# Energy Economics

**Fachbereich 2** Informatik und Ingenieurwissenschaften

## Market turbulence

June 2019

- On 6, 12 and 25 June 2019 balancing energy was not sufficient
- uncertainties in the weather forecast on 6 and 12 June
- prices for electricity at the intraday market higher than prices for electricity at the balancing market

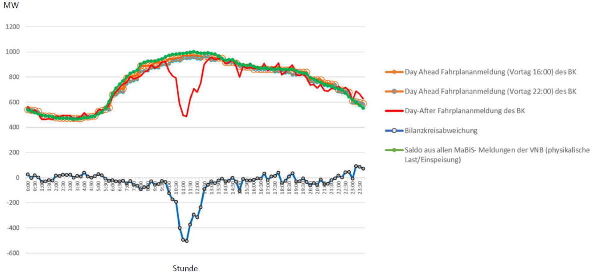


**Figure:** Deviation of electricity supply and demand in an exemplary balancing group; source: 50hertz, Amprion, Tennet, TransnetBW (2019), Investigation on system imbalances in June 2019.

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## Final changes in the auction design

- 22 July 2019: decision of the Higher Regional Court (OLG) Düsseldorf: "mixed bid auction" with constant weighting factor is unlawful

⇒ back to the 2017 system with price limit of 9,999.99 €

- 2 November 2020: placing a bid for balancing energy without successful capacity bid possible; price limit 99,999.99 €

⇒ hope: higher competition

- 16 December 2020: introduction of a price limit of 9,999.99 €

⇒ Legal action before the Higher Regional Court Düsseldorf

⇒ further integration into a European market...

# Exercise

- Calculate the weighting factor for 2019 for ten deciles and illustrate them.
- Assume a price of 77,777 €/MWh for the last decile:
  - Calculate the expectation value of the price using the weighting factor of the last decile.
  - Calculate the respective price for all deciles assuming the expectation value calculated in the previous task.

# Effect of design changes on the auction design

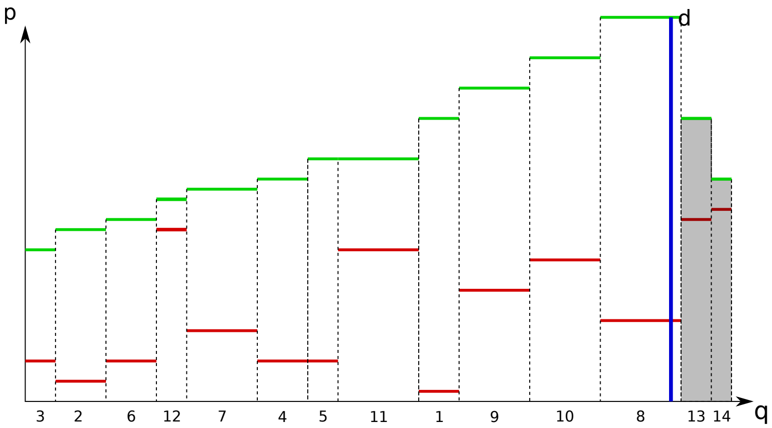



**Figure:** Schematic illustration of the merit order of bids for electricity delivery (green) in the balancing market with bids for capacity (red); own illustration.

# Effect of design changes on the auction design

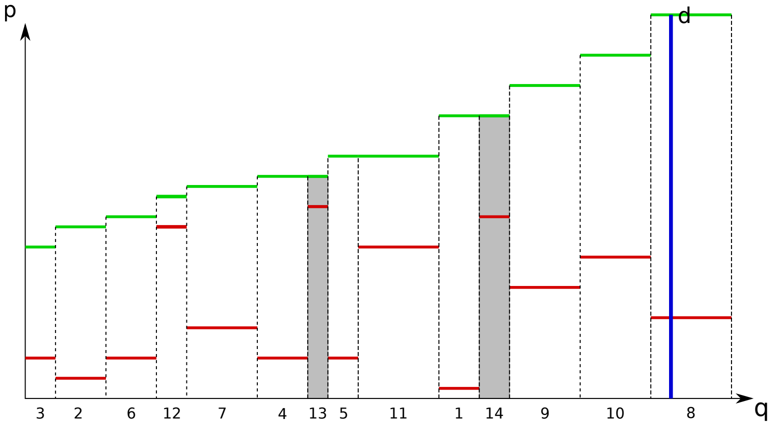



**Figure:** Schematic illustration of the changed merit order of bids for electricity delivery (green) in the balancing market with bids for capacity (red); own illustration.

# Electricity flow from aFRR and mFRR in Germany

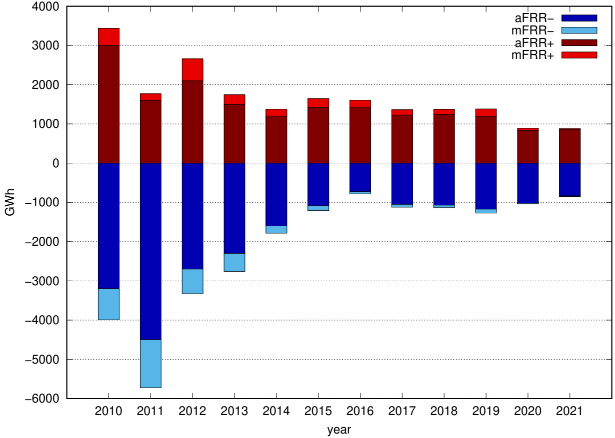



**Figure:** Development of the electricity flow from aFRR and mFRR in Germany between 2010 and 2021; own illustration based on www.smard.de, Bundesnetzagentur and Bundeskartellamt, Monitoringberichte 2012 – 2016.

# Outline

# Optimal consumption

- budget constraint $m = x_1 p_1 + x_2 p_2$
- utility function $u = f(x_1, x_2)$

$\rightarrow$ marginal utility (MU)

$$MU_1 := \frac{\partial u}{\partial x_1}$$

$$MU_2 := \frac{\partial u}{\partial x_2}$$

$\rightarrow$ marginal rate of substitution (MRS)

$$MRS_{1,2} := \frac{MU_1}{MU_2} = -\frac{\partial x_2}{\partial x_1}$$

# Optimal production

- cost function $C = x_1 w_1 + x_2 w_2$
- production function $y = f(x_1, x_2)$

→ marginal product (MP)

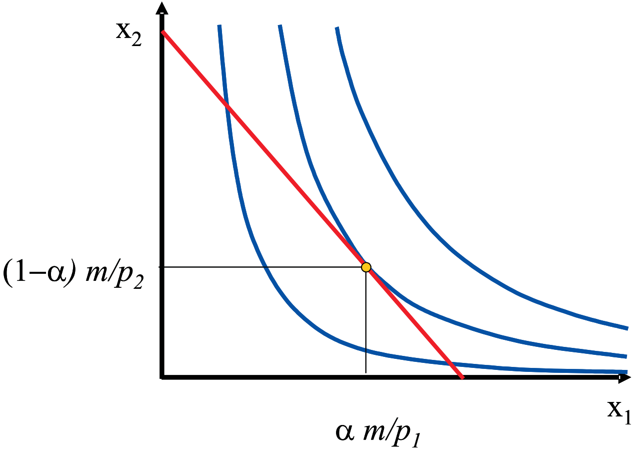
$$MP_1 := \frac{\partial y}{\partial x_1}$$

$$MP_2 := \frac{\partial y}{\partial x_2}$$

→ technical rate of substitution (TRS)

$$TRS_{1,2} := \frac{MP_1}{MP_2} = -\frac{\partial x_2}{\partial x_1}$$

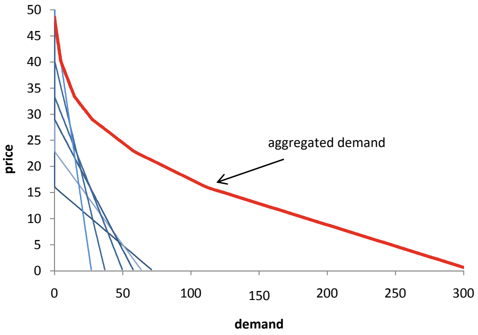
# Cobb-Douglas preferences



## Aggregated demand curve

The aggregated demand at a market, thus also called markt demand of n consumers is given by

$$X_1(p, m^1, \ldots, m^n) = \sum_{i=1}^{n} x_1^i(p_1, p_2, m^i)$$



# Price elasticity of demand

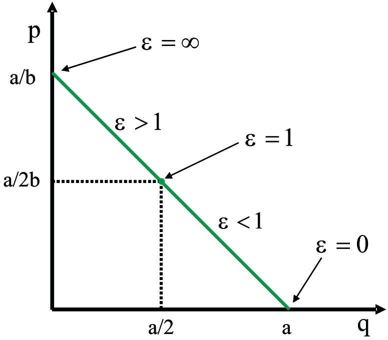
$$\varepsilon_p = \left| \frac{\text{% change of demand}}{\text{% change of prices}} \right| = - \frac{\Delta x / x}{\Delta p / p} = \frac{\Delta x}{\Delta p} \, \frac{p}{x}$$

or for a continuously differentiable demand function

$$\varepsilon_p = - \frac{d\,D(p)}{dp} \cdot \frac{p}{D(p)}$$

- Since the demand for normal goods decreases with increasing prices, the slope (respectively the derivative $d\,D(p)/dp$) is always negative. By definition this compensated by a minus.

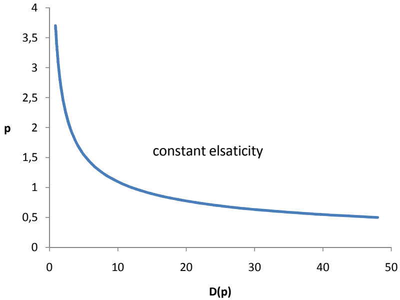
## Elasticity of demand along the price curve




The elasticity of demand changes along the demand curve although the slope is constant. It varies between $\varepsilon = 0$ (for $p = 0$) and $\varepsilon = \infty$ (for $D(p) = 0$).

## Constant elasticity of demand

Price elasticity along the following curve is constant.




$$D(p) = Ap^{-\epsilon}$$

- high price (low demand) is compensated by a small $D'(p)$.
- high value for $D'(p)$ compensates a low price with high demand.

## Economies of scale

The effect of a simultaneous increase of all input factors is measured by the so-called economies of scale

If all input factors are increased by a factor $t > 1$, we face

**constant economies of scale** if the output equals the original output multiplied with $t$, $f(tx_1, tx_2) = tf(x_1, x_2)$

**increasing economies of scale** if the output increases to more than the original output multiplied with $t$ $f(tx_1, tx_2) > tf(x_1, x_2)$

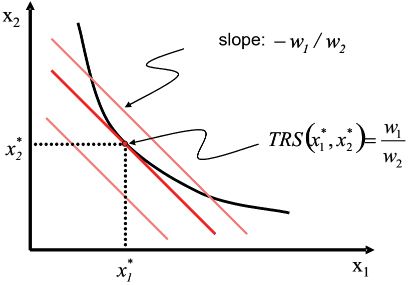
**decreasing economies os scale** if the output increases to less than the original output multiplied with $t$ $f(tx_1, tx_2) < tf(x_1, x_2)$

# Minimizing costs

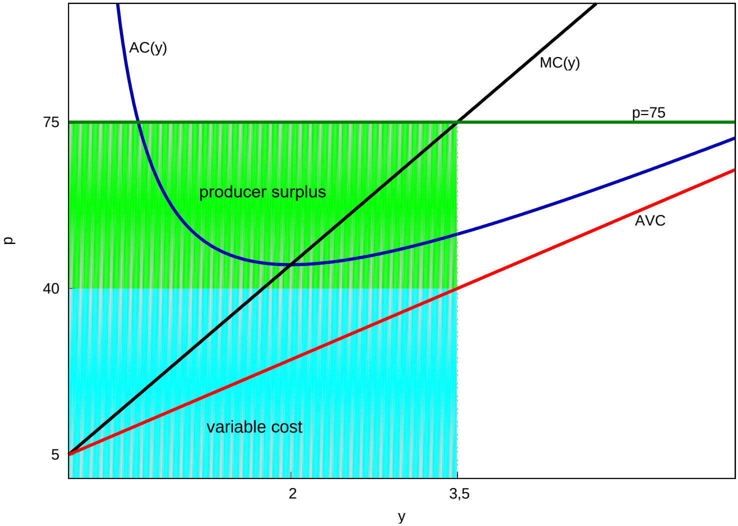
**optimum condition of minimal cost**

For a given output level we are searching for the lowest cost level
$\rightarrow$ tangent point of isocost line and production isoquant

$$TRS(x_1^*, x_2^*) = \frac{w_1}{w_2} = \frac{MP_1(x_1^*, x_2^*)}{MP_2(x_1^*, x_2^*)}$$



# Cost, profit, producer surplus



# Supply of a company

**profit maximization by quantity management**

For a company acting as price taker (**perfect competition**) we find the following objective function

$$\max_{y} \Pi = p\,y - C(y)$$

$\rightarrow$ decisive variable: output $y$

- first order condition (FOC) for profit maximization

$$\frac{\partial \Pi(y)}{\partial y} = 0 \quad \hookrightarrow \quad p - \frac{\partial C(y)}{\partial y} = 0 \quad \hookrightarrow \quad p = MC$$

# Supply of a company

**profit maximization by quantity management**

For a company acting as **monopolist** we find the following objective function

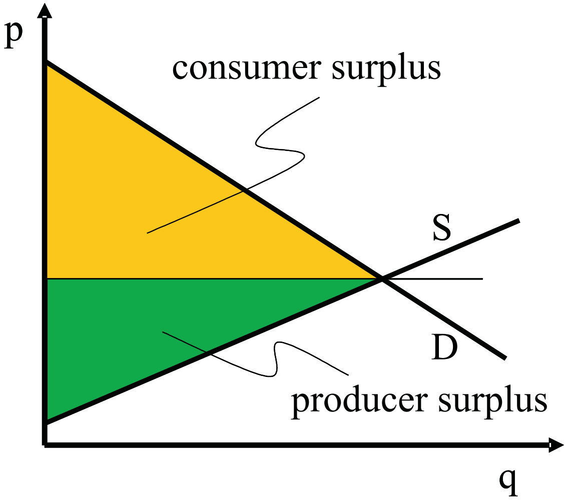
$$\max_y \Pi = p(y)\,y - C(y)$$

$\rightarrow$ decisive variable: output $y$

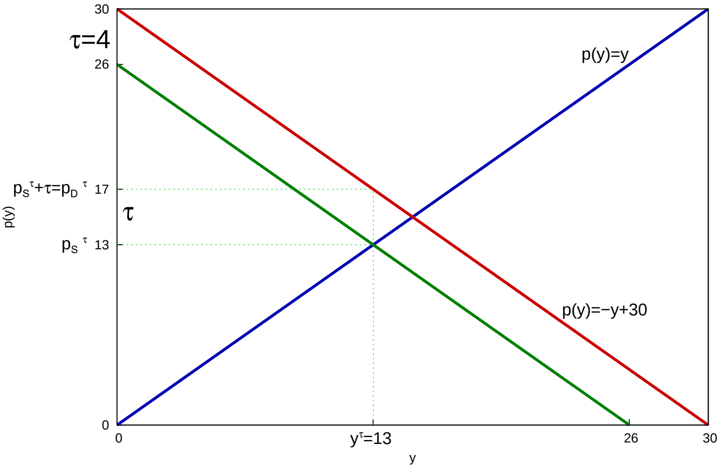
- first order condition (FOC) for profit maximization

$$\frac{\partial \Pi(y)}{\partial y} = 0 \quad \hookrightarrow \quad \frac{\partial p(y)}{\partial y} + p(y) = \frac{\partial C(y)}{\partial y} \quad \hookrightarrow \quad MR = MC$$

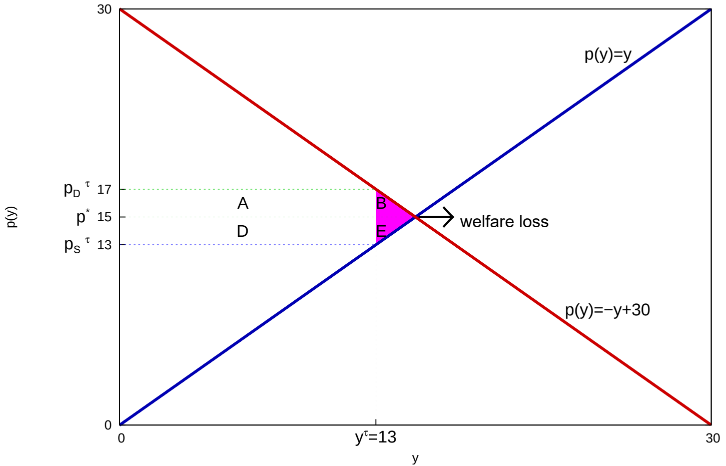
# Welfare



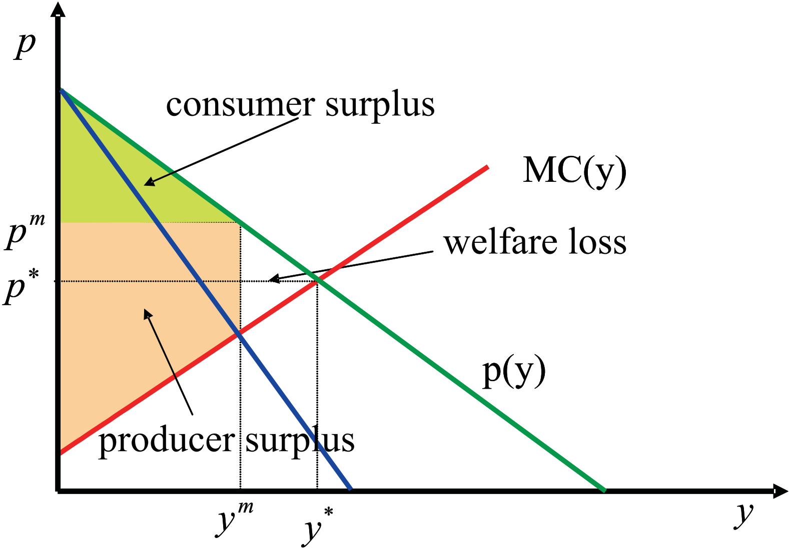
# Equilibrium and taxes



## Taxes and welfare



# Inefficiency of a monopoly



## Gas price cap – calculations

- insert the known prices of 50 and 300 €/MWh into the demand function

$$950 = A50^{\epsilon}$$

$$710 = A300^{\epsilon}$$

- division of first equation by the second yields

$$\frac{950}{710} = \frac{50^{\epsilon}}{300^{\epsilon}}$$

$\Leftrightarrow$

$$\ln\left(\frac{950}{710}\right) = \epsilon \ln\left(\frac{50}{300}\right) \Leftrightarrow \epsilon \approx 0.1625$$

# Main result of the paper

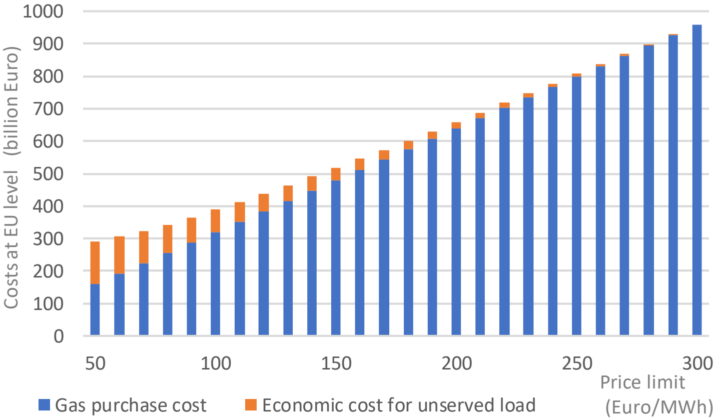



**Figure:** Cost to EU consumers after a supply interruption of Russian gas; source: Neuhoff (2022).

# Development of gas prices


**Figure:** Price evolution for TTF gas from January 1, 2022 until January 6, 2023; source: tradingeconomics.com (2023).

# Electricity generation in Germany

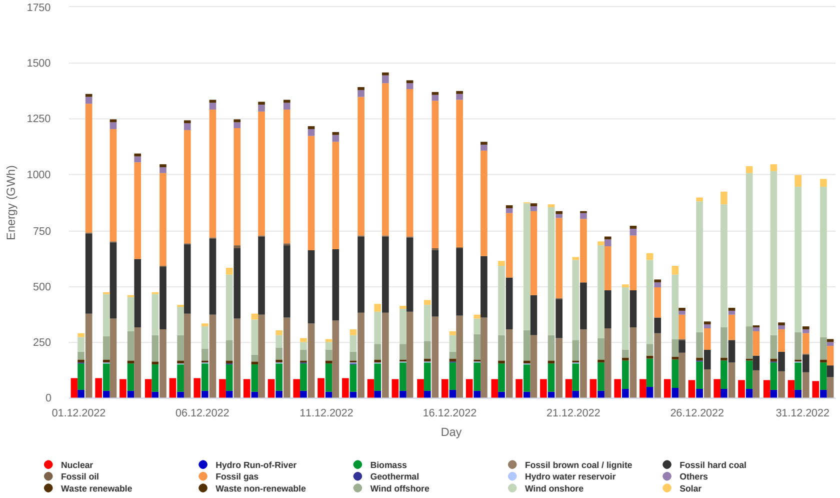



**Figure:** Total net electricity generation in Germany in December 2022 (energetically corrected values); source: Energy-Charts (2023).

## Oil price cap game revisited

Impact on payouts in a more general form

| | | **Russia** | |
|---|---|---|---|
| | | not accept | accept |
| **EU+G7+Australia** | draw back | (<-d?; 0) | (–; –) |
| | hold out | (-d>-c; -c<-b) | (a; -b) |

with $c > b$ and $c > d$
payoffs Π: $(\Pi_{EU+G7+Australia};\Pi_{Russia})$

⇒ Minister for foreign affairs of Estonia demands a reduction of a cap on January 5, 2023

# Development of price ratio

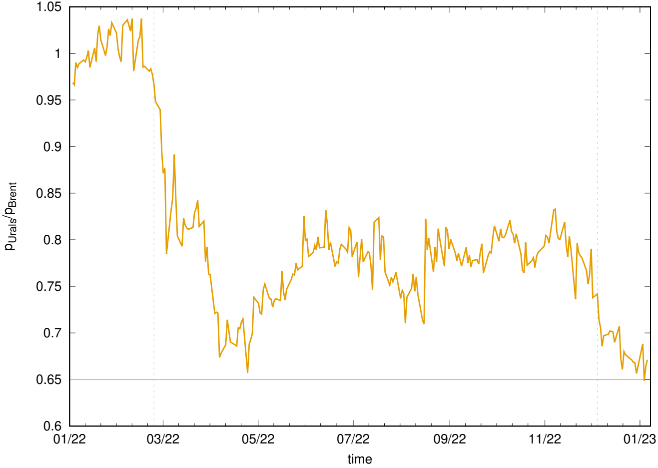



**Figure:** Evolution of the ratio of spot prices for Urals and Brent Crude Oil from January 1, 2022 until January 6, 2023; own illustration using data from investing.com (2023).

# Model system with different power plants

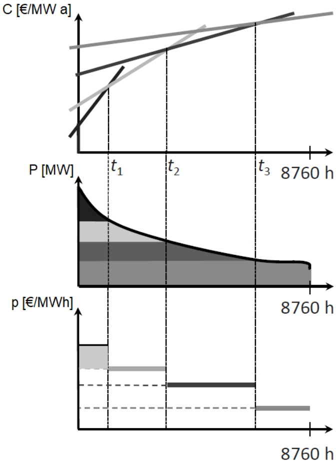



**Figure:** Model system with an optimal power plant mix resulting from total costs; taken with adjustments from Schwintowski *et al.* (2021).

# Spot market

- day ahead (auction), intraday (continuously)
- price range -1000 € – 3000 €

| hour\price | 0 | 6,9 | 7 | 16,9 | 17 | 17,1 | 17,2 | 149,9 | 150 | 3000 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 200,0 | 200,0 | 100,0 | 100,0 | 0,0 | -75,0 | -75,0 | -75,0 | -275,0 | -275,0 |
| 2 | 154,9 | 154,9 | 42,6 | 42,6 | 6,3 | 6,3 | 0,0 | 0,0 | -20,0 | -20,0 |
| 3 | -57,0 | -57,0 | -100,0 | -100,0 | -100,0 | -175,0 | -175,0 | -175,0 | -325,0 | -325,0 |
| 4 | 200,0 | | | | | | | | | 200,0 |

**Figure:** Exemplary bid at the day ahead market skipping negative prices; taken with adjustments from Schwintowski *et al.* (2021).

## Electricity market equilibrium

Assume a perfect electricity market

- optimal power plant mix
- scarcity pricing exactly covers fixed cost of all power plant operators

$\Rightarrow$ equilibrium

Now demand increases by 10 % (shifting the load curve)

- scarcity rent (also called peak energy rent – PER) increases
- revenue for **all** power plant operators increases to the same extent since all power plants are running in an event of scarcity

$\Rightarrow$ a profit occurs

$\Rightarrow$ incentive for investments into all types of power plants

## Electricity market equilibrium

Now demand increases by another 1 GW every hour

- scarcity rent increases more
- revenue for **all** power plant operators increases since all power plants are running in an event of scarcity

$\Rightarrow$ a higher profit occurs for base-load power plants

$\Rightarrow$ investments are incentivized particularly for base-load power plants

# Example for a futures contract

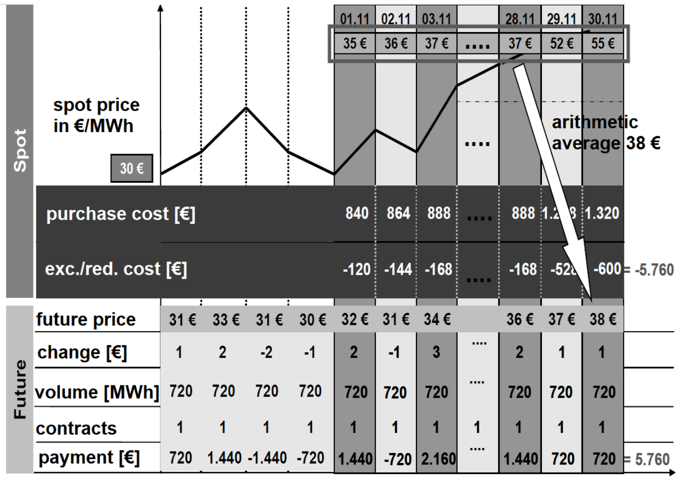



**Figure:** future and spot market results for the can manufacturer; taken with adjustments from Schwintowski *et al.* (2021).

# Electricity supply and futures markets

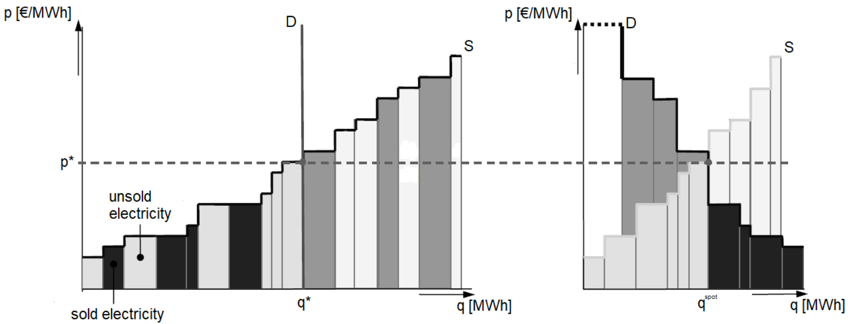



**Figure:** Schematic illustration for the impact of the future market on the spot market for electricity; taken with adjustments from Schwintowski *et al.* (2021).

# Multi unit bidders

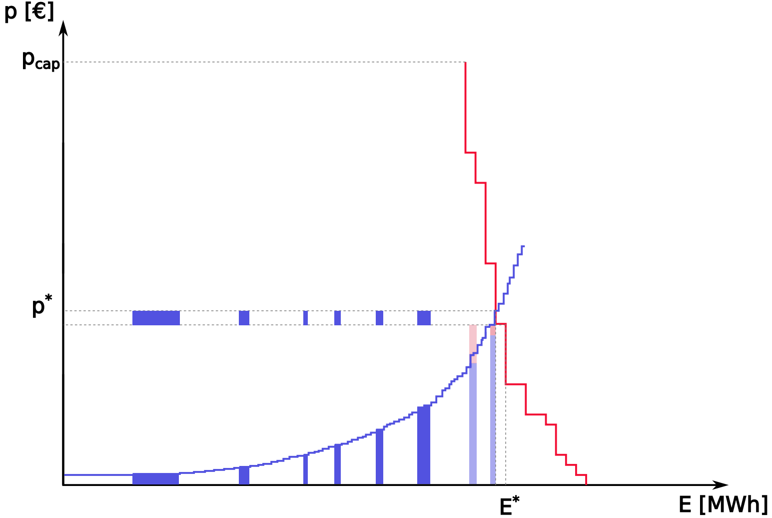



**Figure:** Schematic illustration of the merit order after capacity of two power plants is withdrawn.

# Merit order effect of RES

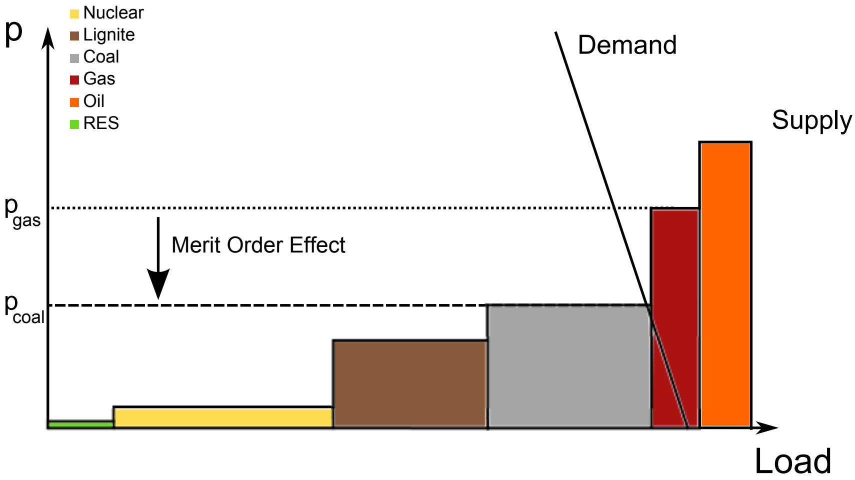



**Figure:** Schematic illustration of the merit order effect of RES as described by De Miera *et al.* (2008); Sensfuß *et al.* (2008); own illustration.

# The missing money problem

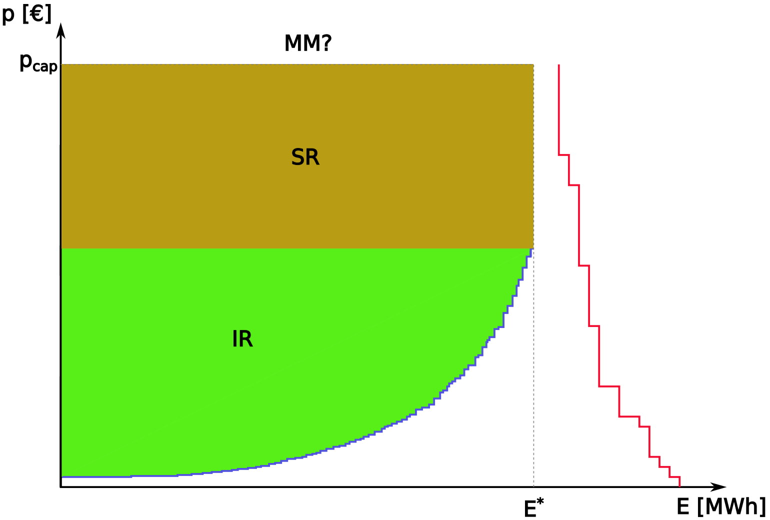



**Figure:** Schematic illustration of the merit with price cap and potential missing money (MM).

## Capacity market equations

- rational equilibrium price assuming truthful bidding

$$p_t^* = p_t(\sum_{i=1}^{m} C_{t,i}) = k_{t,m} + X^e_{PER,t,m} PER^e_t - (1 - X^e_{IR,t,m}) IR^e_{t,m} + \varrho^e_{t,m}$$

- the annual capital decrease equals the revenue of the power plant including MM, if occurring

$$k_{t,i} = (1 - X^e_{IR,t,i}) IR^e_{t,i} + (1 - X^e_{PER,t,i}) PER^e_t + (1 - X^e_{PER,t,i}) MM^e_t$$

- as penalty and penalty factor we receive

$$\varrho^e_{t,i} = X^e_{PER,t,i} MM^e_t \Rightarrow \xi_t := \frac{p_t^*}{PER^e_t}$$

## Capacity market equilibrium

- difference between price bids of power plants $i$ and $j$

$$
\begin{aligned}
\Delta p_{t,j-i} := {} & p_{t,j} - p_{t,i} \\
= {} & \Delta k_{t,j-i} + \Delta X^e_{PER,t} PER^e_t + \Delta \varrho^e_t + (1 - X^e_{IR,t,i}) IR^e_{t,i} - (1 - X^e_{IR,t,j}) IR^e_{t,j} \\
= {} & \Delta \varrho^e_t - \Delta X^e_{PER,t} MM^e_t \\
= {} & 0.
\end{aligned}
$$

$\Rightarrow$ zero arbitrage principle

$\Rightarrow$ in the equilibrium all bids at the capacity market are identical!

## Merit order effect and capacity market

- the impact of an increasing share of RES on residual fossil capacity can be described by

$$\frac{\partial \Delta p_{t,base-peak}}{\partial \varphi_t} = \overbrace{(p_{cap} - p_{strike})\frac{\partial d^e_{spike,t}}{\partial \varphi_t}}^{\frac{\partial PER^e_t}{\partial \varphi_t}} \Delta X^e_{PER,t} + \frac{\partial MM^e_t}{\partial \varphi_t} \Delta X^e_{PER,t}$$
$$- \Delta C^e_t (1 - X^e_{IR,t,base}) \frac{\partial d^e_{t,base}}{\partial \varphi_t}$$
$$> 0.$$

⇒ for an increasing share of RES we find a **comparative advantage for peak-load power plants** at the capacity market.

⇒ the capacity market **opposes the disadvantage for peak-load power plants** at the energy-only market

## Path dependency of the optimal power plant mix

thought experiment with two scenarios

- the share of RES-based electricity generation **increases over time** to the share $\varphi$

$\Rightarrow$ certain age distribution of residual fossil power plants

- the share of RES-based electricity generation **directly increases** to the share $\varphi$ (static one-shot framework)

$\Rightarrow$ residual fossil power plants are all of the same age

$\Rightarrow$ in scenario 2 the capacity mix is a best response to the share $\varphi$ of RES-based electricity generation

$\Rightarrow$ in scenario 1 the age distribution with comparative advantages for older power plants prevents an optimal capacity mix

$\Rightarrow$ In a transition process (to RES-based electricity generation), the advantage of already existing old power plants produces a **“delayed” transformation** of the capacity mix!

# References


De Miera, G. S., del Rio Gonzalez, P. and Vizcaino, I. (2008). Analysing the impact of renewable electricity support schemes on power prices: The case of wind electricity in Spain. *Energy Policy*, **36** (9), 3345–3359.

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