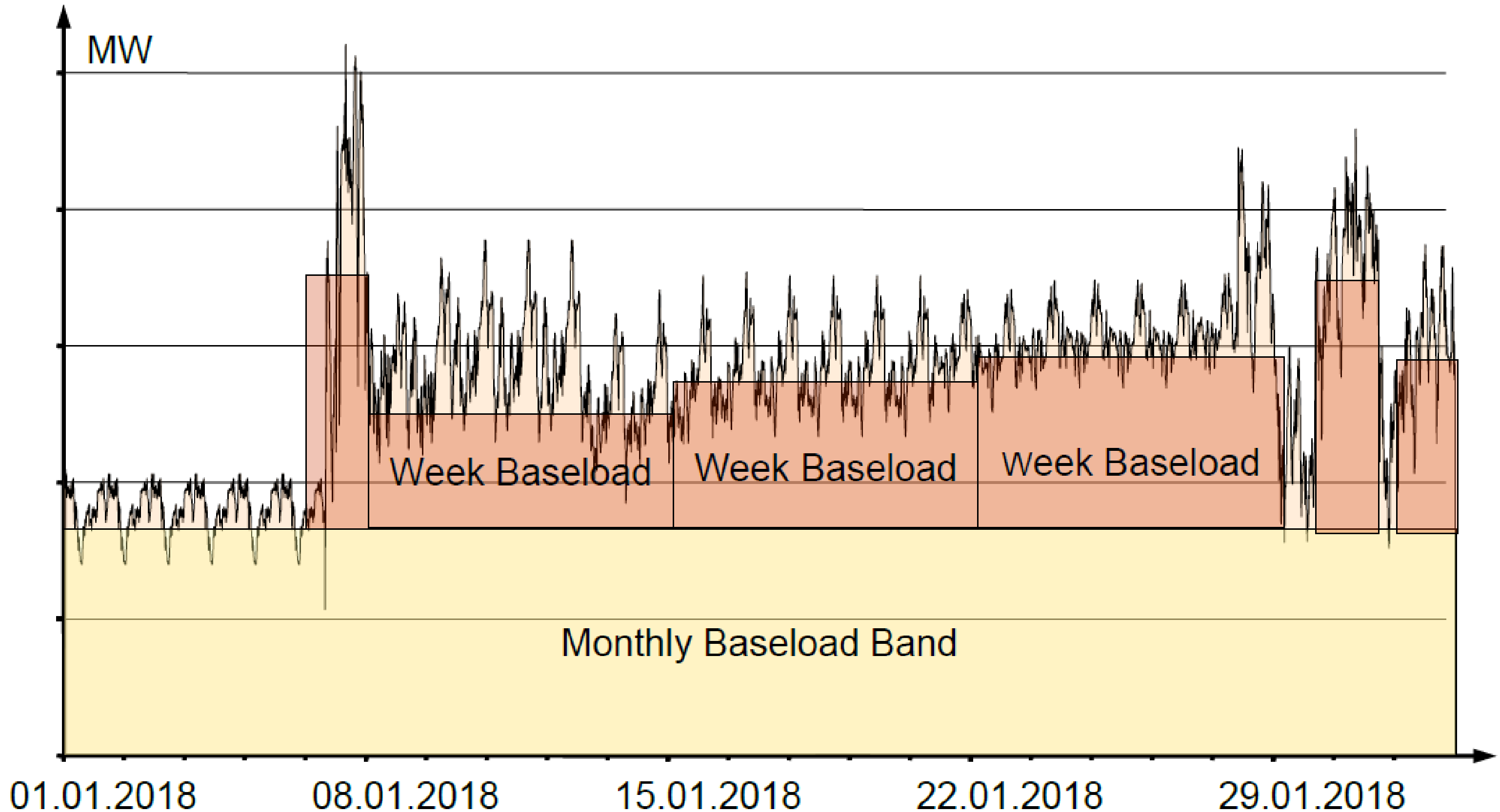
Electricity product types based on delivery period



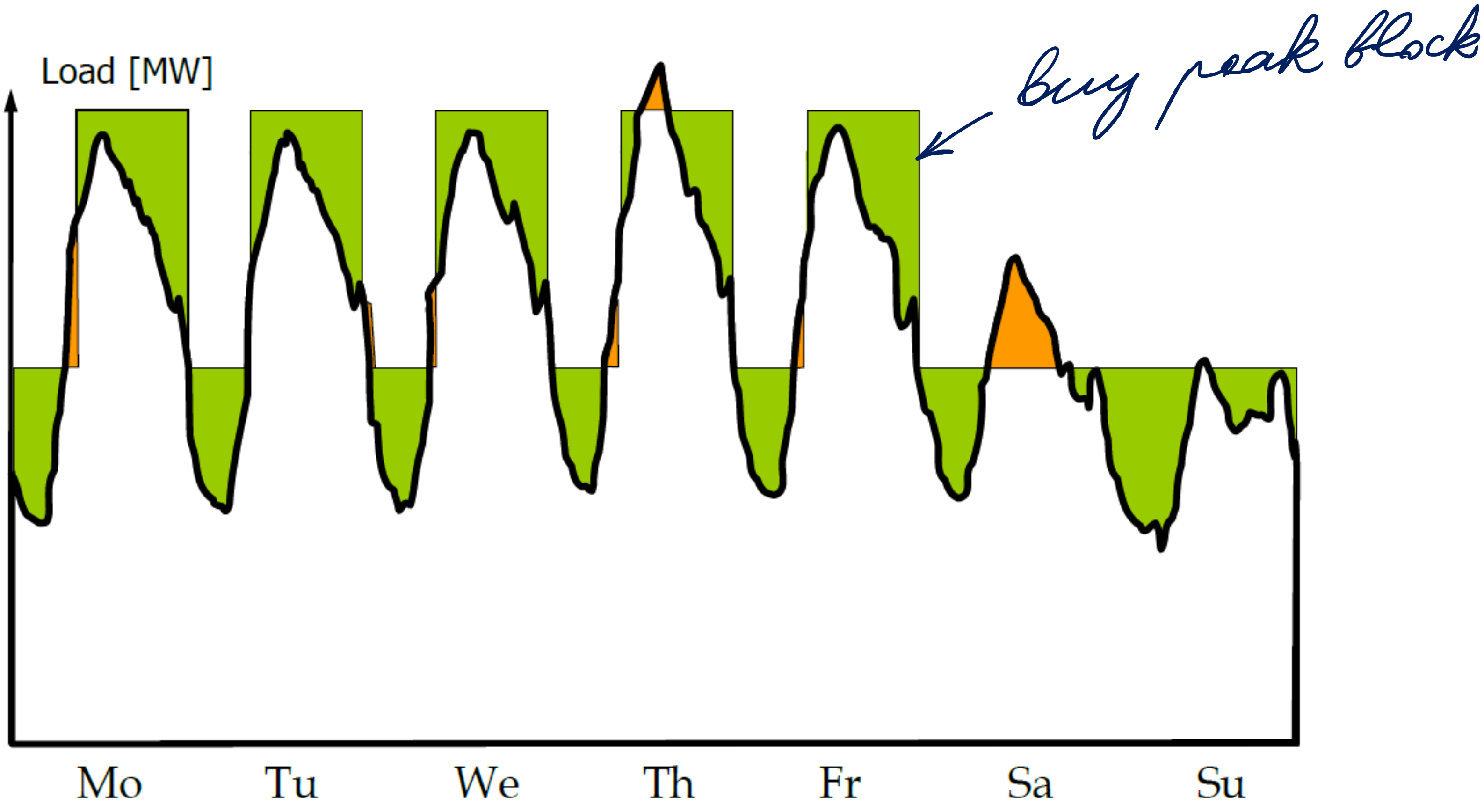
Source: Energy Brainpool

Sample power purchase portfolio

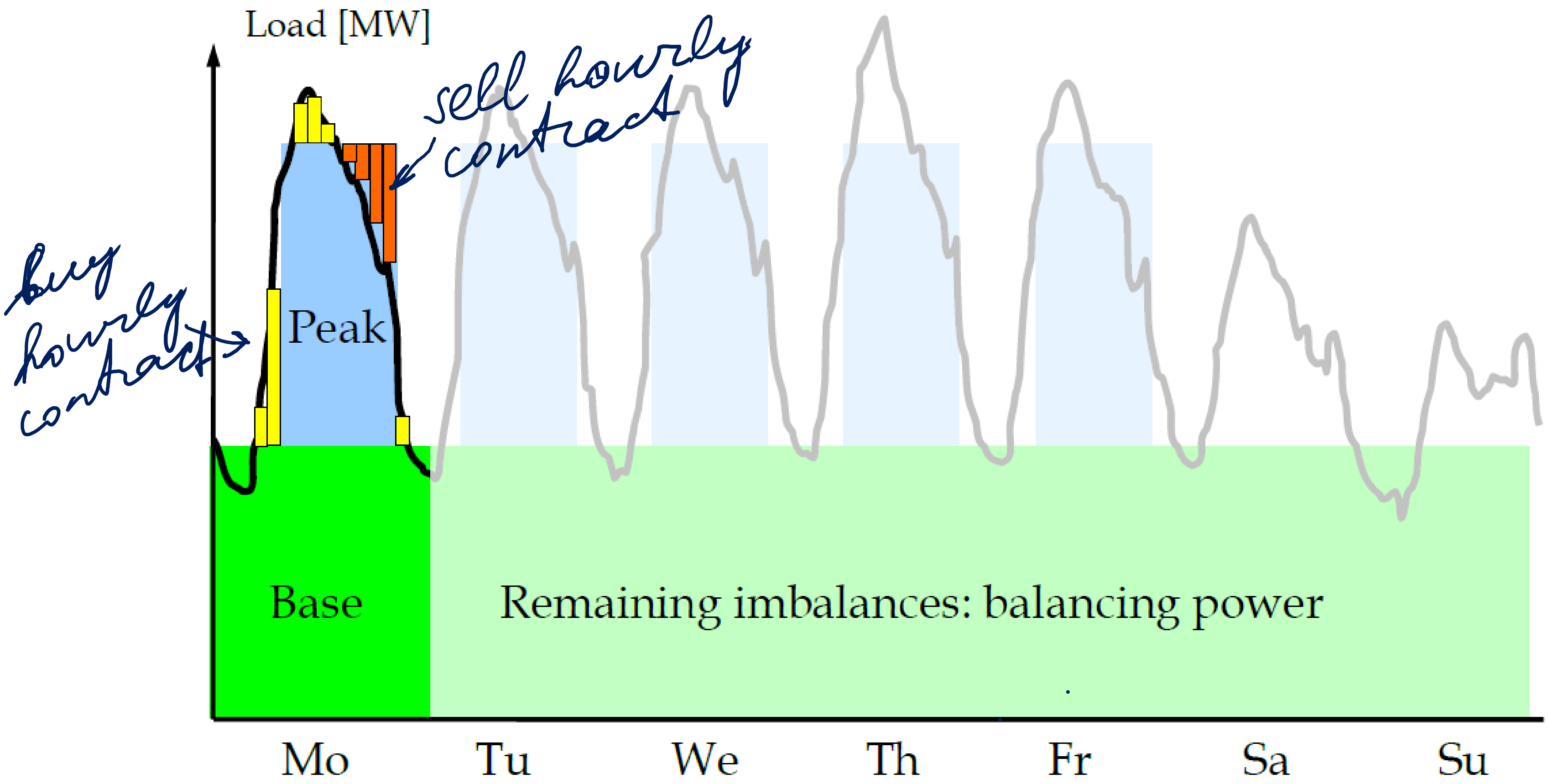
Standardised futures do not match with typical load schedules.



Portfolio management of a power retailer



Day-ahead contracts for singular hours



EPEX Spot Day-ahead auction

Double-sided auction: bid and ask order book (order book trading)

Uniform price auction: market clearing price for each product (hour or block)

Hourly contracts and blocks (base, peak etc.)

Occurs daily at 12h for delivery on the following day (0-24h)

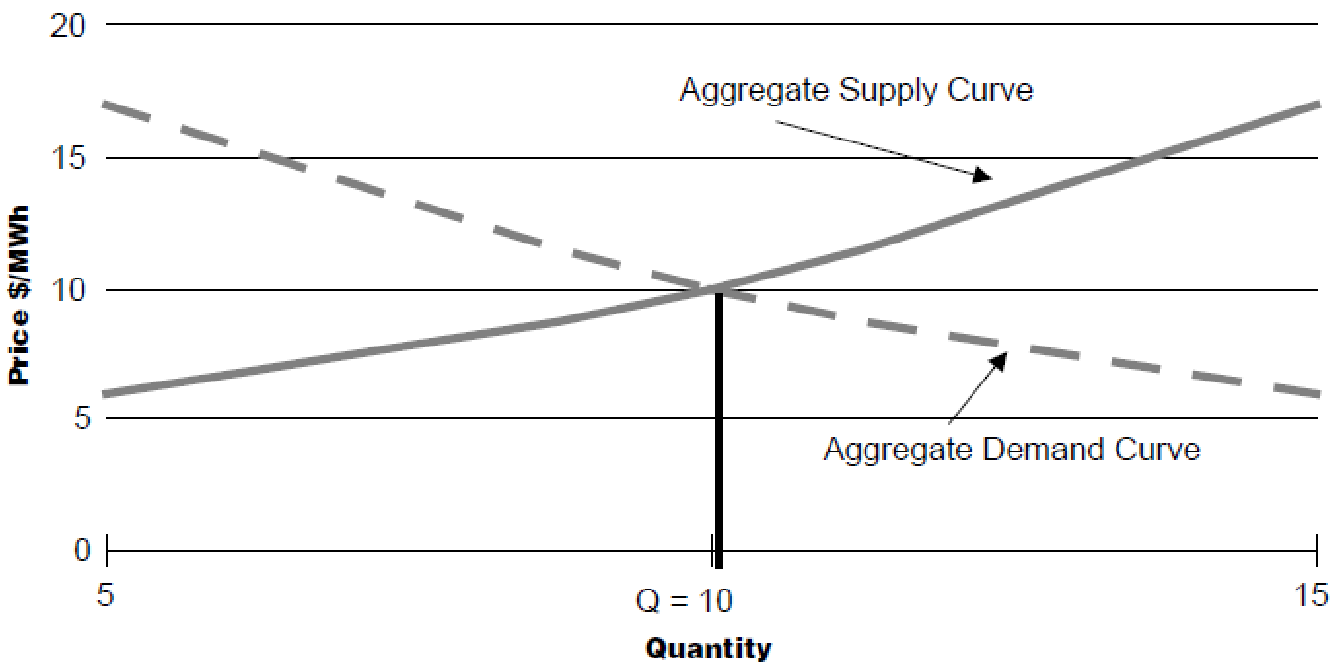
Price publication time: asap from 12:42h

Volume tick (min order amount/amount increment): 0,1 MWh

Min price: -500 €/MWh; Max price: 3.000 €/MWh

Auction design

Goal of an auction is the least-cost dispatch of generation.



Source: Morey, Power market auction design, EEI, 2001, p. 20.

Balancing group: Linking the virtual and physical worlds

Balancing group (BG) is a virtual energy volume account associated with one or more grid users within a control area.

- each grid connection point is allocated to one balancing group
- balance responsible party (BRP) is responsible for balancing its BG's saldo (feed-in and consumption) for each 15 min – incl. through trading on spot markets
- deviations are penalised by imbalance fees

Analogy to a bank account:

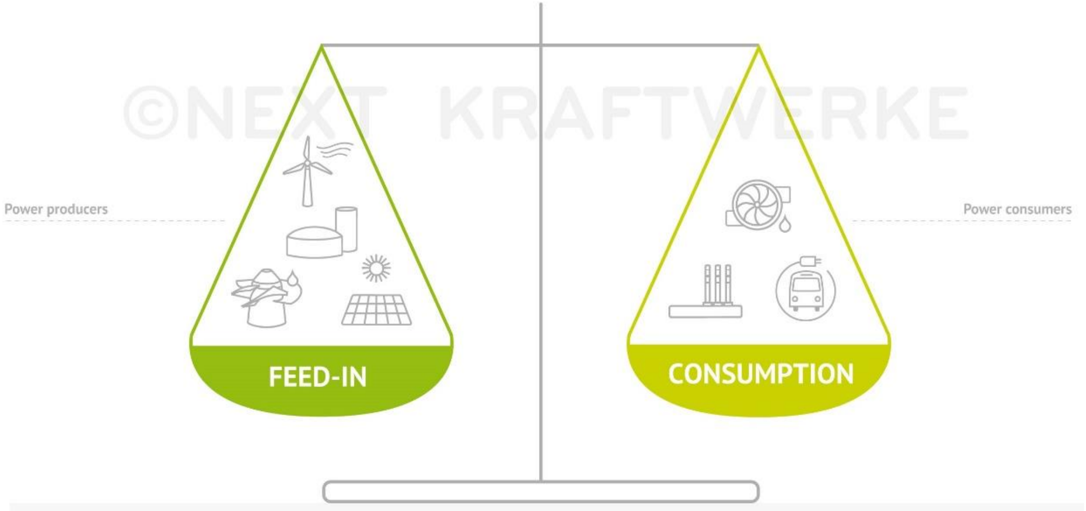
TSO	***≈Bank***
Balance responsible party	*≈Account holder*
EIC	*≈Account number*
Balancing circle	*≈Bank account*
Energy deliveries	*≈Payments*

Balancing group (continued)

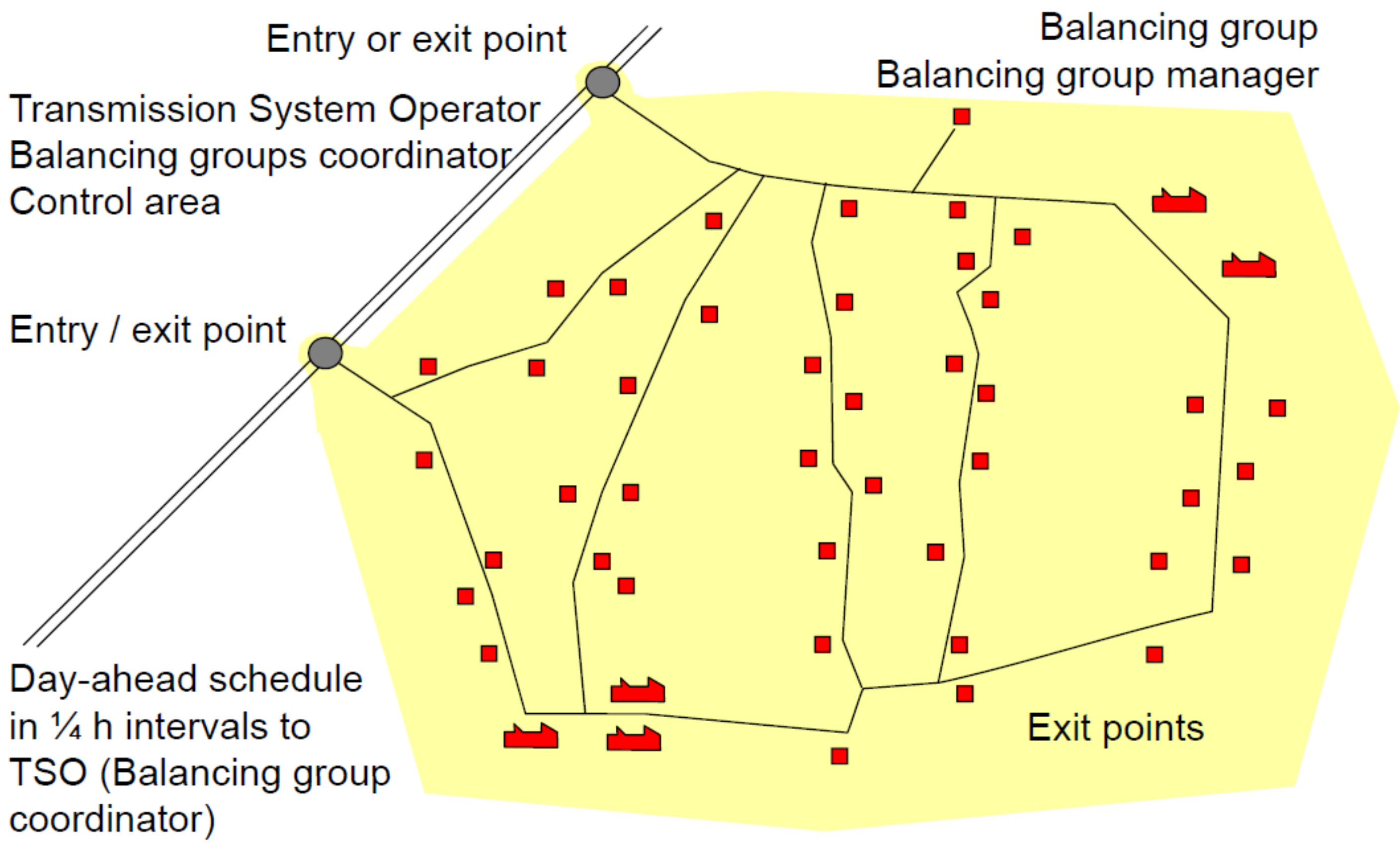
Trading on transmission grid level, i.e. performing delivery by scheduling to TSO, assumes no physical restrictions within a market area.

Depending on the nature and composition of a balancing group, the BGR transmits to the TSO forecasted load or generation and/or buy and sell amounts.

Imbalance fee is uniform for the control area (in Germany: for all four control areas), symmetric and based on actual activation of control power.



Market roles and processes at TSO level



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Tasks of the Balancing group management

Time	
Day-ahead delivery	
before 12:00 h	The balancing group manager (BGM) forecasts a load schedule for each of the 96 ¼ hours of the next day
until 12:00 h	Based on a predefined trading strategy, bid and ask orders are submitted to the energy exchange (EPEX)
12:30 h	EPEX informs market participants on their trading result
until 15:00 h	BGM informs wholesale customers about trading results. The BGM submits the day ahead schedule to the Transmission System Operator TSO. Intraday trade may be used to reduce expected imbalances
Delivery day	
00-24:00 h	Customers and BGM control the power generation and consumption devices according to the schedule. Stochastic deviations are covered by the TSO in form of balancing energy
Following day	Financial settlement of trade results between BGM and EPEX

Reasons for imbalances

- Unplanned outage of generation units
- Unplanned outage or activation of large loads
- Forecast gap in volatile RES generation
- Inaccurate forecast of demand

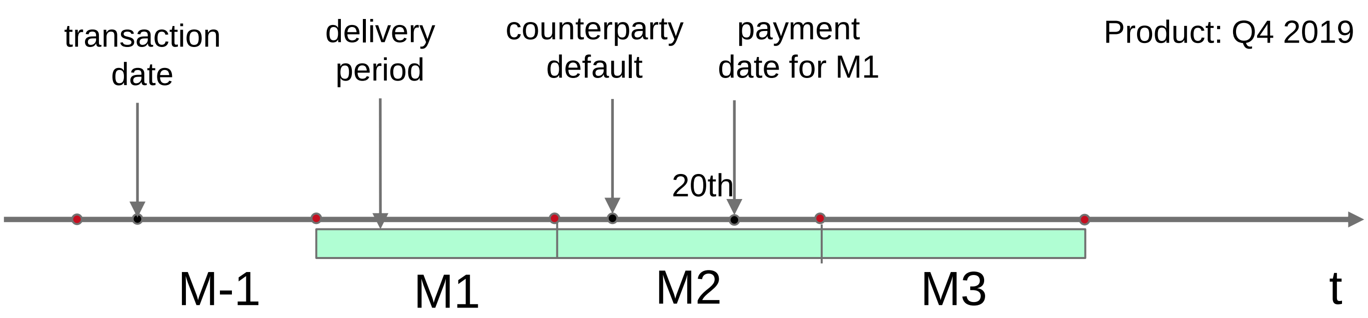
Credit risk management: Terminology

„Exposure is a measure of loss if an adverse materialisation of uncertainties occurs for a particular decision.“ *

Mark-to-market accounting is regular (daily) valuation of all open trading positions based on the current market price of the product.

* Perreira et al, IEEE Computer Applications in Power, vol. 13, 2000, p. 22

Credit risk management: Credit risk exposure – OTC



- **Settlement exposure**: delivered but unpaid amount * contract price (≈50 days; credit exposure updated after payment)
- **Mark-to-market exposure**: contract amount from default date until end of delivery period * mark-to-market

Credit exposure for a portfolio depends on the **netting rules**:

Does the jurisdiction of the counterparty allow cherry-picking, i.e. performing under in-the-money transactions and dropping the ones that are out-of-the-money?

Clearing

Source: Energy Brainpool

Clearing (continued)

Clearing is performed by European Clearing Counterparty (ECC).

Credit risk exposure is determined similarly to OTC trading.

Margining is the process of continuously recalculating the credit exposure under open positions based on the current market price and adjusting the amount of collateral required to cover it.

- Initial margin: cash collateral or other first-class guarantee to ensure that the exchange member fulfills their obligations under open transactions.
- Variation margin: daily margining based on mark-to-market calculation – resulting into a margin call as necessary.

Risk of clearing banks is limited to overnight risk.

Markets for control power

Control power markets serve for frequency control.

Frequency is determined by balance of supply and demand.

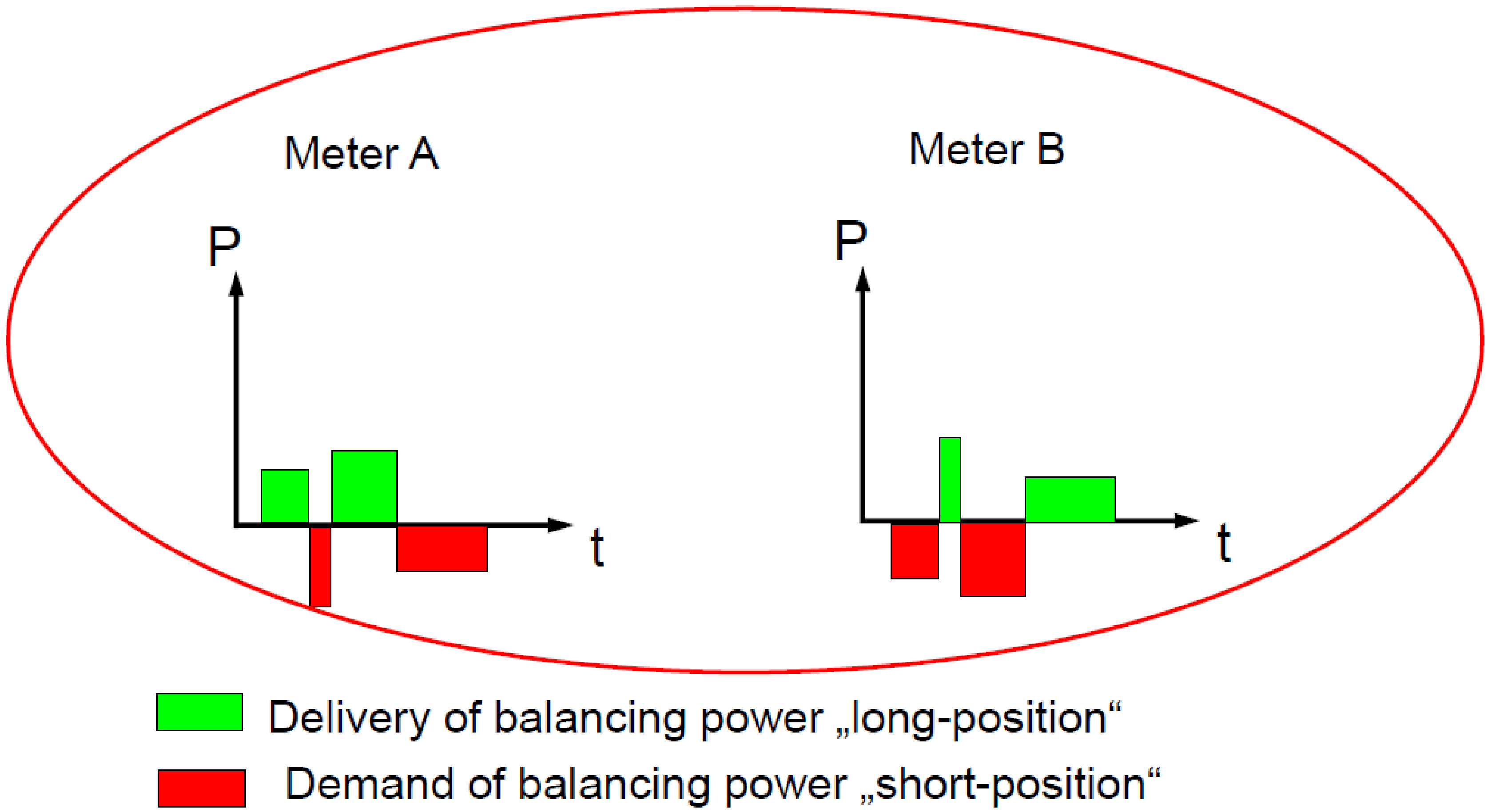
Target frequency in Europe: 50 Hz

Excessive demand → frequency drops → positive balancing energy is procured by TSO

Excessive generation → frequency rises → negative balancing energy is procured by TSO

Source: Zweifel / Praktiknjo / Erdmann, 2017

Netting of balancing power



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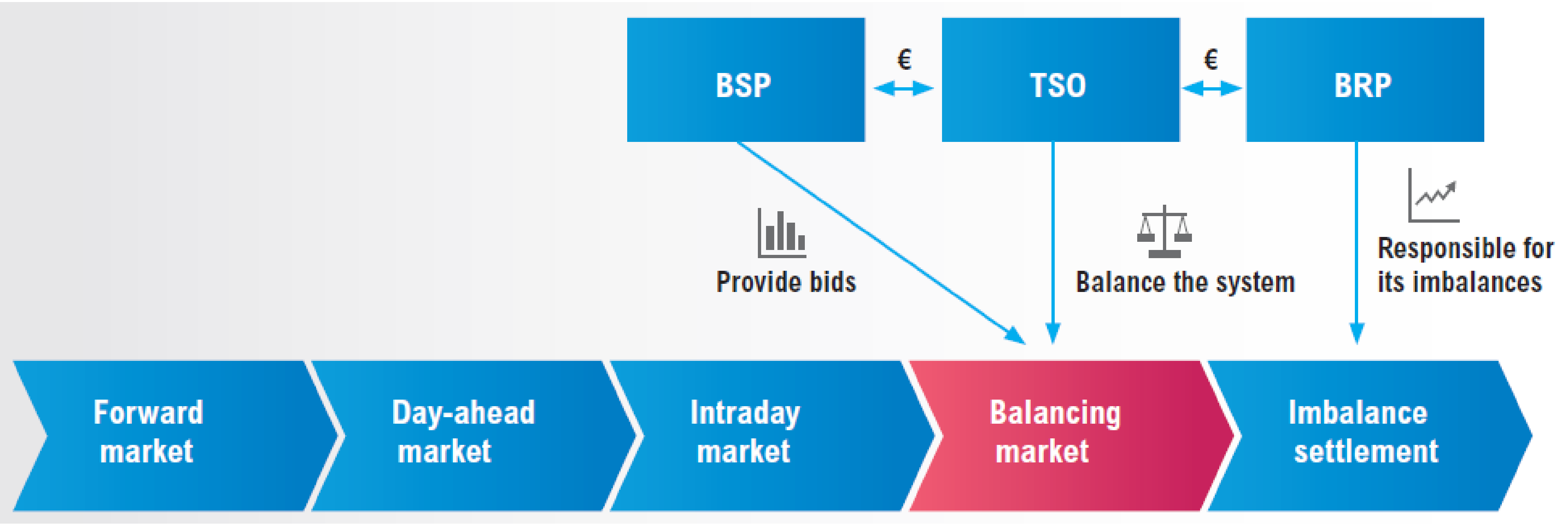
Markets for control power



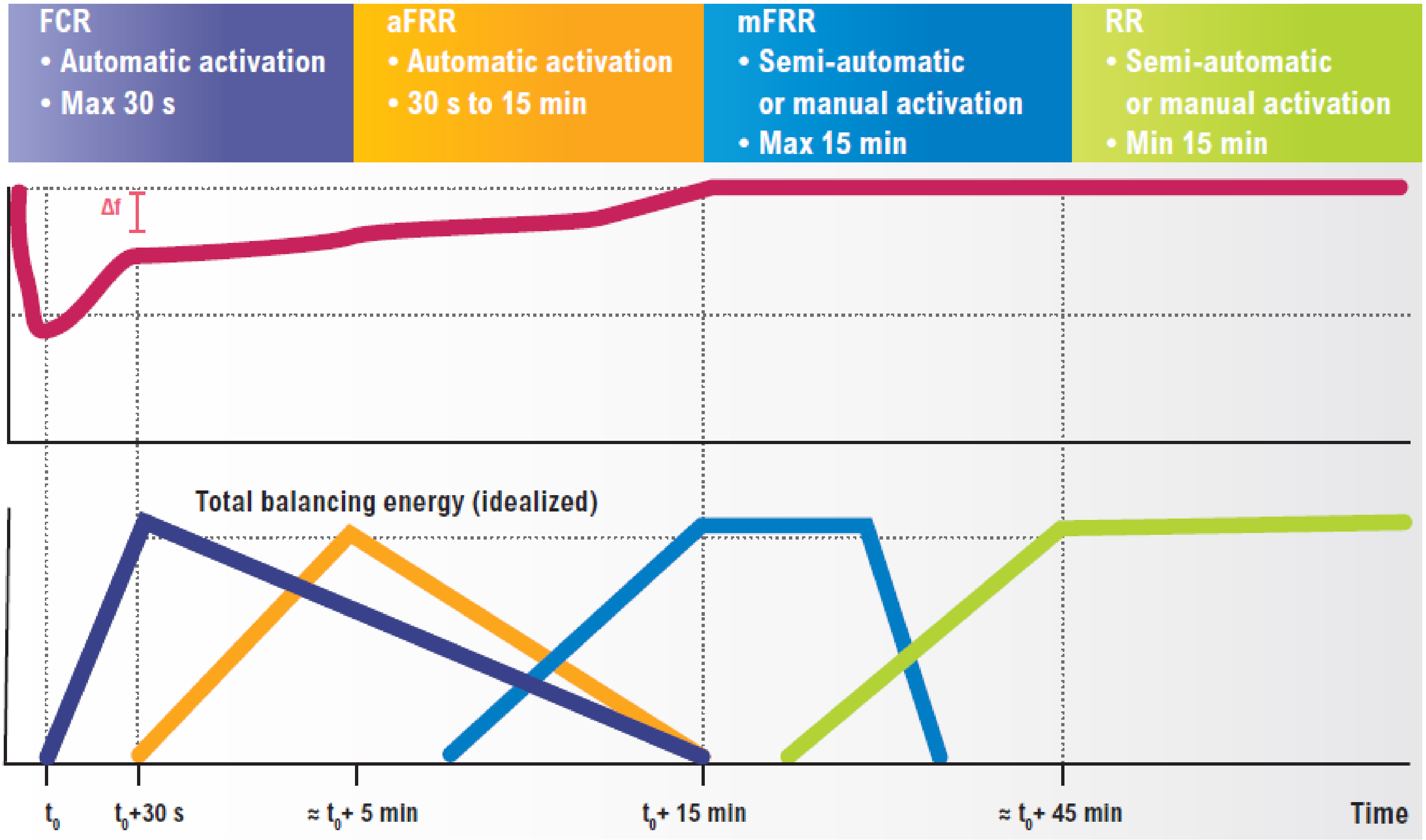
Balancing service providers:

- generators
- demand response providers
- storage facilities operators

System imbalance vs BG imbalance

Source: ENTSO-E, 2018

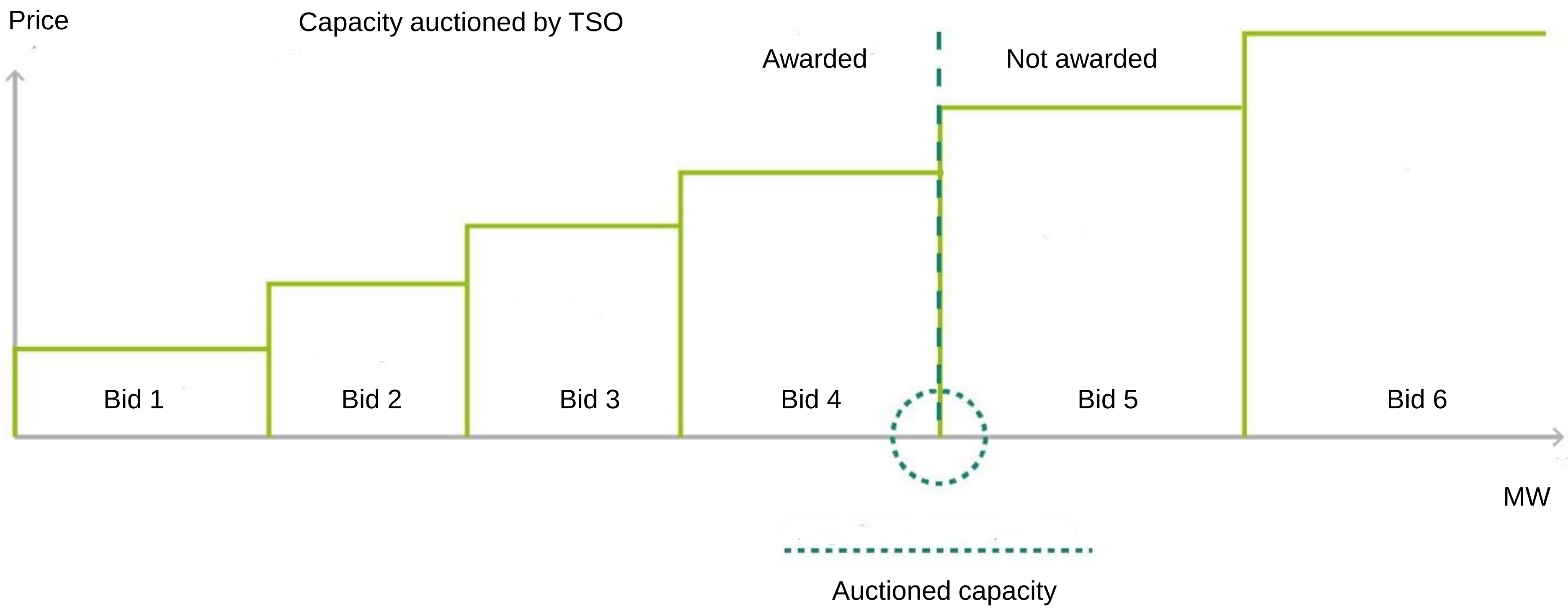
Balancing market processes



+ Imbalance netting (IN): exchange of imbalances between TSOs

Source: ENTSO-E, 2018

Control power auction



Source: Next Kraftwerke

Outline

- Energy balances
- Economics fundamentals
- Financial management
- **Electricity markets: Electricity grid**
- Emissions
- Resources and sustainability
- Oil markets
- Gas markets

Congestion management

Congestion management relieves expected grid bottlenecks due to limited transmission capacity by correcting (cost-based) power plant dispatch decisions.

- Countertrading

TSO counter-trades against the flow of congestion between bidding zones.

- Redispatch

ramping up certain power plants while ramping down certain other power plants

- Feed-in management (Einsman)

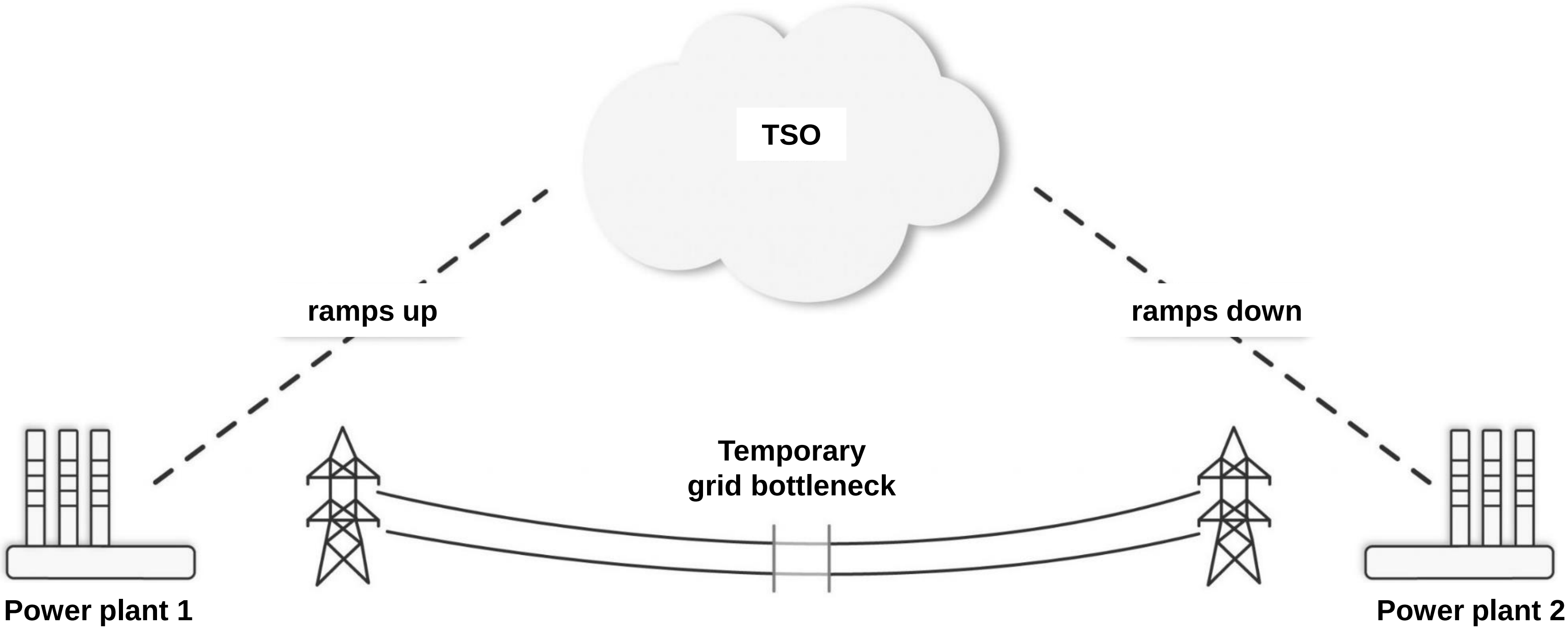
ramping down renewable power plants

- Grid reserve

power plants kept available for service but not operational

against remuneration

Redispatch: example



Source: Next Kraftwerke

Outline

- Energy balances
- Economics fundamentals
- Financial management
- **Electricity markets: Renewables support**
- Emissions
- Resources and sustainability
- Oil markets
- Gas markets

Motives for renewables support

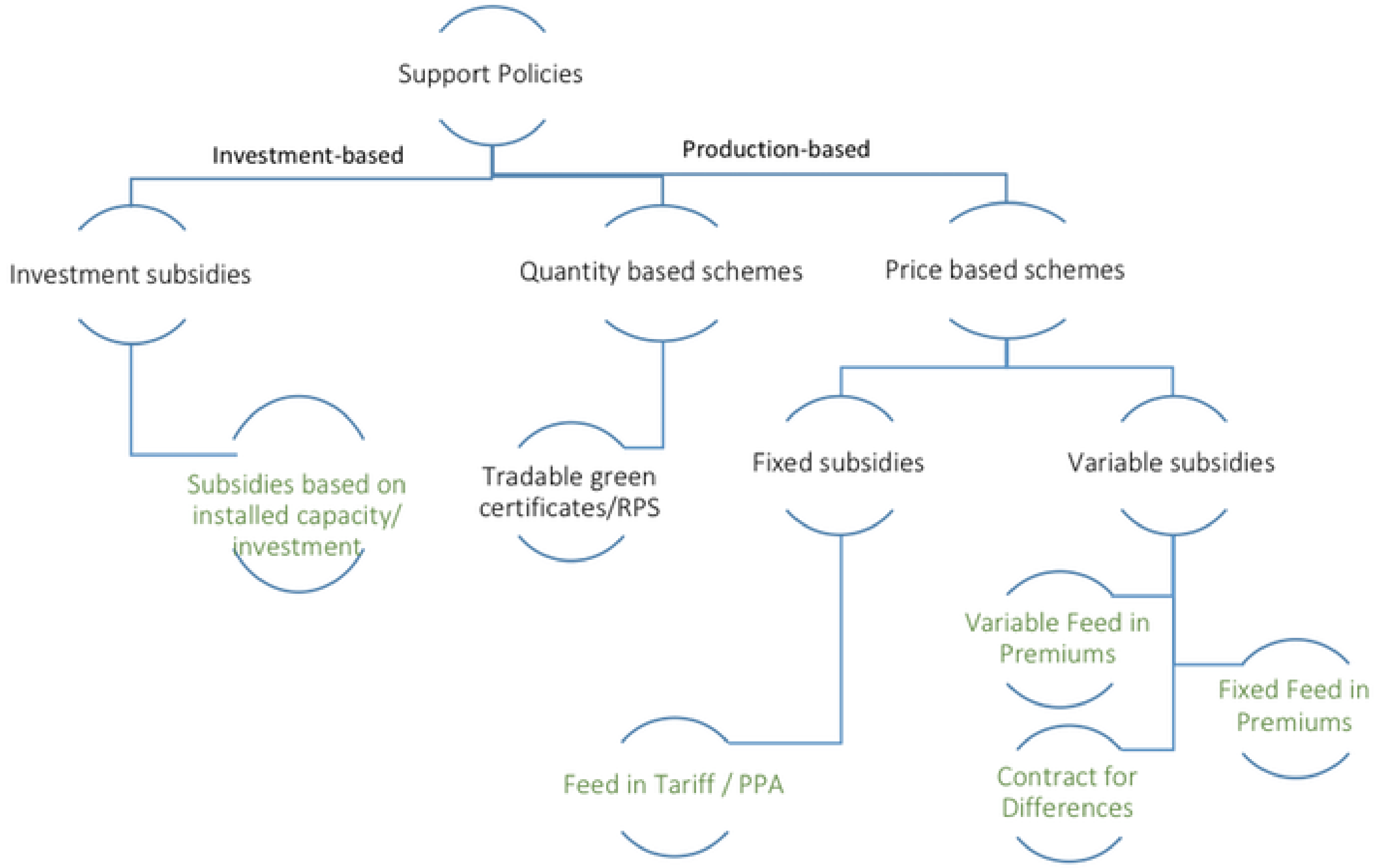
- reducing carbon emissions
- reducing cost through knowledge spillovers
- developing an export industry by early specialisation
- energy security: limiting dependence on fossile fuels imports
- ancilliary benefit: generating employment

Three groups of support schemes:

- Public financing – public investments, loans, grants
- Fiscal incentives – subsidies and tax reductions
- Requirements for electricity consumers to pay for RES:
  - fixing price
  - fixing amount

Source: Green and Yatchew (2012)

Renewable Electricity Support Schemes in Europe



Note: Support levels in these schemes can be set both using auctions or administratively

Source: OEE

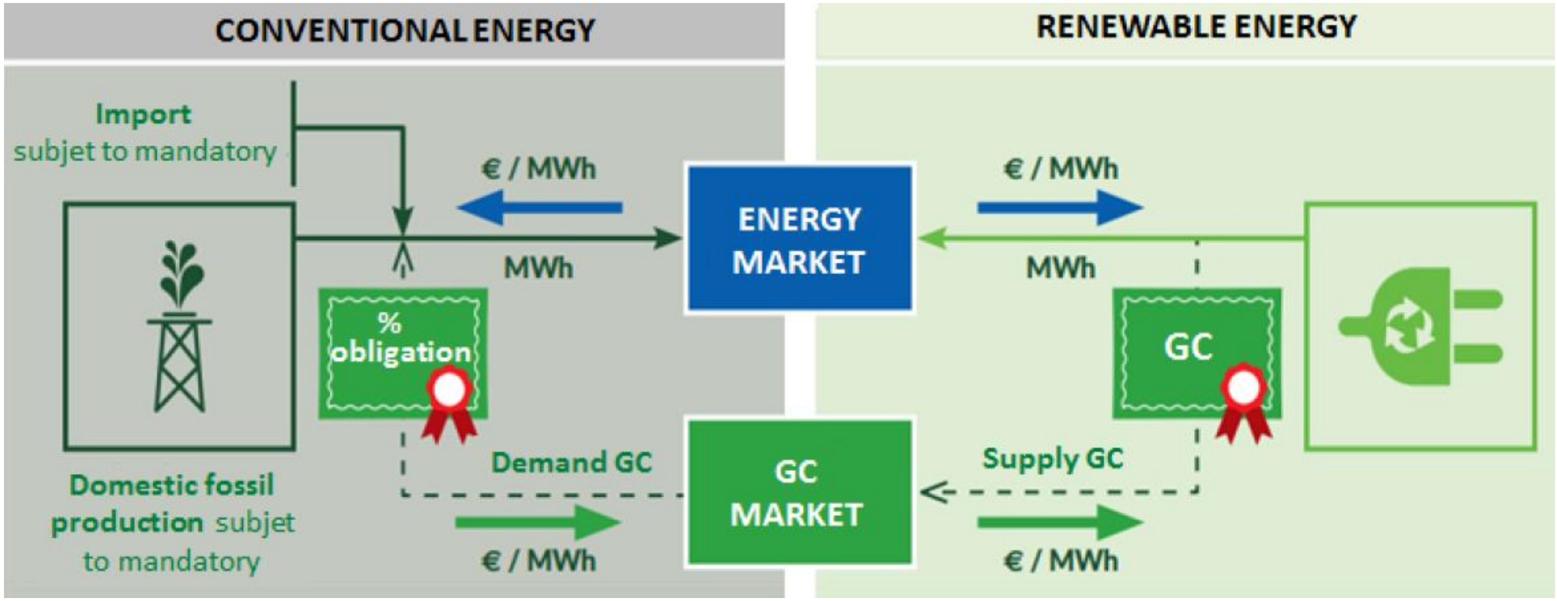
RES support mechanisms: Administered fees (all-inclusive or premium)

- The government fixes the price for each MWh produced or injected into the grid from RES.
- Normally, the fee depends on renewable source and size of power plant.
- Feed-in tarif (FIT)
- Premium ensures that at least FIT is covered and gives incentives for selling RES output directly on the wholesale market
- If the fee is coherent with the production cost, the government's RES output target can be met; otherwise it would be not reached or exceeded.
- The charges linked to the support system are paid by final customers.

RES support mechanisms: Green Certificates (GC)

- Fossile fuel-fired generators are required to replace every year a certain percentage of their energy production with RES
- The balance between demand (from generators and importers under the GC obligation) and supply (RES generators) determined the GC price
- The charges linked to the GC are translated to the final customers through the electricity price (on wholesale or retail market).

Green Certificates Mechanism



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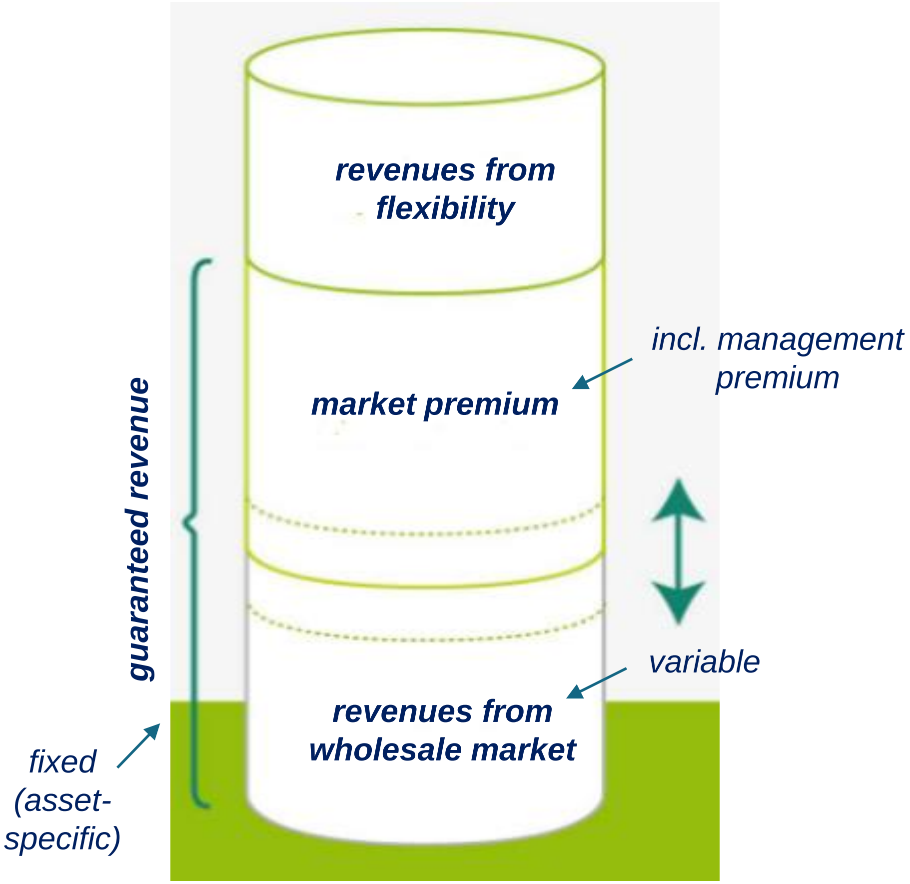
Feed-in-tariff and Market Premium Mechanisms



Source: Next Kraftwerke

Renewables support levy (green fee)

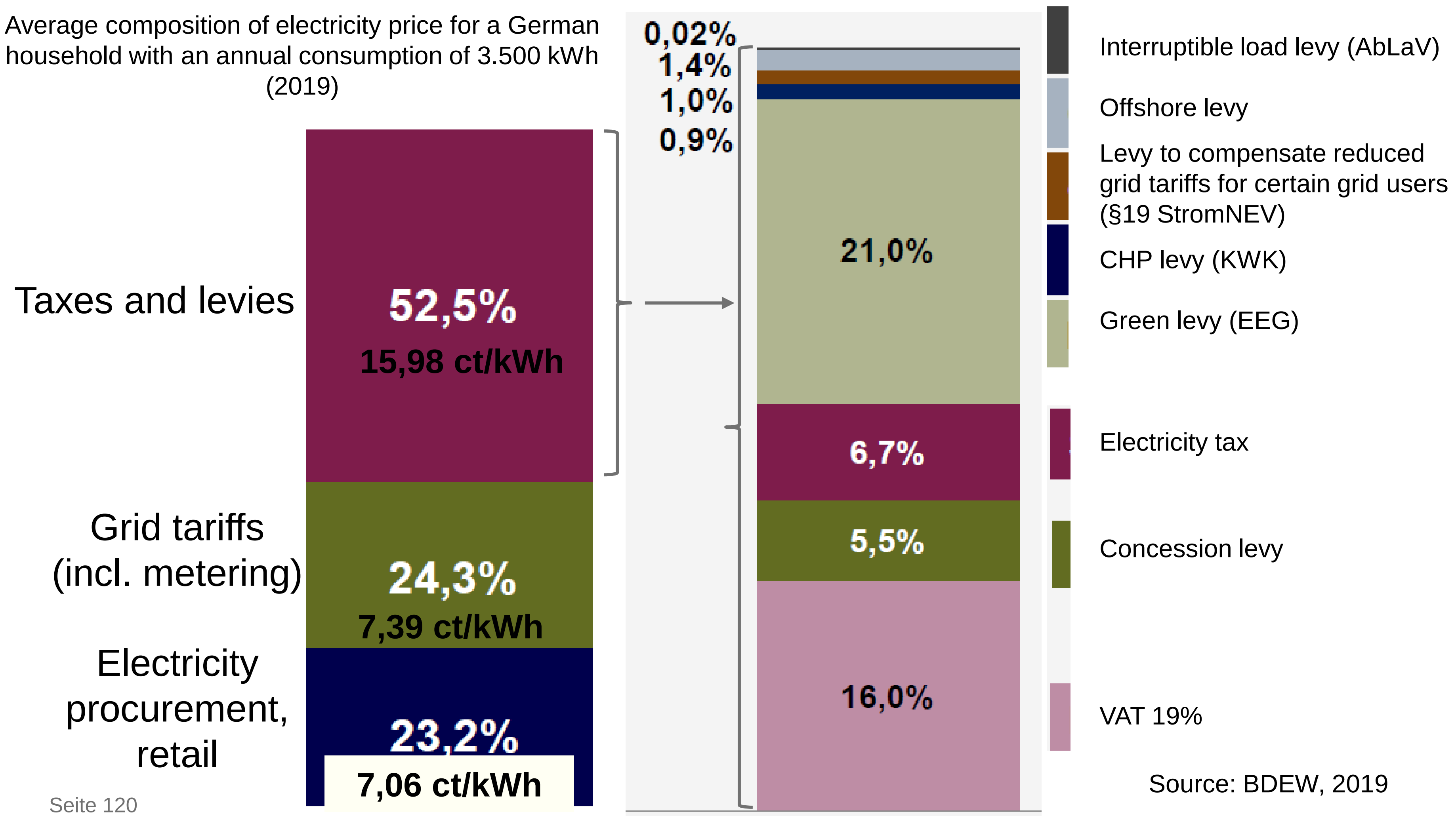
$$\text{RES levy} = \frac{\text{RES support payments} - \text{RES marketing revenue}}{\text{Adjusted non-preferred final electricity consumption}}$$

Adjusted final electricity consumption is equal to total final electricity consumption minus:

- Share of electricity consumption of energy intensive industries, which are exempted from the levy
- Own generation (self-consumption), which is partly exempted from the levy

Retail price composition: Household customers

Average composition of electricity price for a German household with an annual consumption of 3.500 kWh (2019)



Source: BDEW, 2019

Outline

- Energy balances
- Economics fundamentals
- Financial management
- Electricity markets
- **Emissions**
- Resources and sustainability
- Oil markets
- Gas markets

External Costs and Market Failure

Individuals may suffer economic losses from emissions associated with energy activities that are not included in energy prices and thus are not compensated by the polluter

No Pareto-Optimum (some individuals can be better off without negatively affecting the situation of any other individual)

Coase-Theorem: Negotiations between polluters and affected parties could produce the Pareto-optimal condition, but negotiations may not be possible or successful due to

- many perpetrators and victims
- unclear cause-effect relationships
- high transaction costs

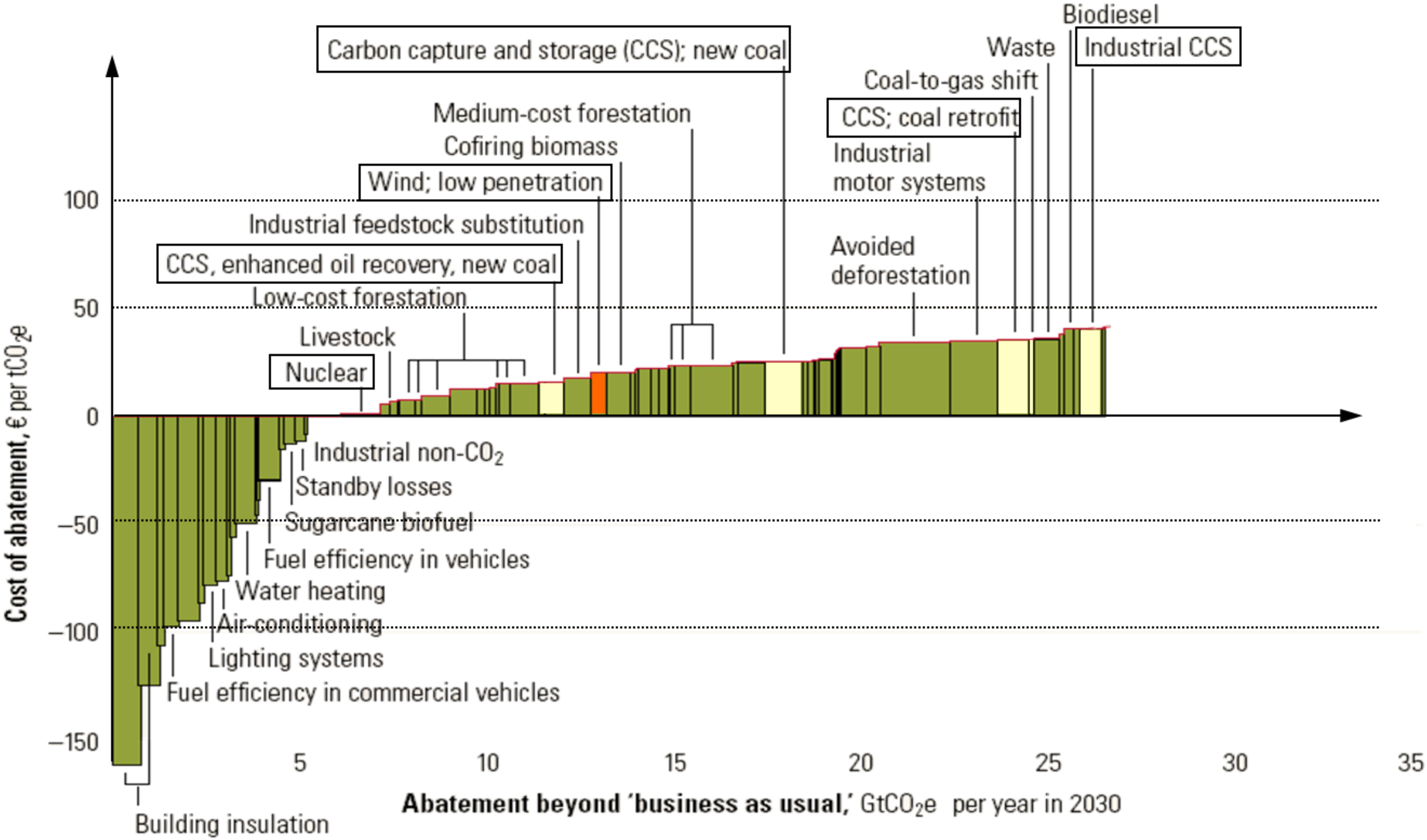
$\Rightarrow$ Market Failure

Strategies to Correct Market Failure

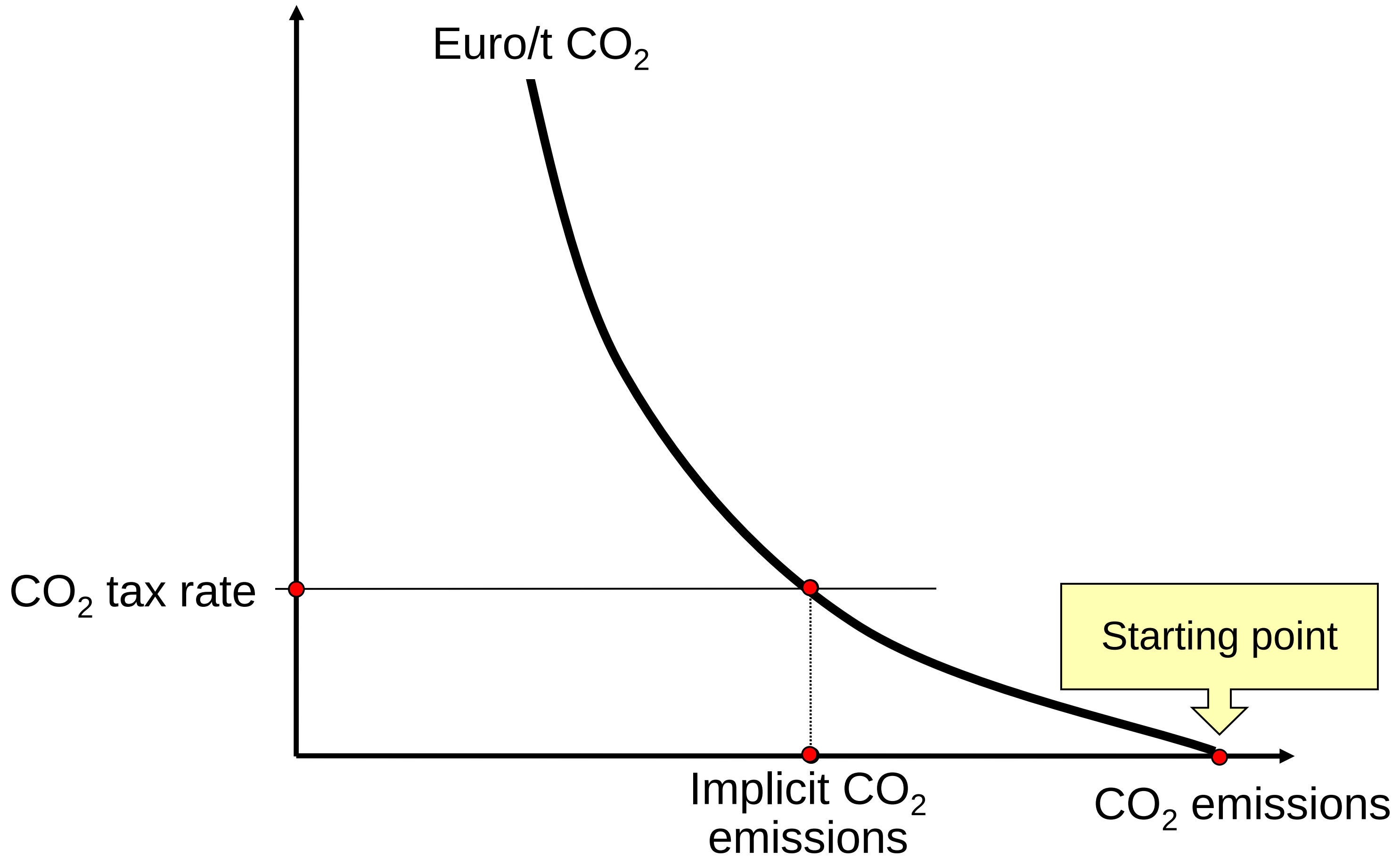
- Emission standards and norms (e.g. mandatory emission controls)
- Emission taxes (Pigou-Tax). By taxing emissions, the government puts a price on them
- Standard Price Approach (BAUMOL, OATES 1988)
    - Government auctions tradable allowances (fiscal instrument)
    - Free allocation of tradable allowances by government (Grandfathering, Benchmarking)

Costs of abating CO_2-Emissions

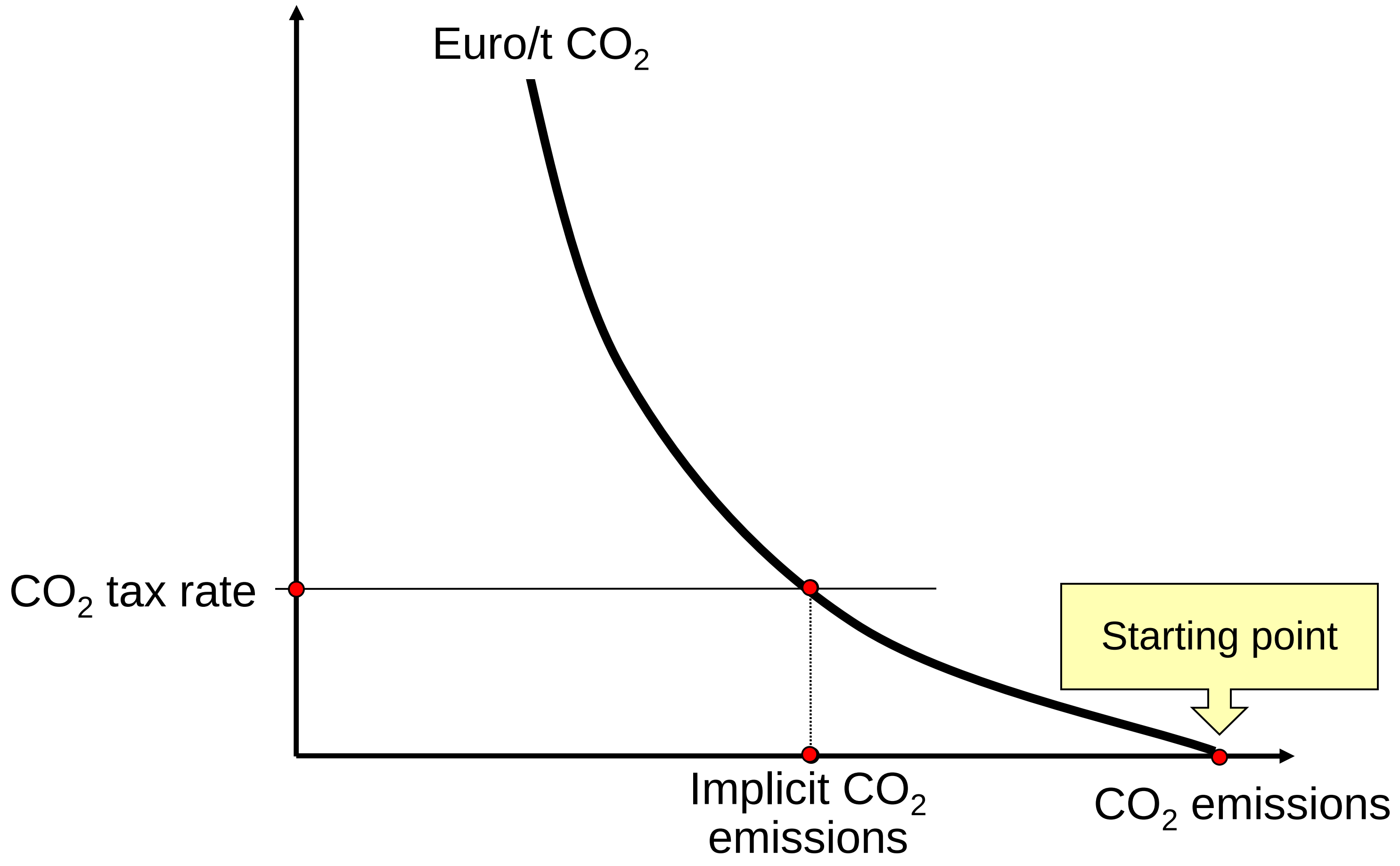
(Source: McKinsey & Company 2007)



GHG Abatement Costs and a Pigou Tax



Unknown GHG Abatement Costs and Pigou Tax



Pigou Tax

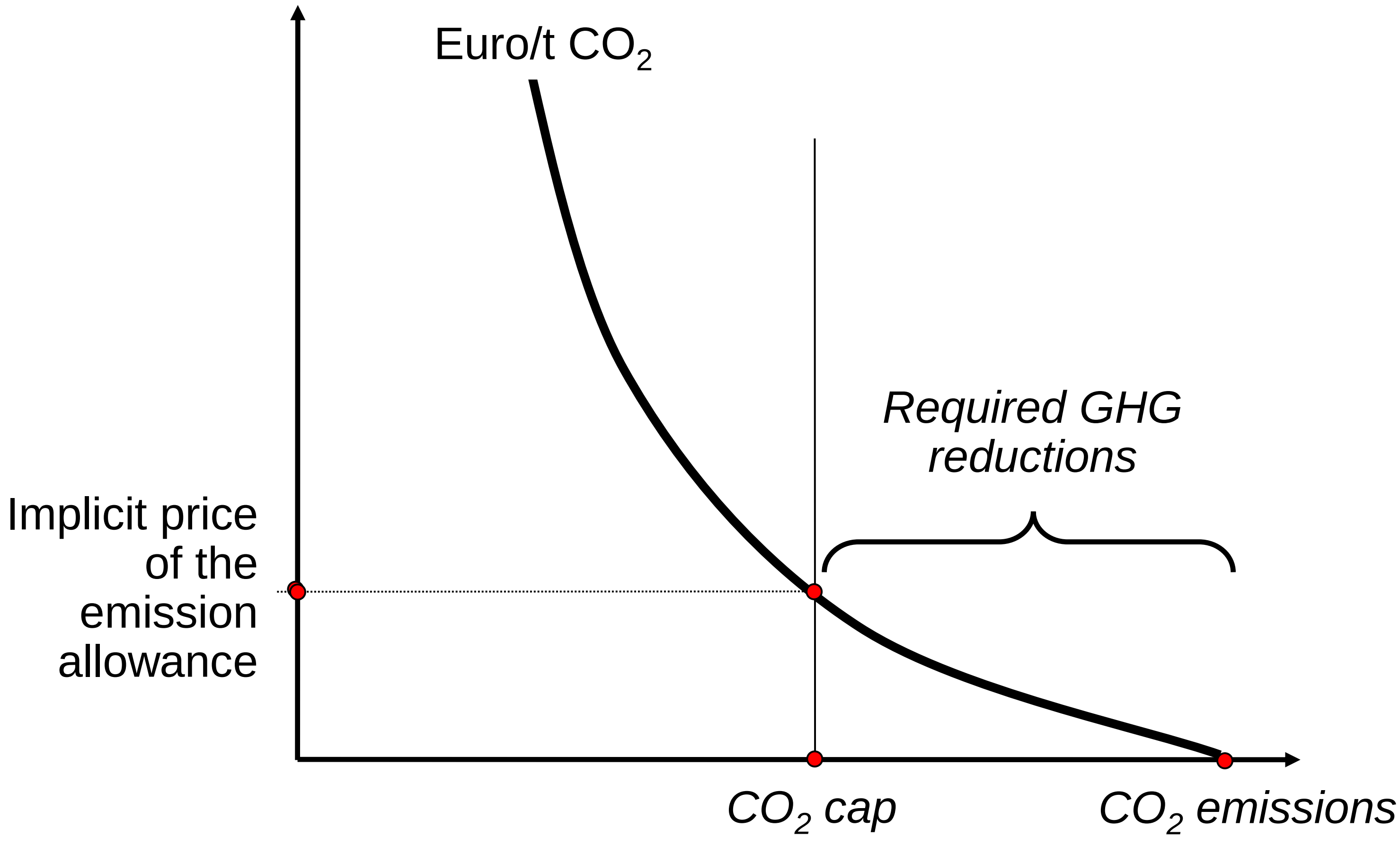
Optimal tax rate must be equal to the marginal cost of emissions.

Without technology differences, all companies reduce their emissions to the same optimal level.

In case of technology differences, the company with lower abatement costs has a higher optimal level.

→ Tax needs to be higher.

Uncertain GHG Abatement Costs Under Cap and Trade



EU Emission Trading System (ETS)

For tax issues all EU member states must agree, but majority vote is sufficient for ETS system

Mandatory "CO_2 Cap and Trade" system for

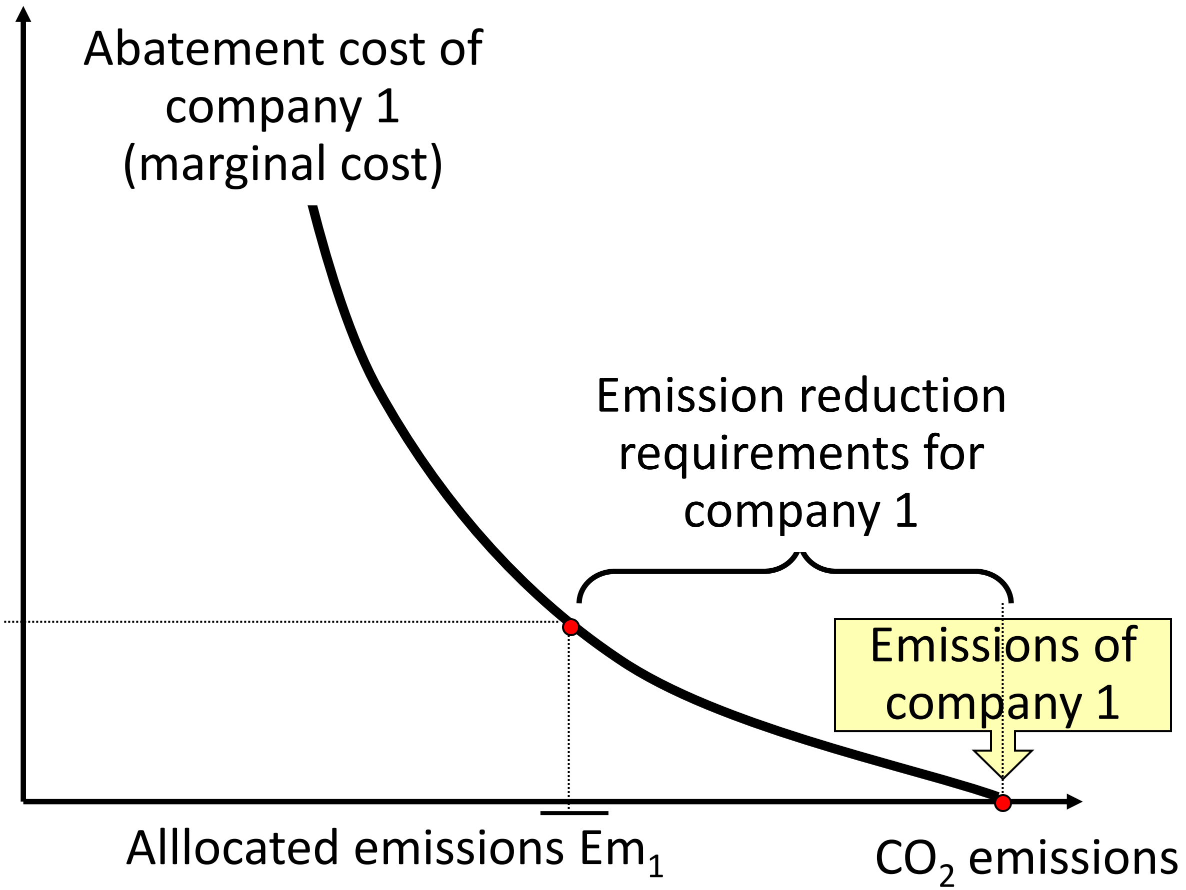
- Installations of power, refinery, steel, glass, cement industries (2071 mio t CO_2 verified emissions in 2005)
- airline business (after 2011)

EU wide annual cap of tradable CO_2 Allowances (EUA)

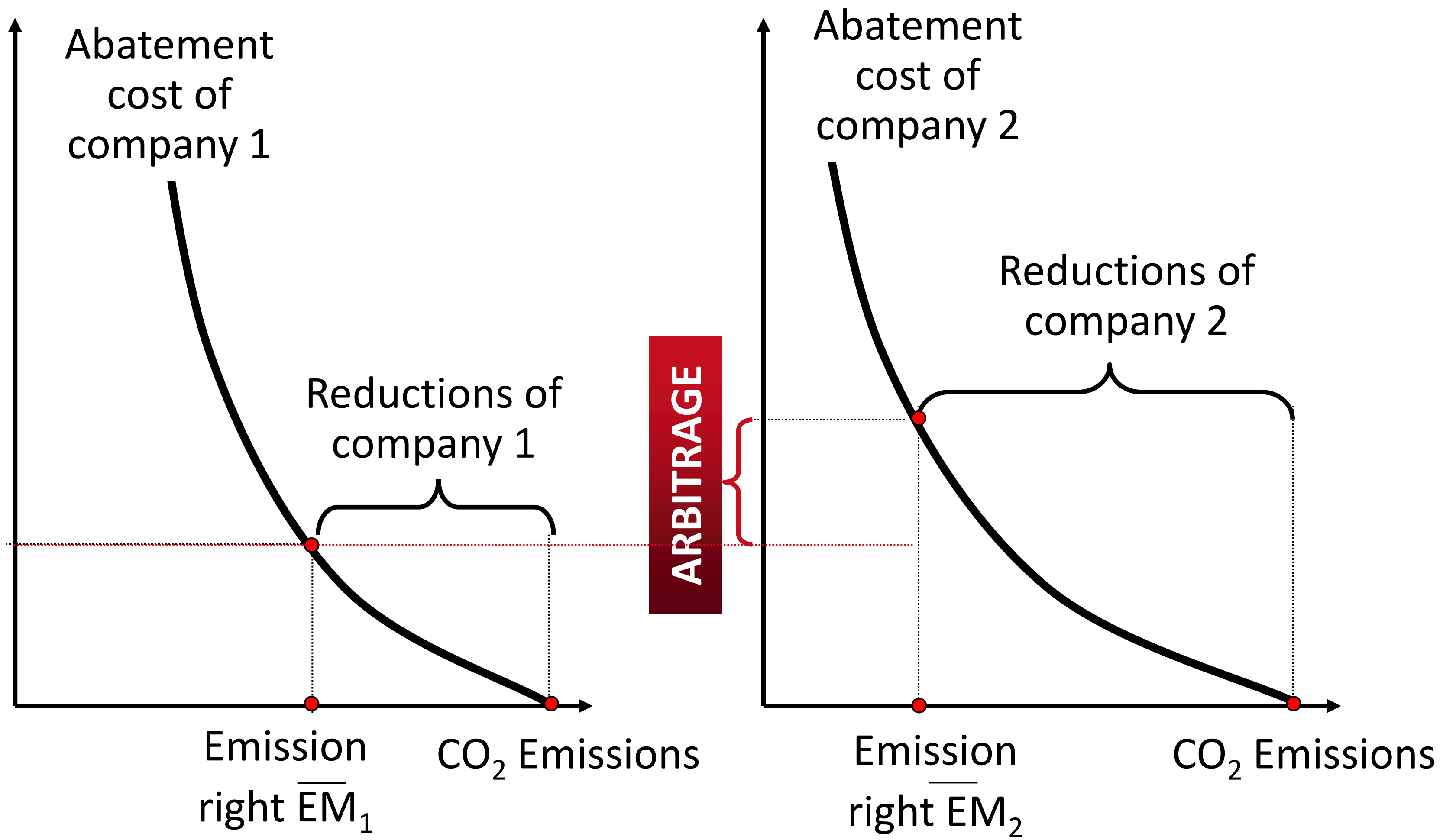
Almost free allocation of emission rights in the first two trading periods 2005/7 and 2008/12 → Windfall profits

System is intended to become the prototype for a global "cap and trade" system

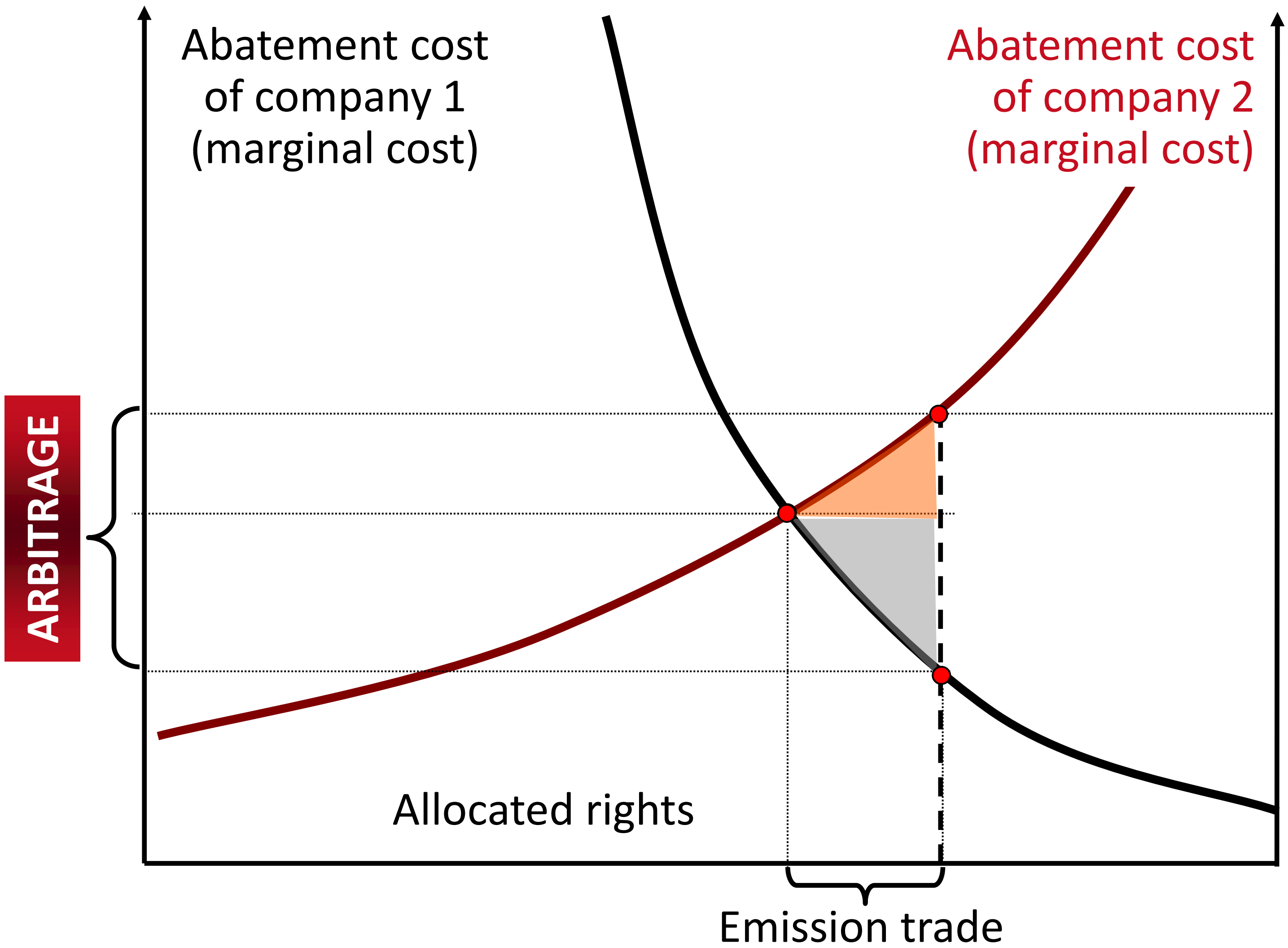
Emission Allowances and Abatement Cost



Trade of Emission Allowances



Trade of Emission Allowances



Trade of Emission Allowances

Effects of the trade:

- The given emissions target can be attained at a lower cost.
- At a given cost, a more ambitious emissions target can be achieved.

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Designing Emissions Trading System

Trading period length:

- If the trading period is too long, the incentives are weak.
- If the trading period is too short, there is lack of certainty for investments.

Allocation of emissions allowances:

- Grandfathering – free allocation → windfall profits

  CO_2 prices are opportunity costs of power plant operators (as certificates could be sold instead of covering emissions from electricity production) and, thus, included into the product price anyway, even if emission allowances are received for free.

- Auctioning – operators buy allowances in auctions.

  Government collects and redistributes auctioning revenues.

  In the EU: min 50% for climate and energy related purposes

Outline

- Energy balances
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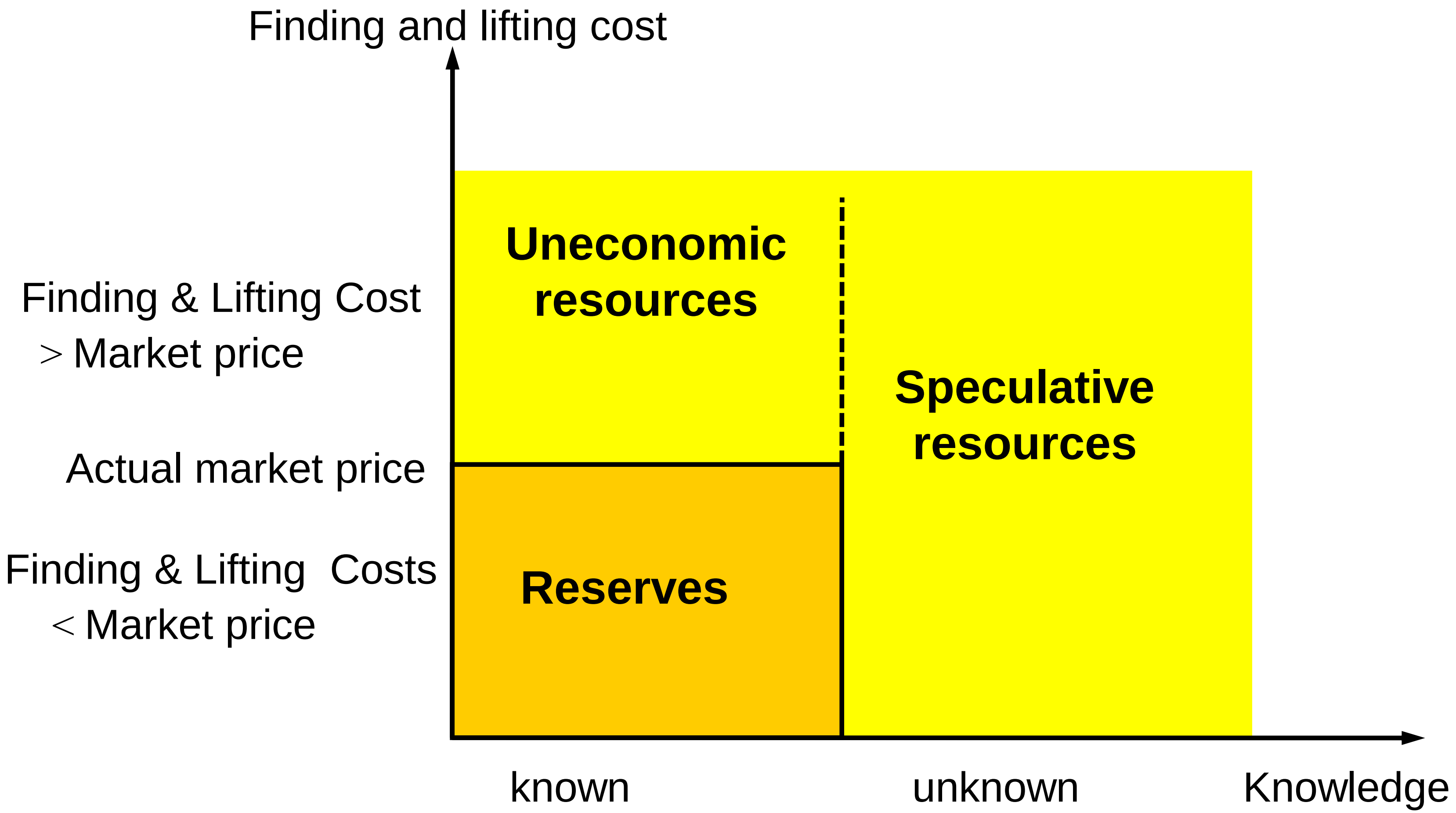
- Electricity markets
- **Resources and sustainability**
- Oil markets
- Gas markets

Brief theoretical summary of the topic: Exhaustible Resources

- Resources and Reserves
- Resource Extraction: Hotelling's Rule
- The Green Paradox

Resources and Reserves



Resource Extraction: Hotelling's Rule

- Basic assumptions
  - Perfectly Competitive Markets
  - Resource Owners:
    - Profit Maximizing Behavior
    - Constant marginal extraction costs *c*
    - Perfect information about the finite resource stock *S*

Basic Decision Problem of the Resource Owner:

- The market Price p_t cannot be influenced by the resource owner ("price taker"), therefore she just adjusts the extraction rate R_t in each period t
- Profit, Π_t, in each period follows as:

$$\Pi_t = p_t R_t - c R_t$$

- To extract, or not to extract?

Resource Extraction: Hotelling's Rule

- If the profit in the next period, Π_{t+1}, is greater than the Profit in the current period times the discount factor (Π_t*(1+i)), **we do not extract**

$$\Pi_{t+1} = p_{t+1}R_{t+1} - cR_{t+1} > \Pi_t(1+i)$$

- If the profit in the next period, Π_{t+1}, is less than the Profit in the current period times the discount factor (Πt*(1+i)), we extract (and put the profit on a bank to earn interest Π_t *(1+i))

$$\Pi_{t+1} = p_{t+1}R_{t+1} - cR_{t+1} < \Pi_t(1+i)$$

- If all resource owners behave profit maximizing, they adjust their extraction rates until:

$$\Pi_{t+1} = p_{t+1}R_{t+1} - cR_{t+1} = \Pi_t(1+i)$$

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Resource Extraction: Hotelling's Rule

- The resource owners maximize the Net Present Values of profits by adjusting the extraction rates each period:

$$NPV = \sum_{t=0}^{T} \Pi_t \cdot (1+i)^{-t} = \sum_{t=0}^{T} (p_t R_t - cR_t)(1+i)^{-t} \rightarrow \max!$$

- Extraction is constrained by the available resource stock, S and hence:

$$\sum_{t=0}^{T} R_t = S$$

- With Lagrange-Multiplier, λ>0, we introduce the constraint into the objective function:

$$L = \sum_{t=0}^{T} (p_t R_t - cR_t)(1+i)^{-t} - \lambda \left(\sum_{t=0}^{T} R_t - S \right) \rightarrow \max!$$

- The first order optimality conditions are:

$$\frac{\partial L}{\partial \lambda} = 0 \Rightarrow \sum_{t=0}^{T} R_t = S \qquad (1)$$

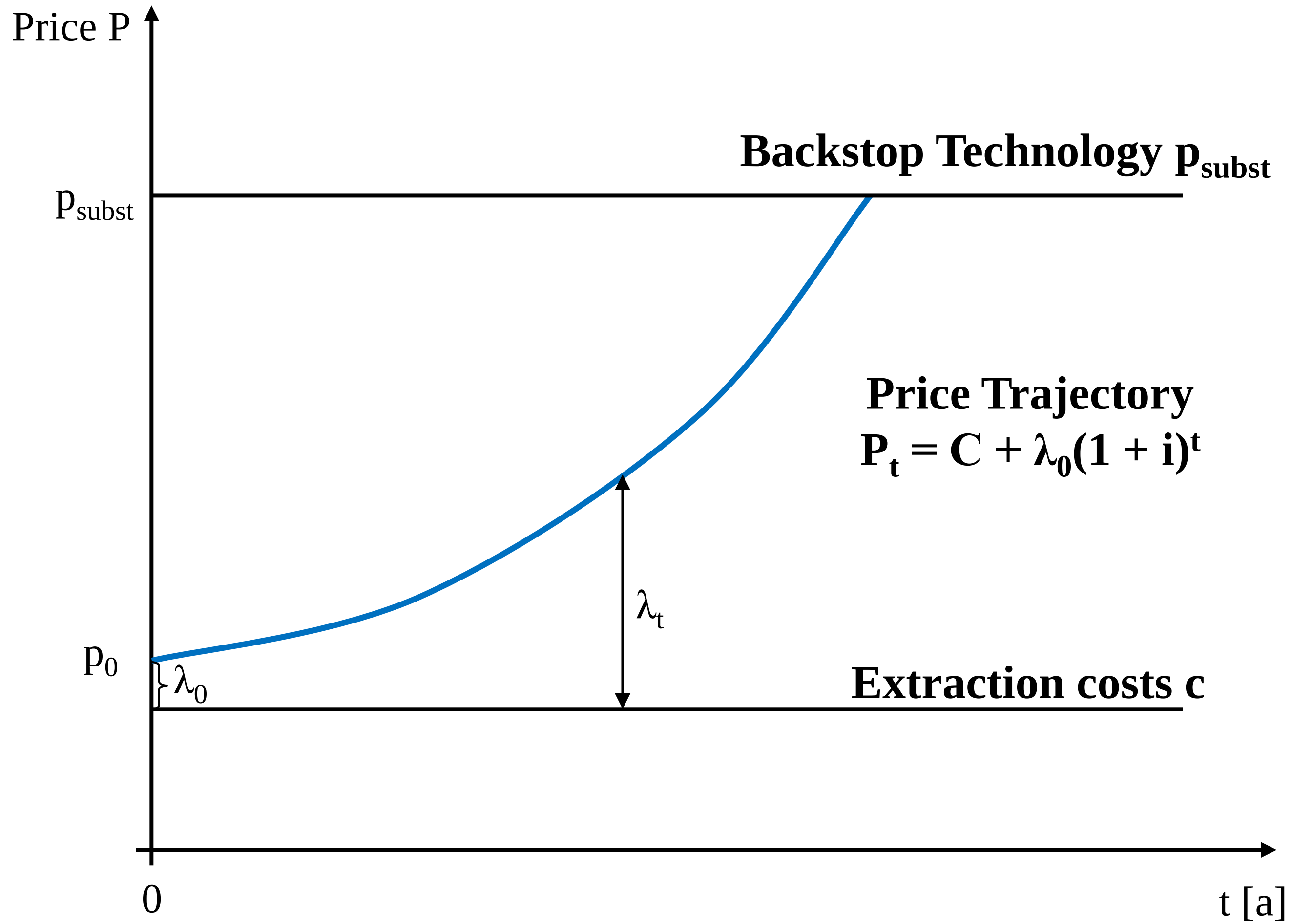
$$\frac{\partial L}{\partial R_t} = (p_t - c)(1+i)^{-t} - \lambda = 0 \qquad (2)$$

$$\Rightarrow p_t = c + \lambda (1+i)^t \quad \text{Hotelling Rule}$$

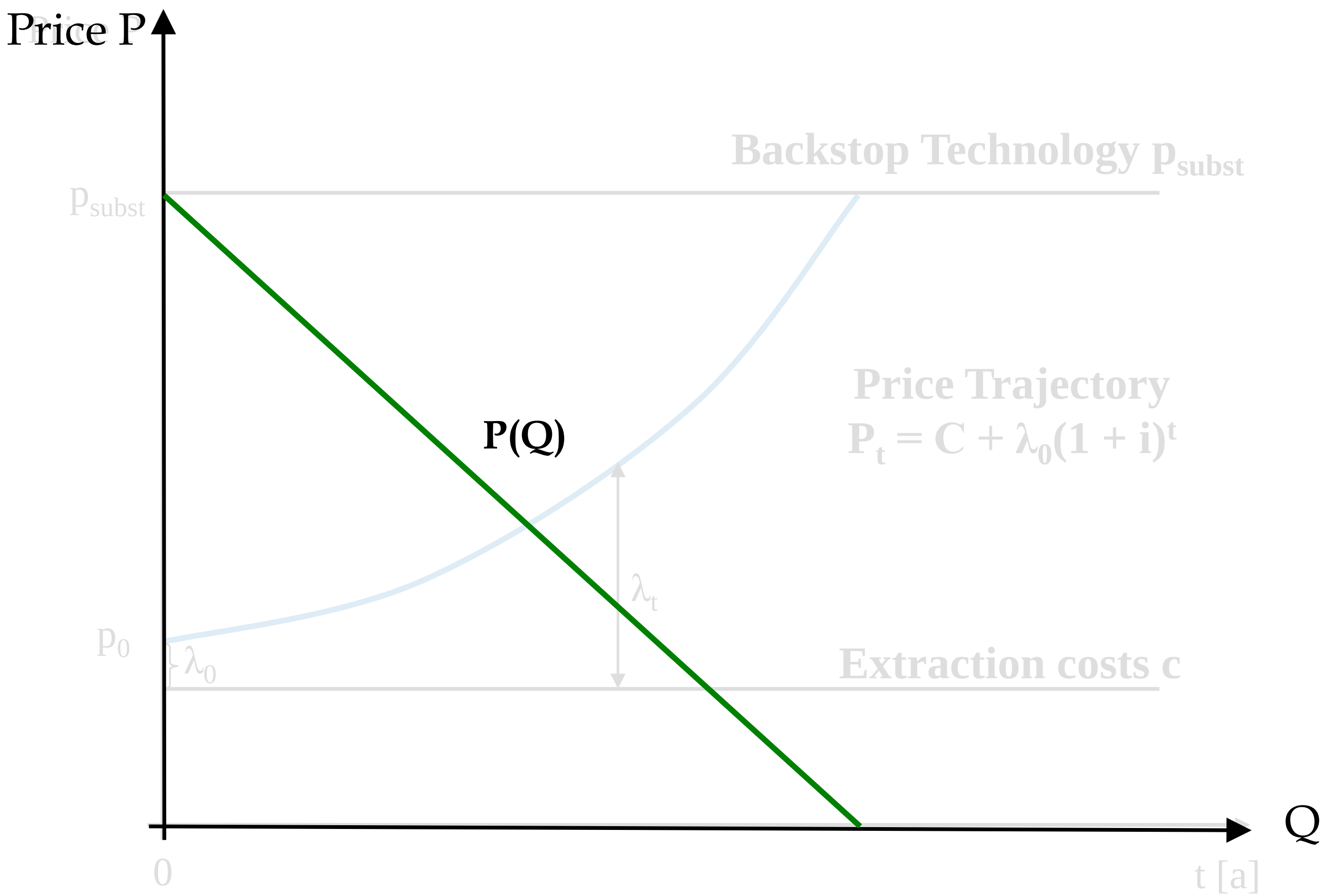
Resource Extraction: Hotelling's Rule
Price Formation

- Scarcity rent (*Knappheitsrente*) λ_t: $\lambda_t = p_t - c = \textit{value of reserve}$
- Decision criterion in $t = 0$: $\lambda_1 < \lambda_0\,(1+i)$ or $\lambda_1 > \lambda_0\,(1+i)$
  with the capital market interest rate i)
- Equilibrium (indifference condition): $\lambda_1 = \lambda_0\,(1+i)$
- Trajectory of the resource rent: $\lambda_t = \lambda_0\,(1+i)^t$
- Price trajectory under constant extraction cost c: $p_t = c + \lambda_t = c + \lambda_0\,(1+i)^t$
- Resource rent at exhaustion $T > t$: $\lambda_T = p_{subst} - c$
  with the backstop technology price p_{subst}
- Optimal trajectory for $t < T$: $\lambda_t = \lambda_T\,(1+i)^{t-T} = (p_{subst}-c)\,(1+i)^{t-T}$

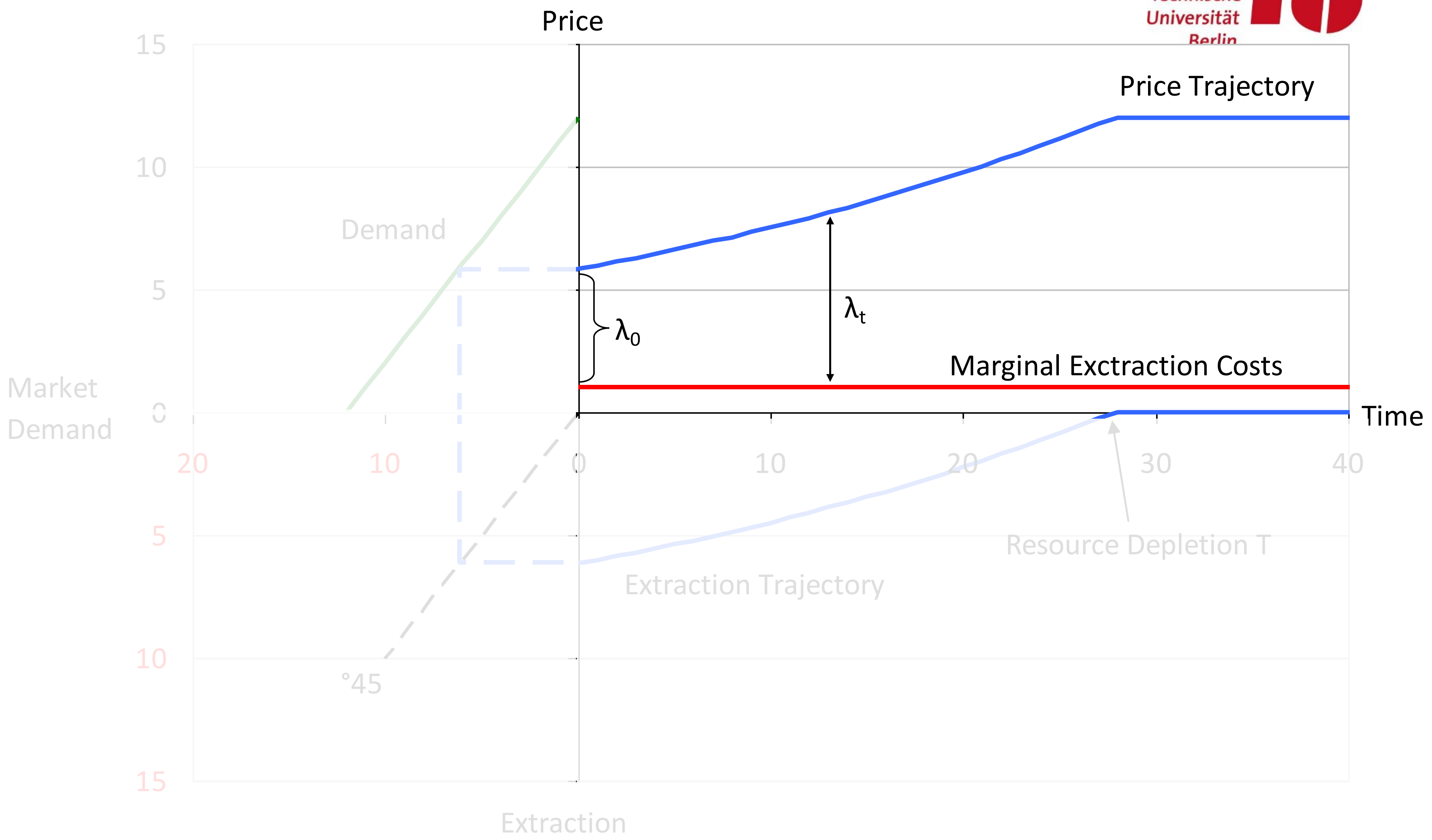
Hotelling Price Trajectory



Hotelling Price Trajectory: Demand P(Q)



Task 2) Hotelling's Rule



Outline

- Energy balances
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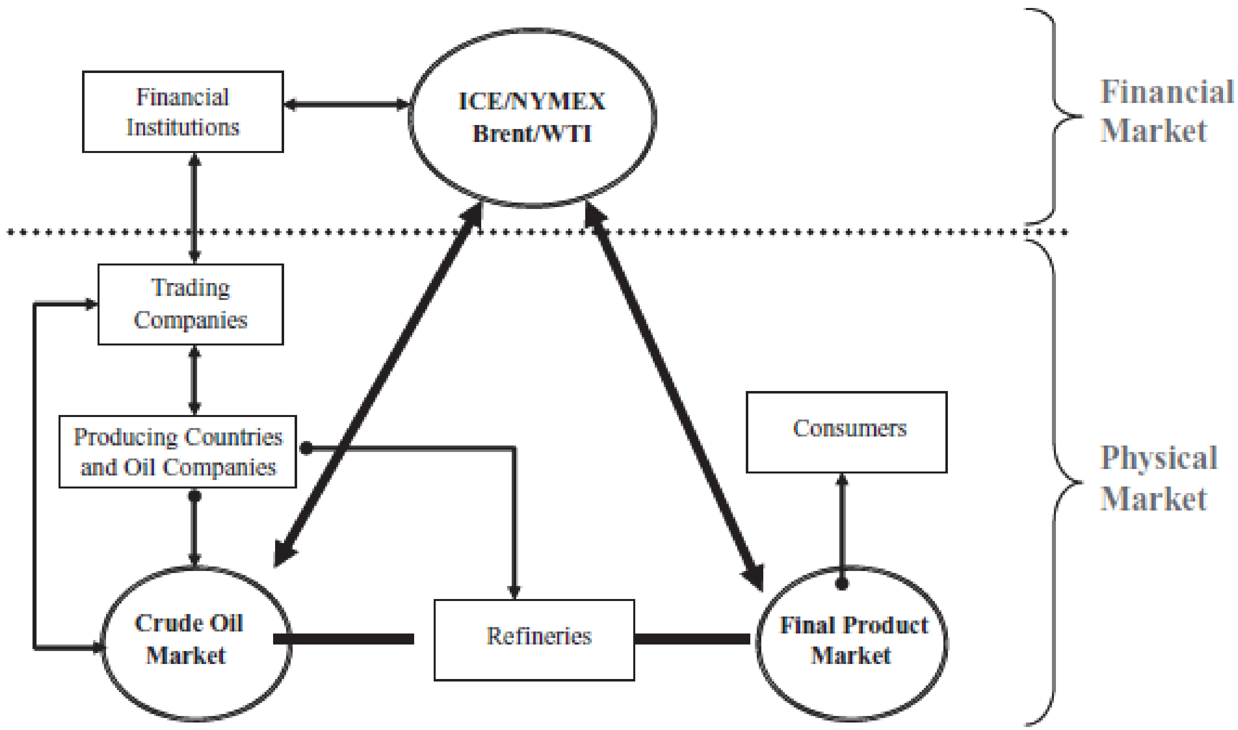
- Emissions
- Resources and sustainability
- **Oil and gas markets**

Oil Market

Market participants:

- Producers
- Refiners
- Marketers
- Retailer*
- Consumers

Price reporting agencies:
Platts, Argus etc.

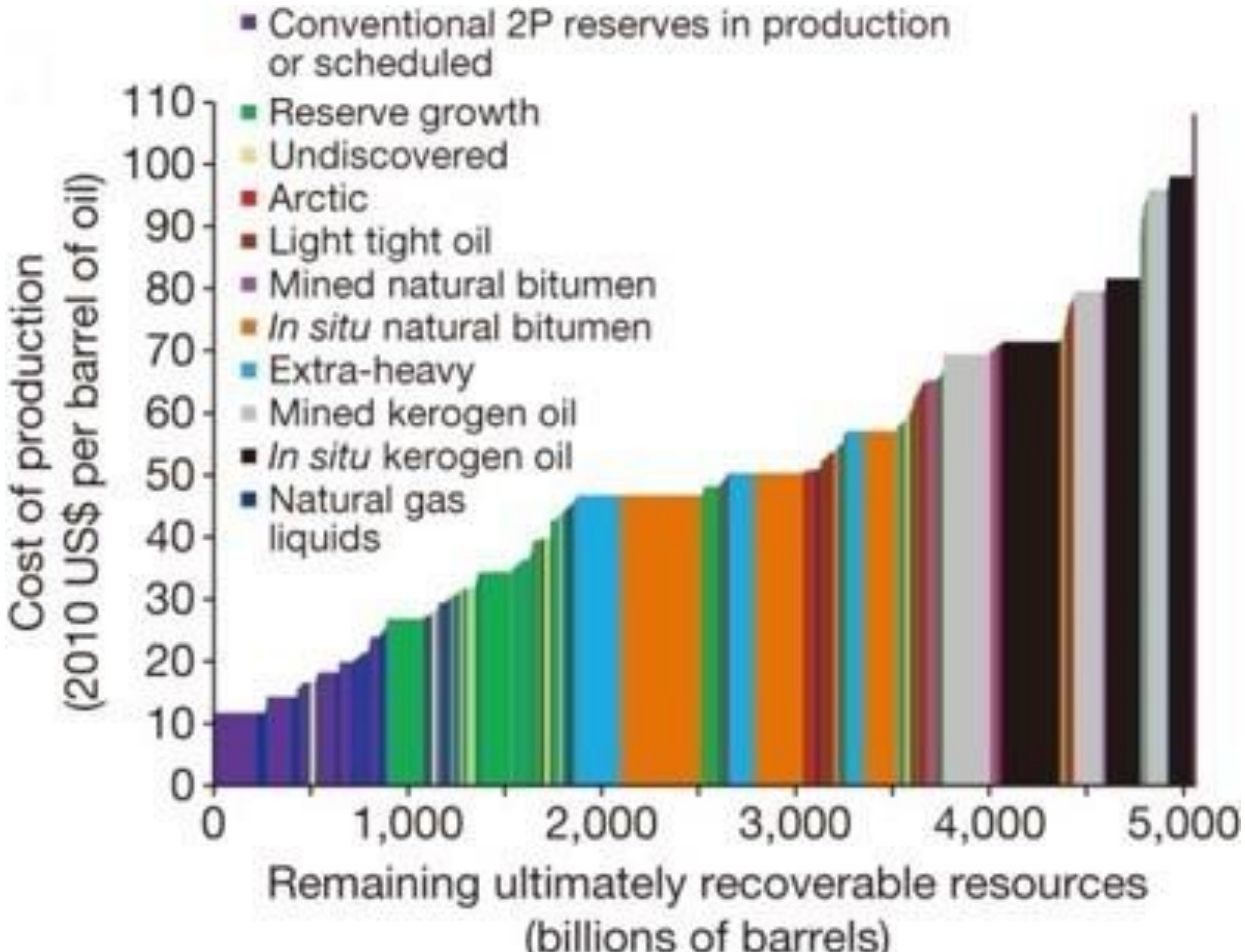


- Gasoline
- Diesel
- Jet fuel
- Fuel oil
- Chemical feedstock
- Lubricants

Source: Carollo (2012)

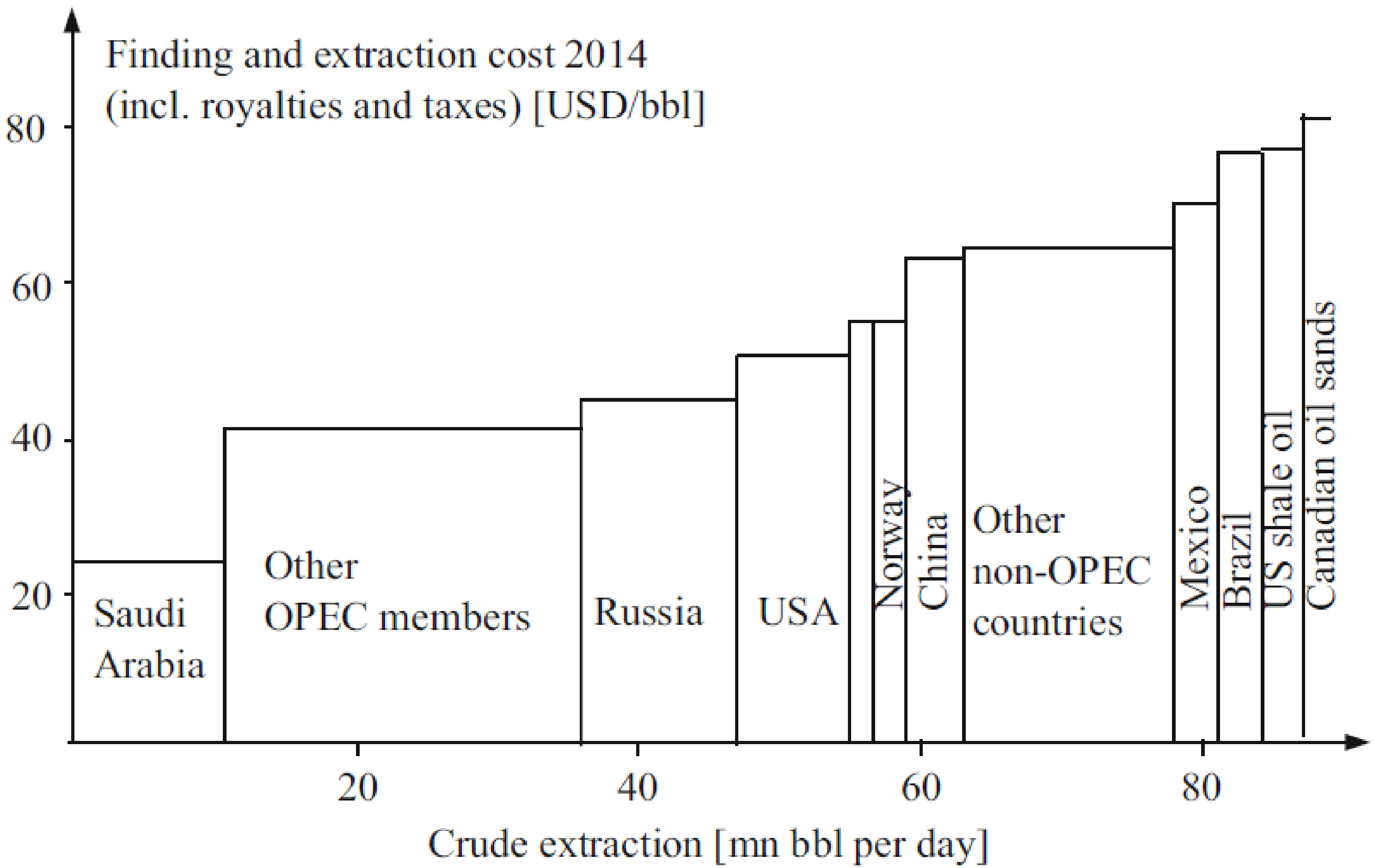
* oil products

Cost of Production by Oil Source



Source: McGlade and Ekins (2015)

Cost of Production by Country



Source: Zweifel / Praktiknjo / Erdmann (2017) with reference to Oil Industry Trends

Crude Oil Specifications

Crude oil is a heterogeneous commodity.

- density / viscosity:
  - light oil has low density
  - heavy oil has high density (large portion of low-value products to be removed through processing)

- sulfur content:
  - sweet oil has low sulfur content
  - sour oil has high sulfur content (>0,5%)

    (Price spread on different markets depend on local environmental regulations.

    IMO limits sulfur content in marine fuels to max. 0,5% since 2020.)

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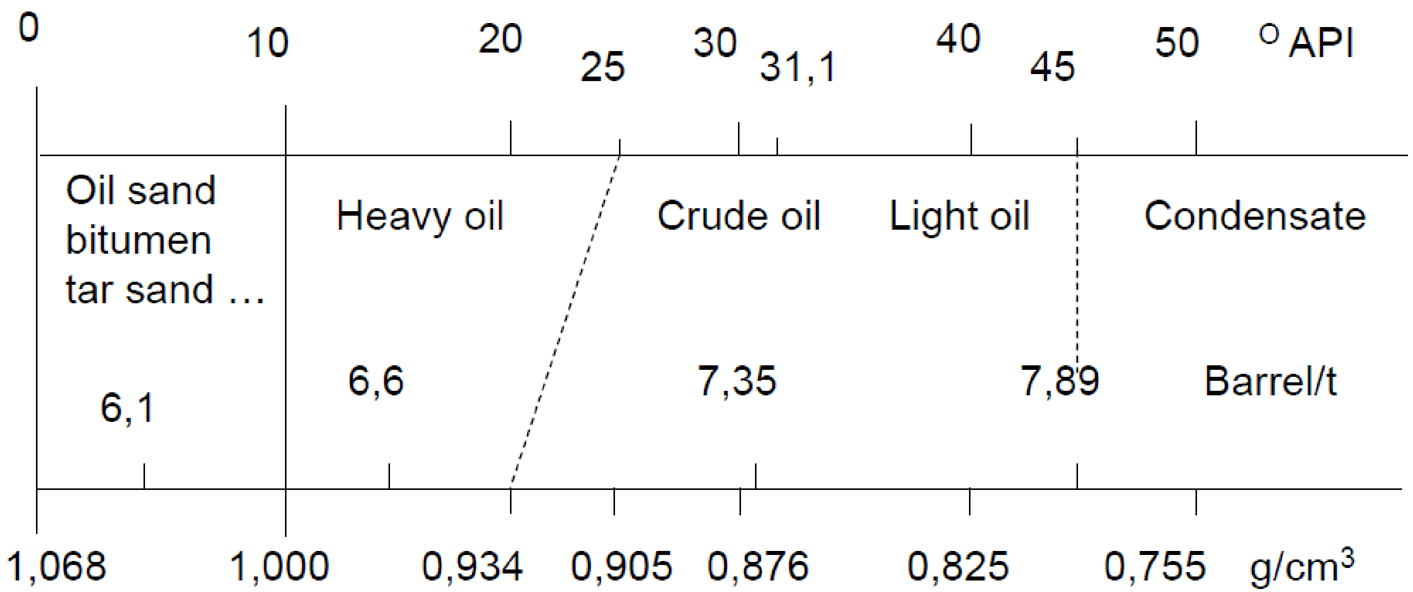
Properties of Crude Oil Varieties



Source: American Petroleum Institute API

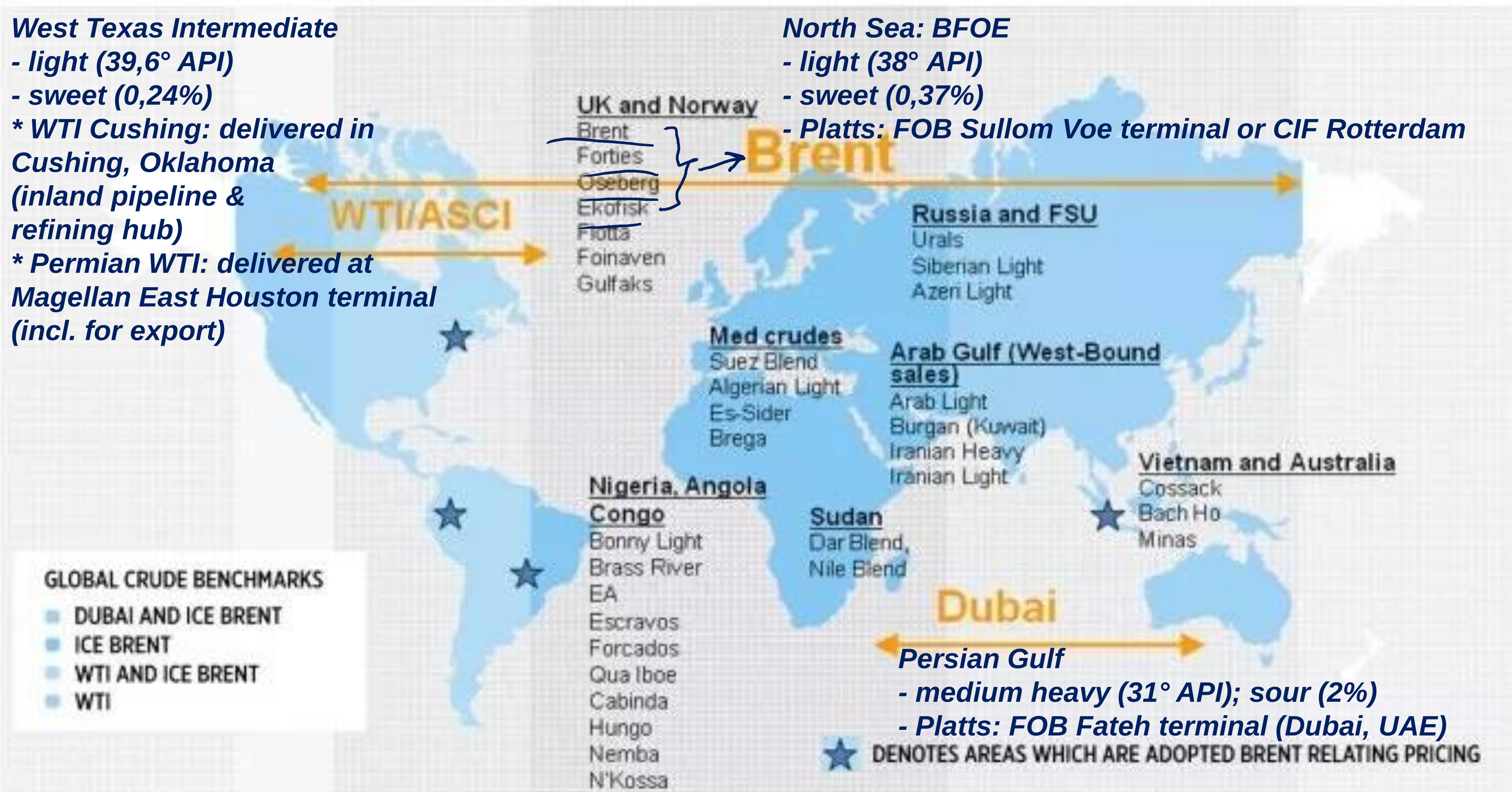
Transformations of the Oil Industry

- Vertical monopoly
- Vertical oligopoly of the „7 sisters“
- OPEC cartel (Organization Petrol Exporting Countries)
  - 1960 founded by Iran, Iraq, Kuwait, Saudi-Arabia, Venezuela
  - Qatar (1961), Indonesia and Libya (1962), the United Arab Emirates Emirate (1967), Algeria (1969) and Nigeria (1971)
  - 1970-1975: Posted Price regime
  - 1976-1984: Production control by OPEC governments
  - 1985-2001: Production quotas with *Swing Producer*
  - 2002-2005: Production quotas with price corridor (22-28 USD/b)
- Oligopoly of national oil companies (NOCs)

Crude Oil Benchmarks

West Texas Intermediate
- light (39,6° API)
- sweet (0,24%)
**** WTI Cushing: delivered in Cushing, Oklahoma (inland pipeline & refining hub)***
**** Permian WTI: delivered at Magellan East Houston terminal (incl. for export)***

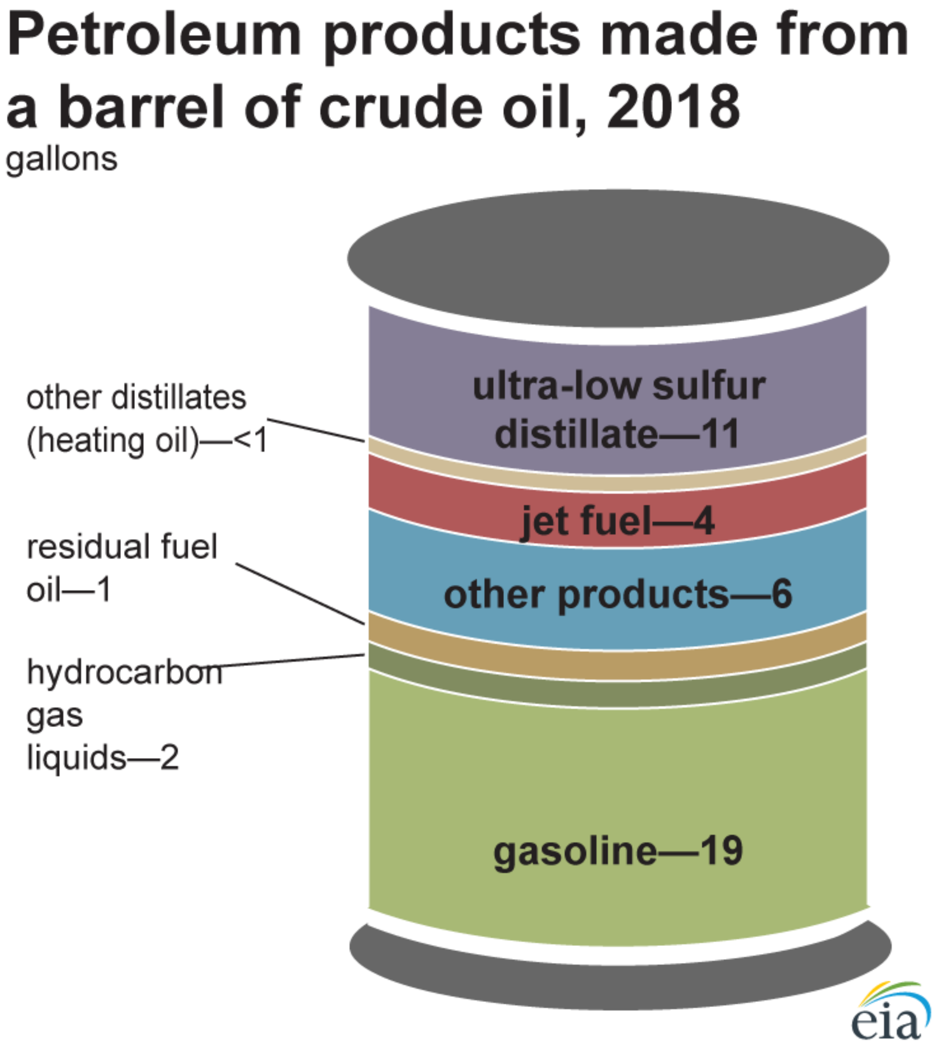
North Sea: BFOE
- light (38° API)
- sweet (0,37%)
- Platts: FOB Sullom Voe terminal or CIF Rotterdam



Persian Gulf
- medium heavy (31° API); sour (2%)
- Platts: FOB Fateh terminal (Dubai, UAE)

Source: IntercontinentalExchange (ICE)

Petroleum Products

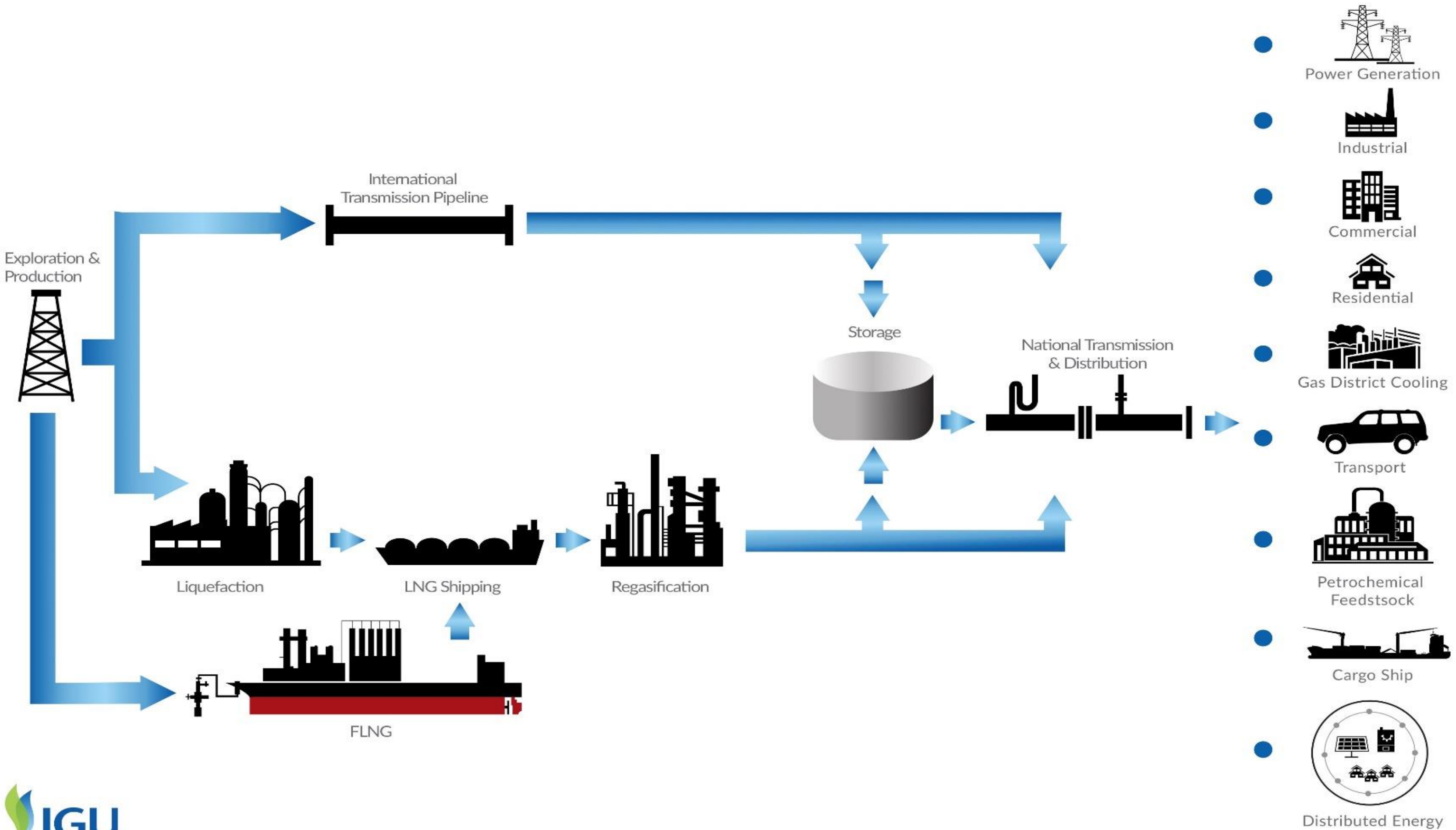


Refining: crude oil is separated into oil products through distillation.

Note: A 42-gallon (U.S.) barrel crude oil yields about 45 gallons of petroleum products because of refinery precessing gain. The sum of the product amounts in the image may not equal 45 because of independent rounding.

Source: U.S. Energy Information Administration, Petroleum Supply Monthly, April 2019, preliminary data

Natural gas value chain



Economics of Gas Pipelines

$$Q \sim \sqrt{\frac{P_1^2 - P_2^2}{l / d^2}}$$

Throughput is the volume of gas passing through a pipeline in a period of time.

[m³/h]

Pipeline capacity is the maximum throughput.

- Q Gas transport volume
- P_1 Presure at the beginning of the section
- P_2 Pressure at the end of the section
- l Length of the pipeline section (between two compressor stations)
- d Diameter of the pipeline

- Long-distance gas tranasport no natural monopoly (Pipe-to-Pipe competition, Pipe-in-Pipe competition)
- *Hold-up*-Problem: After realizing a pipeline project, the investor finds himself in a strategically weak position based on the irreversible nature of the investment: The Pipeline operator's profit depends on the goodwill of the contract partner located at the end (beginning) of the pipeline

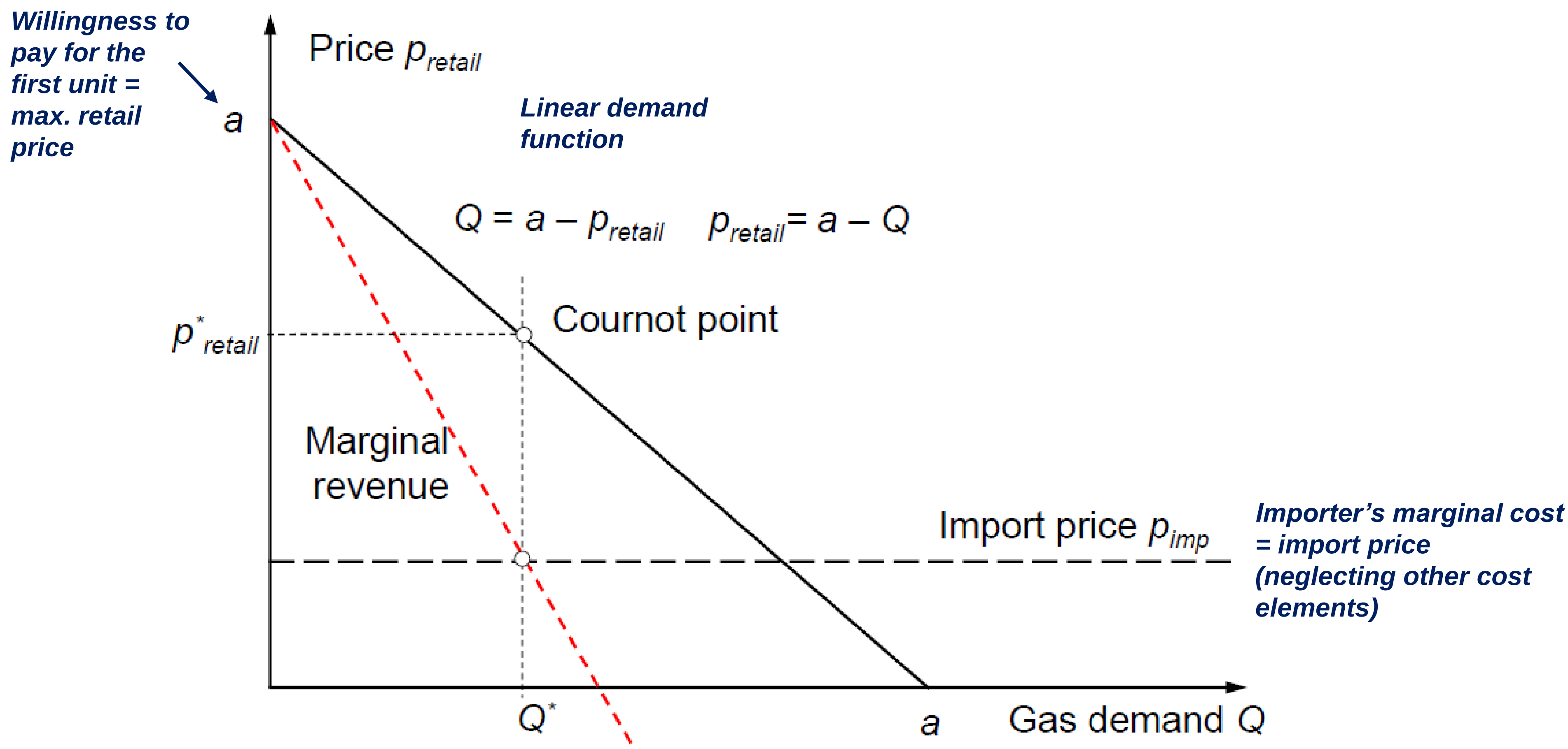
Game Theory: Double Marginalisation

- Two companies: monopolistic gas importer who supplies the retail market, and a monopolistic pipeline operator who is also a dominant gas producer in the exporting country
- In the first step of the game theoretic model the pipeline operator optimizes his pipeline capital stock K. In the second step the import price $p_{imp}(K)$ is determined by negotiations between the two monopolists
- Both parties optimize independent from each other their profit (non-cooperative game)

Gas producer is able to infer on the import price resulting from gas importer's optimisation based on the domestic demand curve. It then optimises its profit at the given import price.

- Mathematical solution of the model in the opposite order: First the condition for the import price is determined, i.e. the result of the negotiations between the two monopolists in step 2

Retail Gas Price set by the Monopolistic Gas Importer



Game Theoretical View of the Gas Importer

$$Q = a - b \cdot p_{retail}, \quad b = 1$$

Q	Gas demand
a	Maximal gas retail price
p_{retail}	Gas retail price

$$\Pi_{importeur} = (p_{retail} - p_{imp}) \cdot (a - p_{retail})$$

$\Pi_{importeur}$	Profit of the importer
p_{imp}	Import price

$$p^*_{retail} = \frac{a + p_{imp}}{2}$$

Profit maximizing gas retail price

$$Q^*(p_{imp}) = \frac{a - p_{imp}}{2}$$

Optimal sales volume

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Game Theoretical View of the Pipeline Operator

$$\Pi_{produzent} = \left(p_{imp} - c(K)\right) \cdot Q^* = \left(p_{imp} - c(K)\right) \cdot \frac{a - p_{imp}}{2}$$

$\Pi_{produzent}$	Profit of the pipeline operator
p_{imp}	Import price
K	Pipeline Capital stock
c	Unit cost of pipeline operation

Transactions are only possible under $a > c(K)$

$$p^*_{imp}(K) = \frac{a + c(K)}{2} > c(K)$$

Deviation of the profit function to p_{imp} under the condition that the unit cost $c(K)$ is independent from the transport volume Q and thus independent from the import price p_{imp}

The solution is a Nash equilibrium of a non cooperative game between two mopololists along the value chain: Each player selects the individually optimal price given the price of the other player

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Solution under "Cooperation"

$$\Pi_{coop} = (p_{retail} - c(K)) \cdot (a - p_{retail})$$

Π_{coop} Common profit under cooperaton

$$p^*_{retail,coop} = \frac{a + c(K)}{2} < \frac{a + p_{imp}(K)}{2} = p^*_{retail}$$

There is a welfare loss if two monopolists along the value chain don't cooperate („double marginalization")

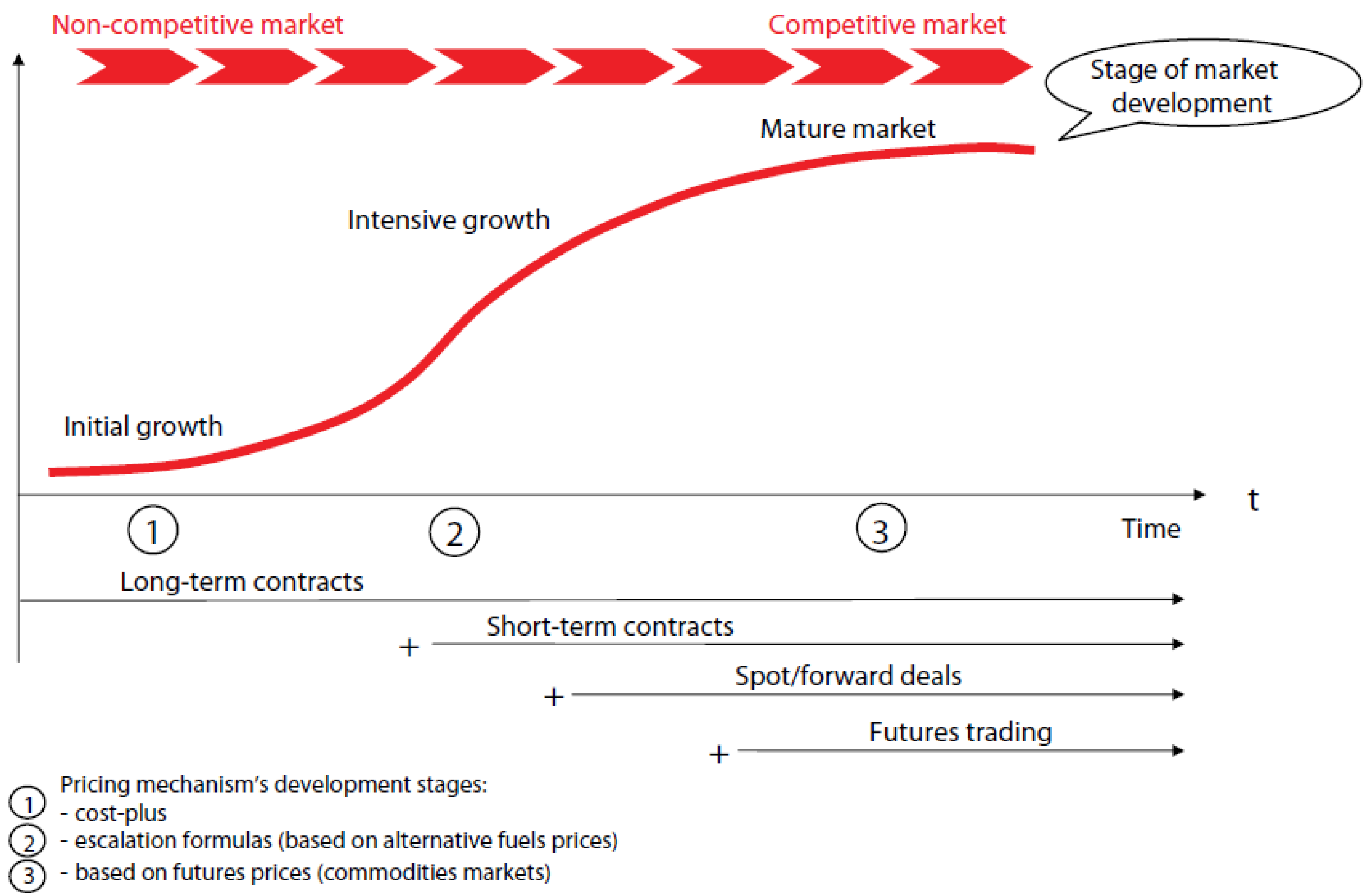
What is worse than a monopoly: Two monopolies

The aggegate profit under cooperation is

$$\Pi^*_{coop} = \left(\frac{a - c(K)}{2}\right)^2$$

$$\Pi_{no-coop} = \Pi^*_{importeur} + \Pi^*_{produzent} = \frac{3}{4}\left(\frac{a - c(K)}{2}\right)^2$$

Dynamics of Gas Market Development



Source: Energy Charter Secretariat (2007) with reference to Konoplyanik

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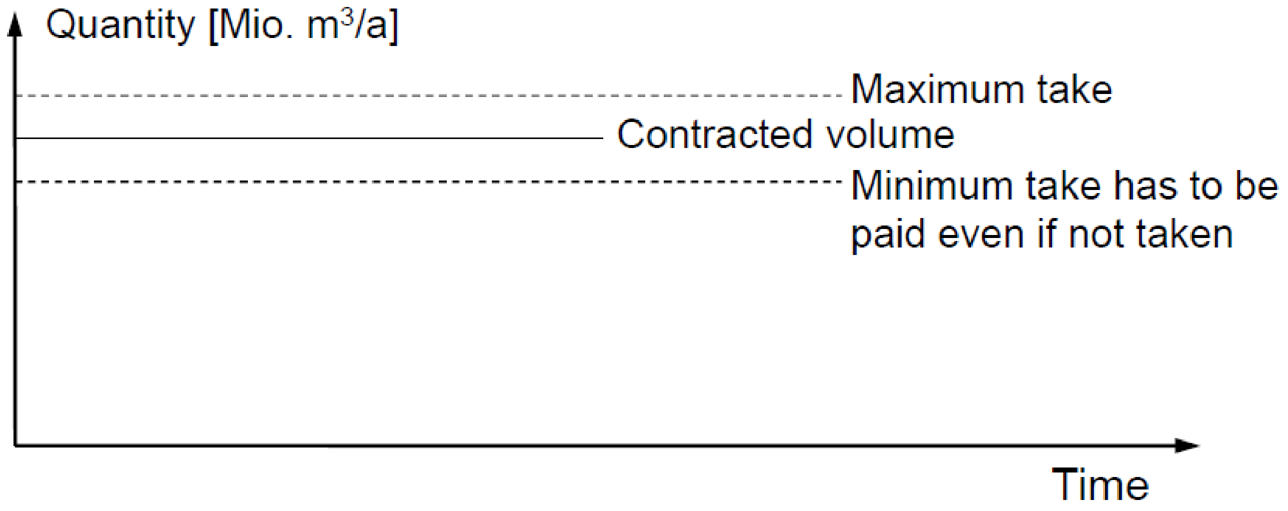
Take-or-Pay Clause in Long Term Contracts

- Volume Risk taken by the importer



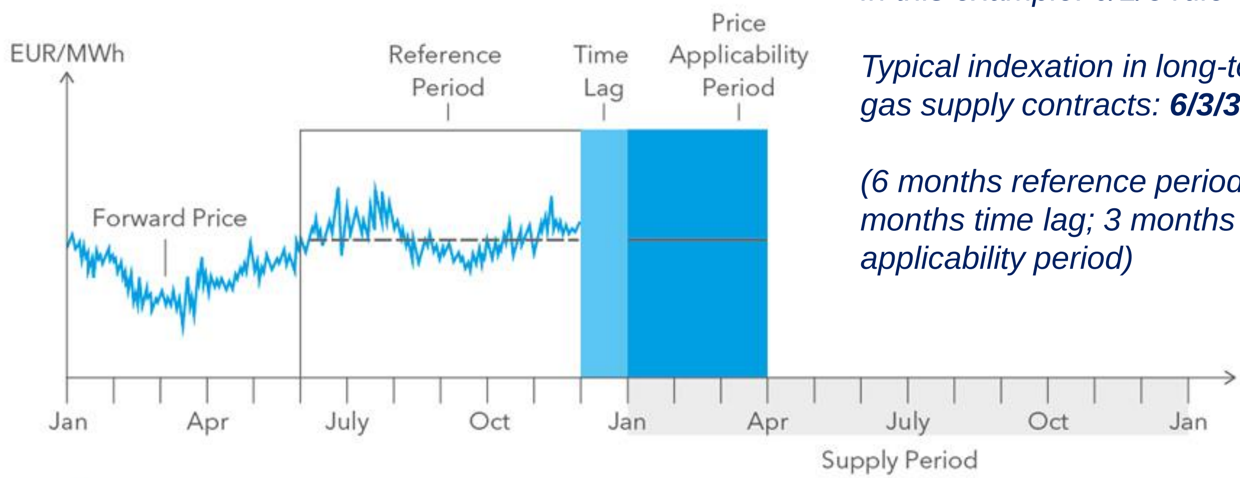
- Price Risk taken by the exporter according to a price formula that depends, among others, on the heating oil price "*Rheinschiene*" published monthly by the German Federal Statistical Office (*Bundesamt für Statistik Destatis*)

Index-based Gas Price

In this example: 6/1/3 rule

*Typical indexation in long-term gas supply contracts: **6/3/3 rule***

(6 months reference period; 3 months time lag; 3 months price applicability period)



Forward Price (Forward Contract – Quarter)

Arithmetic mean of the daily price quotation

Applicable Commodity Charge

Time period in or for which (depending on the specific index type) the index is published →

The **Reference Period** in this example adds up to six months. The value of the gas indexed commodity charge is the result of the arithmetic average mean of the daily price quotation for the forward contract "Quarter" within this six months (average price).

Time lag between the reference period and price applicability period →

The **Time Lag** in this example is one month.

The **Price Applicability Period** in this example adds up to three months respectively a "Quarter".

Part of the delivery period to the calculated price applies.

Souce: WINGAS

Oil-product linked gas prices

Initial rationale for oil-based indexation is that users can choose between burning gas and oil products.

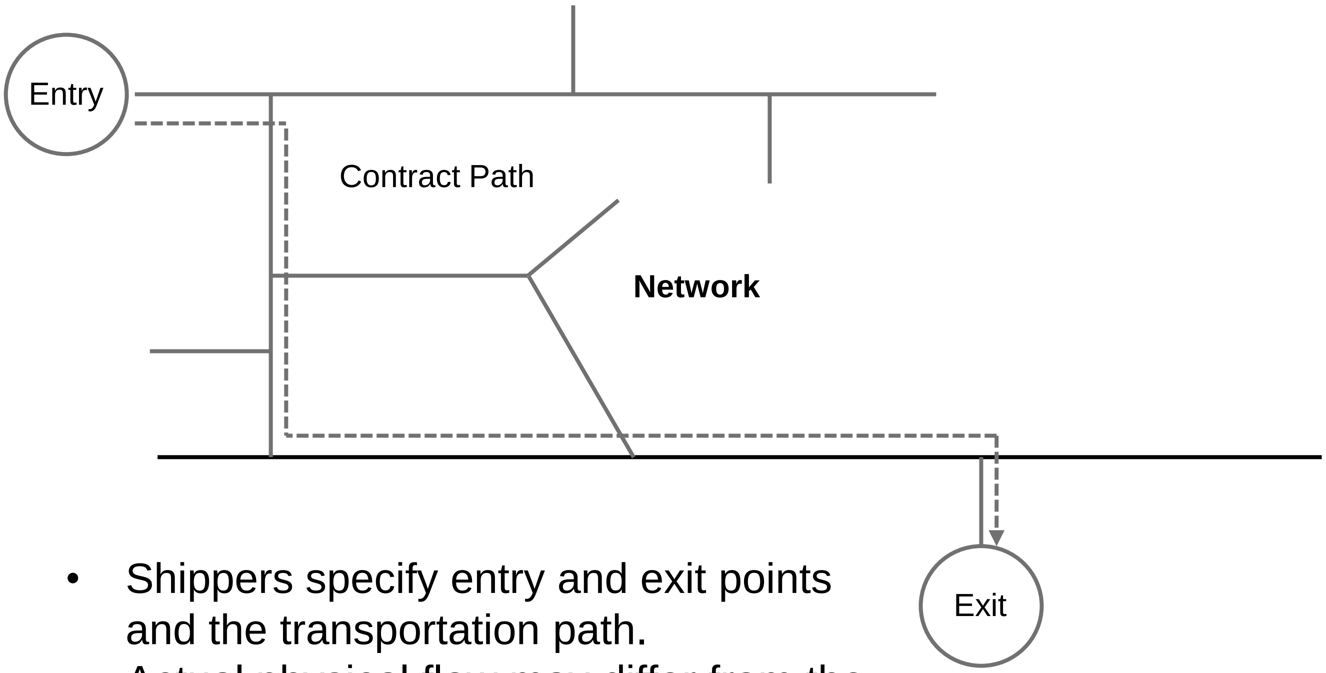
Early liberalised gas markets of the US and the UK with a liquid wholesale trading in natural gas resulted into gas-to-gas competition.

Long-term supply contracts for Continental Europe were initially linked to oil prices.

Since late 2000s European gas markets have shifted significantly from oil indexation towards hub-linked prices.

Renegotiation of price formulas in long-term supply contracts followed.

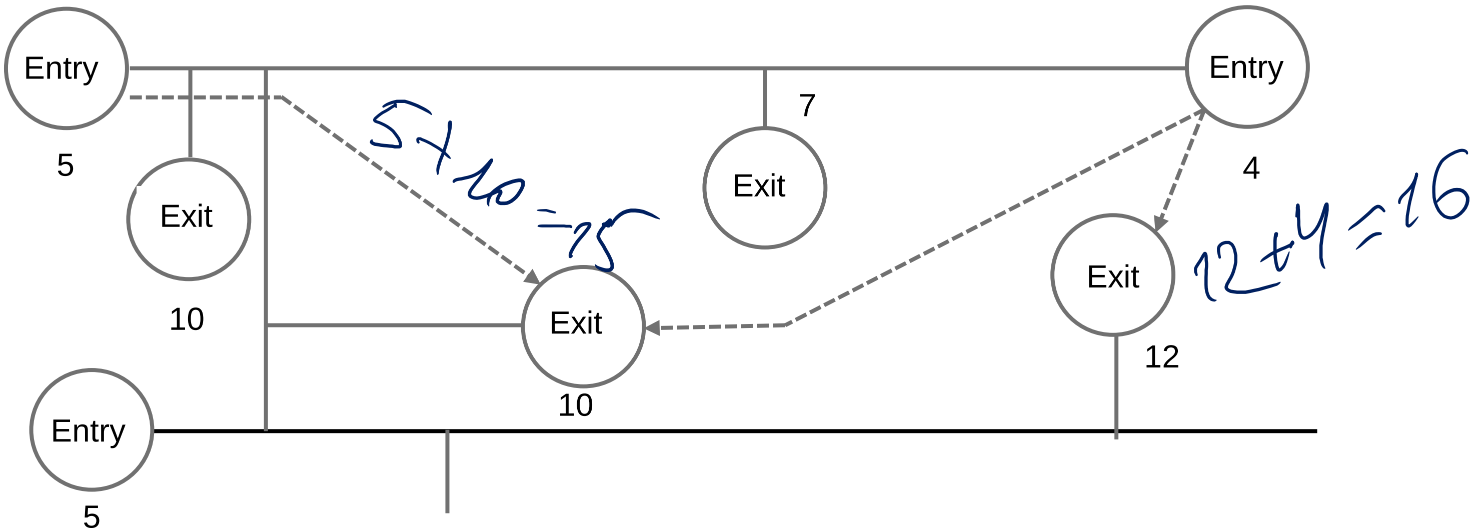
Third-party access: Point-to-point Model



- Shippers specify entry and exit points and the transportation path.
- Actual physical flow may differ from the contracted path.
- Entry and exit capacities cannot be separated from each other and from the gas (commodity) transaction.

Source: Hewicker & Kesting, 2009

Third-party access: Entry-exit Model



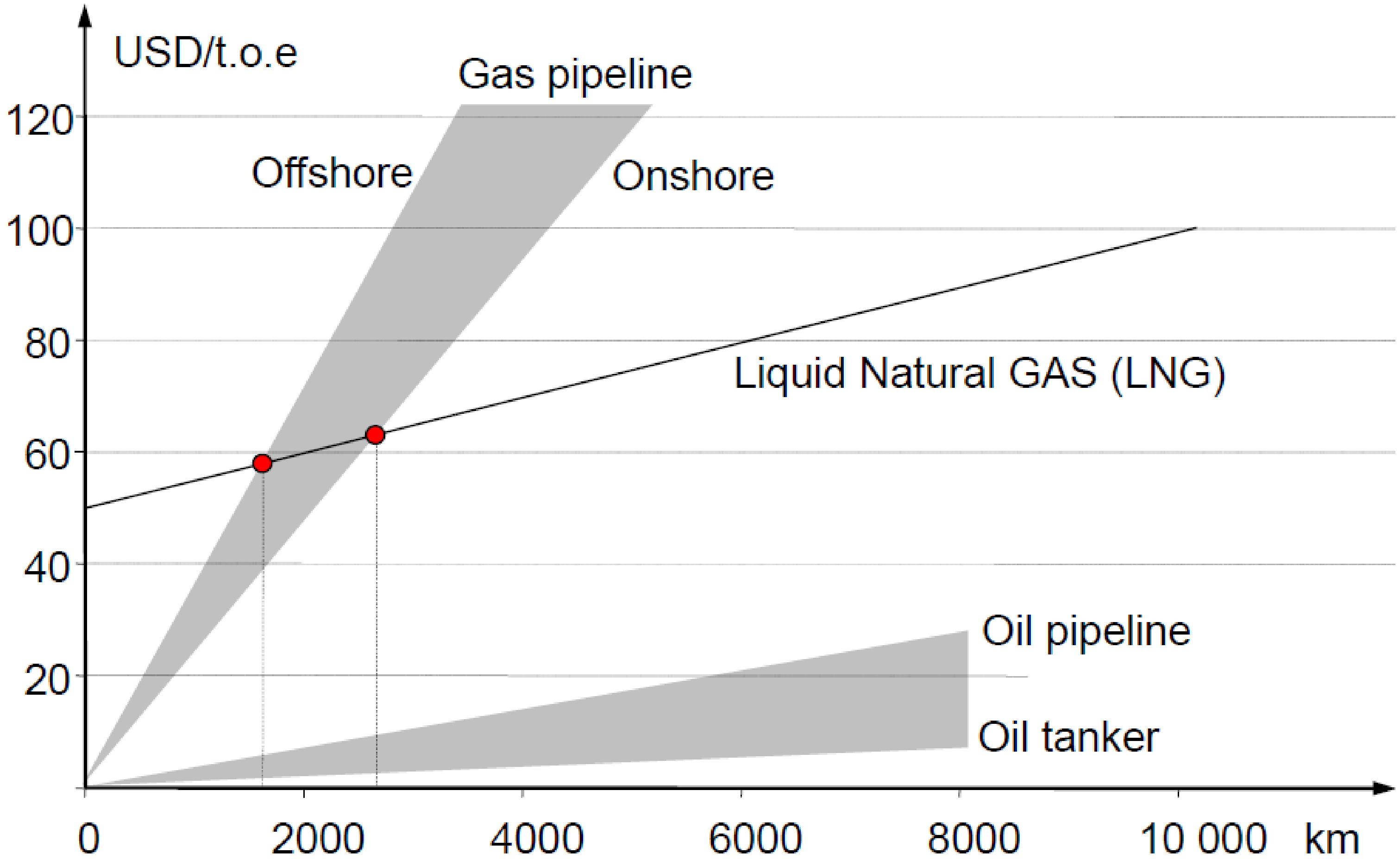
- Shippers book entry and exit capacity independently from each other.
- No need to specify transportation path or distance.
- Contracts for entry and exit capacities are independent from each other and from commodity transactions.
- Entry and exit tariffs are set independently for each entry/exit point
- Different tariffs for each point
- All network operators in a network zone cooperate and set tariffs on a cost-reflective basis.

Source: Hewicker & Kesting, 2009

European gas regions, markets and hubs

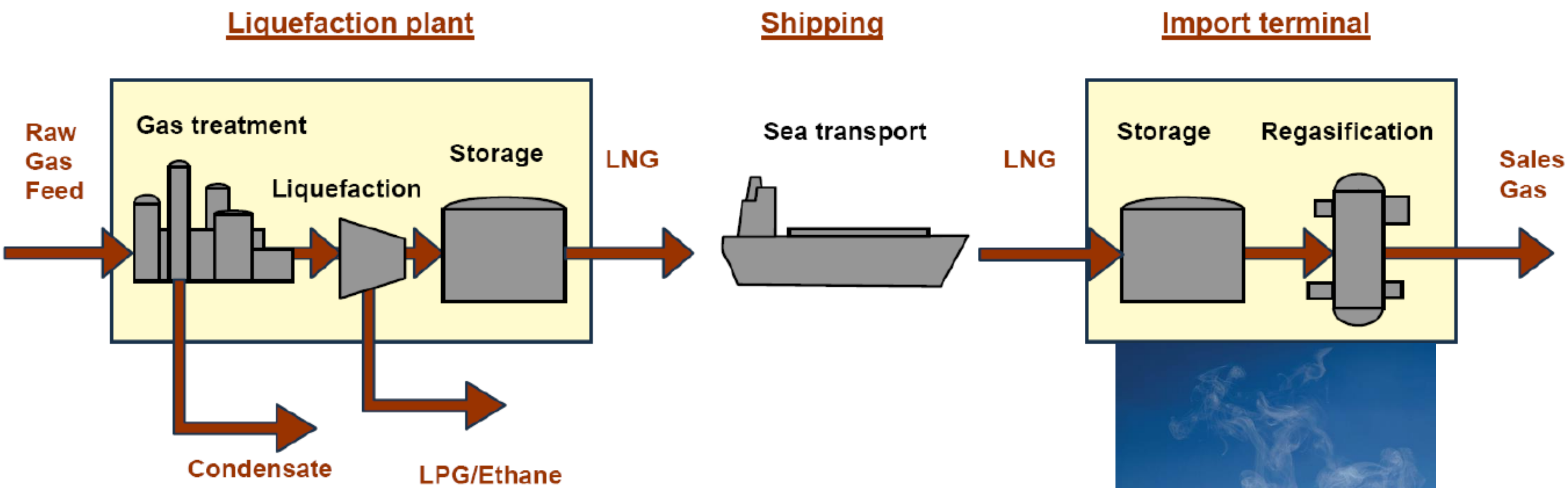
Source: OIES (2017) with reference to www.worldatlasbook.com and P. Heather

Transportation Cost of Hydrocarbons

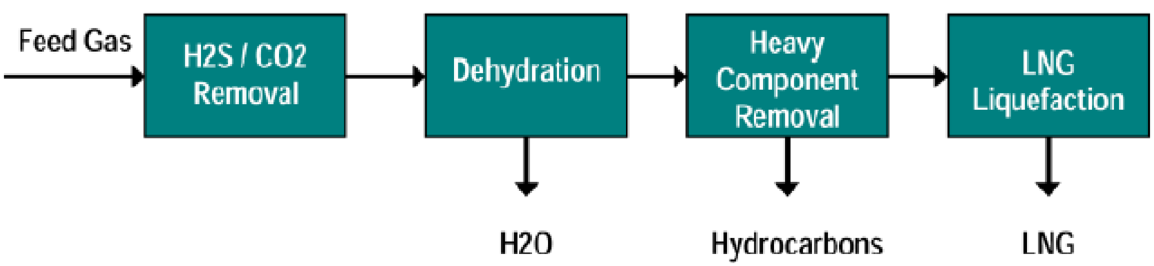


Source: Zweifel / Praktiknjo / Erdmann, 2017

LNG Process Chain



Boiling point of methane −162 °C (−259.6 °F)
Approx. 600 times volume reduction



Source: Osaka Gas

Source: BV 2009 / GIIGNL

Cost Structure of LNG Process Chain

Liquefaction plant:	
Investment outlay	900M €
Operating expenses	0,04 €/m³
LNG tanker fleet	*e.g. 2 vessels á 135T t each*
Investment outlay	360M €
Operating expenses	0,014 €/m³
Regasification plant w. storage	e.g. 80T m³ (Cartagena)
Investment outlay	320M €
Operating expenses	0,015 €/m³
Own gas requirement	1/3 of transported gas

Source: Zweifel / Praktiknjo / Erdmann (2017), after Cayrade (2014)

LTC Renegotiation

Driving factors for transition to hub-linked gas prices:

- US shale gas production
- Qatari LNG available in Europe
- Reduction in gas demand

→ new buyer/seller balance

Gas importers stayed bound by LTC at oil-linked prices incurring losses.

Renegotiation of LTC followed to introduce hub indexation.

Trends in newly signed contracts:

→ shorter duration period (10-15 years)

→ full hub indexation

Comparison Electricity – Gas

Electricity Market	Gas Market
Transmission system operator (TSO)	Transmission system operator (TSO)
Balance group coordinator	Market area coordinator (NCG, Gaspool)
Distribution system operator (DSO)	Regional and local system operators (DSO)
Control area BG per control area Balance Responsible Party (BRP)	Market area / Virtual trading point BG per market area Balance Responsible Party (BRP)
SLP and RLM customers	SLP and RLM customers
Symmetrical imbalance price	Positive and negative imbalance price

Outline

- Energy balances
- Economics fundamentals
- Financial management
- Electricity markets
- Emissions
- Resources and sustainability
- Oil and gas markets
- **Energy and Development**

Access to energy

Proximity and availability of modern energy sources

Electricity, natural gas, liquid petroleum gas, biogas, ethanol

Availability of efficient end-user applications

Cooking units, lighting, water pumps, food processing, energy-efficient housing and transport

Economy and security of supply

Access includes affordable and stable supply of clean energy, reliability of supply and quality

Energy poverty and energy access

Two main ways to look at the subject

- Energy poverty as the energy consumption habits of populations who are deemed poor by other measures, such as income

- Energy poverty is itself a form of deprivation, so that energy-poor populations are those that lack access to the energy required to meet their basic needs

  → Many populations must expose themselves to undue risks (such as risks from pollution) or hardships (such as having to walk long distances and expend significant amounts of time collecting fuelwood) in order to meet their basic energy needs

Energy poverty and energy access

→ Energy poverty as the energy usage habits of the poor

- People, no matter how poor, need some basic amount of energy to survive
- The extent to which poor people spend a greater portion of their income and time meeting their energy needs than do wealthy households, despite the fact that wealthy households tend to consume more energy overall
- accessing even the small amount of energy needed for survival can mean spending a greater proportion of their income on energy than the proportion spent by wealthy households that consume much more energy (often fuels and appliances are less efficient than those available to wealthy populations → spend more time and money
- Empirics: poor households spend somewhere between 5 and 20 percent of their income on meeting their energy needs
- Considered *energy poor* if spend more than 10% of income on energy needs

Energy poverty and energy access

→ Energy poverty as deprivation

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The experience of deprivation or exposure to undue risks or hardships

- The idea is that the availability of energy itself has no direct impact on human well-being
- When energy is able to provide services, such as heat for cooking or light for illumination, it can have a profound effect on human well-being
- It matters to provide people with the energy services required to meet their basic needs
- Focusing on energy services makes clear that definitions of energy poverty are both context specific and subjective (what are basic needs?) (Bhattacharyya, 2012)
- Energy poverty defined as deprivation of "the full range of energy supplies and services required to support human social and economic development ...[for]... households, enterprises and community service providers" (Practical Action, 2014, p. 2)

  → Thresholds pertain to illumination, thermal energy, cooling, refrigeration, and access to information and communications technology (risks & opt costs)

Energy poverty and energy access

→ Multi-tier matrix of energy access

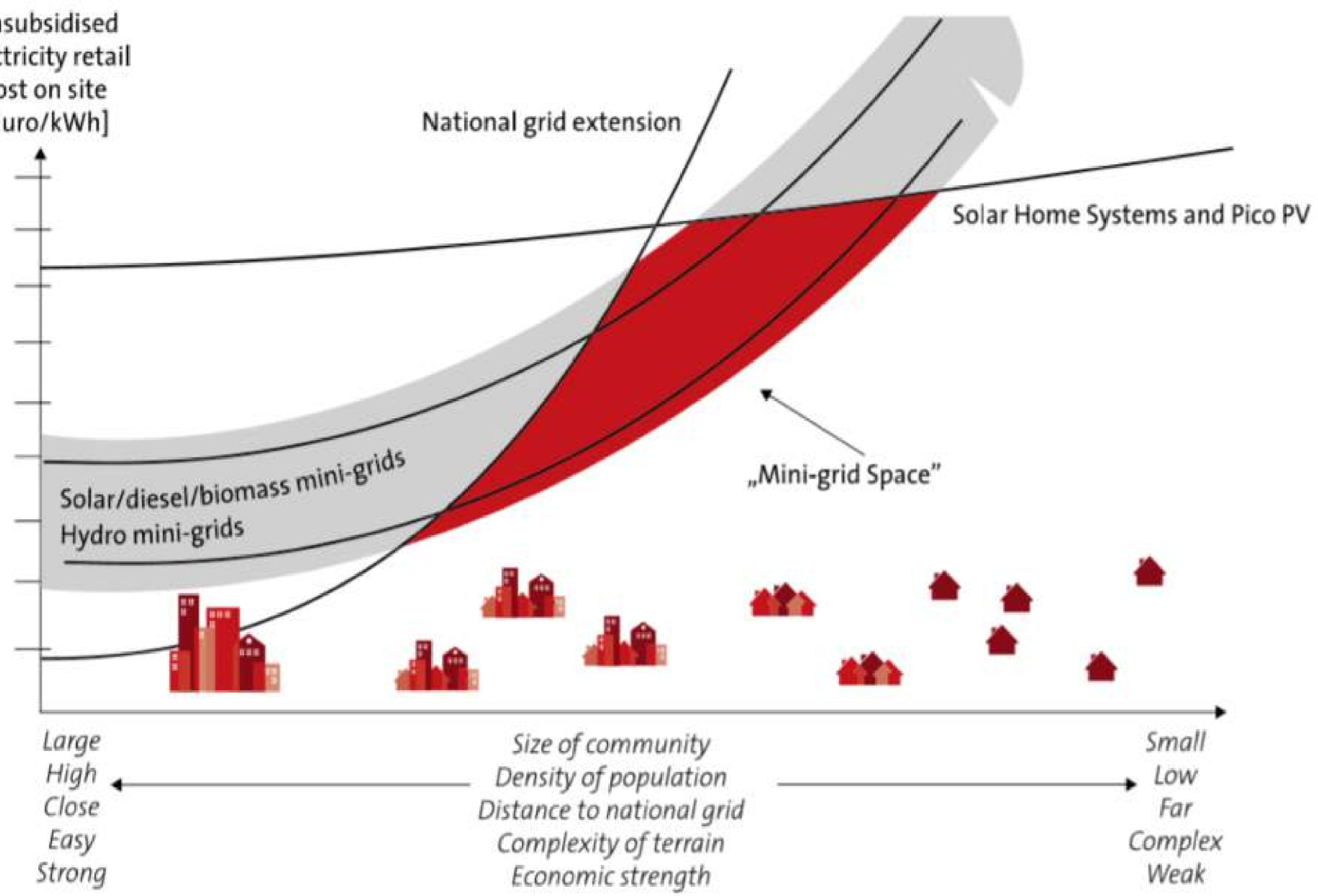
Attributes of energy supply		Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Capacity	Household electricity	No electricity[a]	Very low power	Low power	Medium power	High power	
	Household cooking	Inadequate capacity of the primary cooking solution				Adequate capacity of the primary cooking solution	
Duration and availability	Household electricity	<4 hours	4–8 hours		8–16 hours	16–22 hours	>22 hours
	Household cooking	Inadequate availability of the primary cooking solution				Adequate availability of the primary cooking solution	
Reliability	Household electricity	Unreliable energy supply				Reliable energy supply	
Quality	Household electricity/cooking	Poor quality of energy supply			Good quality of energy supply		
Affordability	Household electricity	Unaffordable energy supply		Affordable energy supply			
	Household cooking	Unaffordable energy supply				Affordable energy supply	
Legality	Household electricity	Illegal energy supply			Legal energy supply		
Convenience	Household cooking	Time and effort spent sourcing energy cause inconvenience			Time and effort spent sourcing energy do not cause inconvenience		
Health and safety	Household electricity	Unhealthy and unsafe energy system				Healthy and safe energy system	
	Household cooking[b]	Level 0	Level 1	Level 2	Level 3	Level 4	Level 5

It has been challenging to move the conversation beyond a simple focus on electrification as a means to address energy poverty, and the binary definitions of energy access this focus has created

Source: World Bank, Spalding-Fecher et. Al. 2015

Expanding access to electricity

- Grid vs. Mini-grid as small-scale electricity generation (10kW to 10MW) in isolation supplying relatively dense settlements with electricity at grid quality level



Source: Mini-Grid Policy Toolkit

Relative strengths and challenges
→ Four approaches

Expanding the grid	Success in providing electricity to populations around the word Advantage of economies of scale Large role for the state	Can sell electricity at low cost Can provide large quantities of electricity Essential for increasing overall penetration of renewables Known technology	Very expensive to build State bureaucracy and unresponsiveness Currently heavily reliant on fossil fuels
Mini-grid	Very limited economies of scale New technology Amenable to future reductions in price of solar and storage	Very large scope for renewables Can provide large quantities of electricity Lower capital costs Quick to deploy Some role for the private sector	Relatively expensive electricity Relatively high capital costs (for local investors) Requires resource-intensive, bespoke approaches to make electricity affordable Current lack of supply chains and relevant skilled personnel First-order challenges to new technology
SHSs	No economies of scale Amenable to future reductions in price of solar and storage	Large role for private sector 100% renewable Relatively established technology	Expensive electricity Limited quantities of electricity Novel challenges around system management
Solar appliances	No economies of scale	100% renewable Large role for the private sector Potential to drive rapid changes in household fuel use	Very limited quantities of electricity Very expensive electricity Difficult to exercise quality control over different appliances

Source: Oxfam research backgrounder on energy poverty and access