Energy Economics

Fachbereich 2 Informatik und Ingenieurwissenschaften

Revisiting the merit order effect of RES

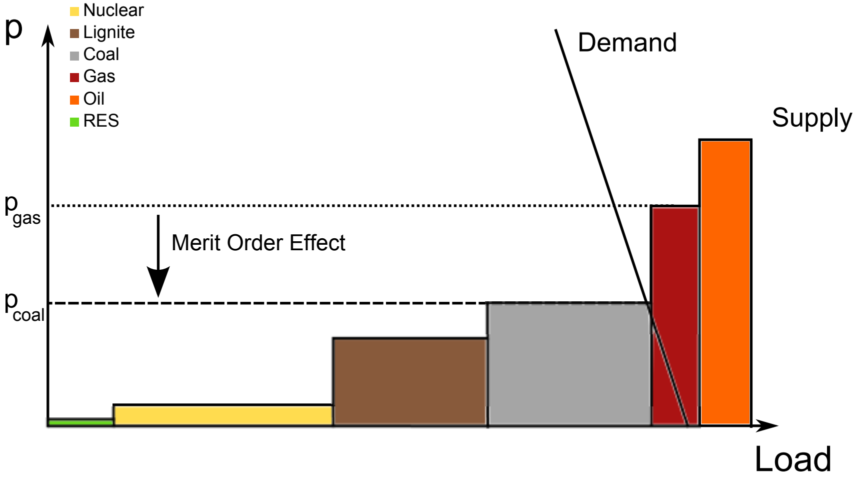

Figure: Schematic illustration of the merit order effect of RES as described by De Miera *et al.* (2008); Sensfuß *et al.* (2008); own illustration.

Impact of RES – exercise

capital costs peak-load	$k_{t,peak}$	490,000 €/MW
failure rate peak-load	$X^e_{PER,t,peak}$	0.02
capital costs base-load	k_{base}	871,000 €/MW
failure rate base-load	$X^e_{IR,t,base}$	0.035
	$X^e_{PER,t,base}$	0.03
$\mathrm{IR}^e_{t,base}$	$(p_{strike} - C_{G,t,base} - C_{E,t,base})d_{t,base}$	250,000 €/MW
PER^e_t	$(p_{cap} - p_{strike})d^e_{spike,t}$	400,000 €/MW

The expected potential PER decreases less than the expected potential IR in this example as empirical data suggest (Nicolosi and Fürsch, 2009).

Calculating the penalties – solution

- the penalty factor will be calculated by the regulator on behalf of the clearing price

$$\xi = \frac{500{,}000 + \frac{X}{1 - X^e_{PER,t,peak}}}{400{,}000} = 1.25 + \frac{X}{392{,}000}$$

$$\begin{aligned}
\varrho^e_{t,base} &= ((1.25 + X/392{,}000) \cdot 400{,}000 \text{ €/MW} - 400{,}000 \text{ €/MW}) \cdot 0.03 \\
&= 3{,}000 + \frac{0.03}{0.98} X \text{ €/MW}.
\end{aligned}$$

$$\begin{aligned}
\varrho^e_{t,peak} &= ((1.25 + X/392{,}000) \cdot 400{,}000 \text{ €/MW} - 400{,}000 \text{ €/MW}) \cdot 0.02 \\
&= 2{,}000 + \frac{0.02}{0.98} X \text{ €/MW}.
\end{aligned}$$

New capacity – exercise

- Calculate the price bids of
  a) existing base-load power plants
  b) existing peak-load power plants
  c) new peak-load power plants
- What is the market price p^* all participants receive if existing capacity is not sufficient?
- Compare expected consumer expenses with ξ_c^e and without ξ_{eo}^e capacity market for the already existing power plants. Assume ρ_{peak}/ρ_{base} as average full load hours per capacity unit of a peak-load/base-load power plant.
- Calculate capital cost coverage with and without capacity market.

Comparing payments with and without capacity market

- Without a capacity market we find for the already existing power plants spot market revenues equal to

$$R^e_{t,peak} = PER^e_t(1 - X^e_{PER,t,peak}) = 392{,}000 \text{ €}/\mathrm{MW},$$
$$R^e_{t,base} = PER^e_t(1 - X^e_{PER,t,base}) + IR^e_t(1 - X^e_{IR,t,base}) = 629{,}250 \text{ €}/\mathrm{MW}$$

- expected consumers' expenses without a capacity market for the already existing power plants are

$$\xi^e_{eo} = 629{,}250\rho_{base}\underline{C}_t \text{ €}/\mathrm{MW} + 392{,}000\rho_{peak}\underline{C}_t \text{ €}/\mathrm{MW}.$$

Comparing payments with and without capacity market

- With capacity market we find $p^* = 500{,}000 + \frac{X}{0.98}$ which allows to calculate missing money MM

$$MM = p^* - PER = 100{,}000 \text{ €/MW} + \frac{X}{0.98} \text{ €/MW},$$

- expected consumers' expenses in a capacity market for the already existing power plants are

$$\xi_c^e = \left(726{,}250 + \frac{1 - X^e_{PER,t,base}}{1 - X^e_{PER,t,peak}} X \right) \rho_{base} \underline{C}_t \text{ €/MW} \\ + (490{,}000 + X)\, \rho_{peak} \underline{C}_t \text{ €/MW}.$$

Comparing payments with and without capacity market

- Subtracting capital costs from these expenses provides information about capital cost coverage of the already existing power plants leading to

$$
\begin{aligned}
&\xi_c^e - \rho_{t,base}\underline{C}_t \cdot k_{t,base} - \rho_{t,peak}\underline{C}_t \cdot k_{t,peak} \\
&= \underbrace{X\rho_{t,peak}\underline{C}_t}_{\geq 0} \text{ €/MW} \\
&\underbrace{-(144,750 - \left(\frac{1 - X^e_{PER,t,base}}{1 - X^e_{PER,t,peak}}\right)X)\rho_{t,base}\underline{C}_t}_{<0} \text{ €/MW}.
\end{aligned}
$$

⇒ additional payments to peak-load power plants are limited to the “age effect”

⇒ base-load power plants will not be able to cover capital cost if the “age effect” is smaller than the cost difference between peak-load and base-load pwer plants (reasonable assumption)

Summary

properties of a capacity market

- risk reduction by replacement of PER by an annual payment
- solution of the MM problem
- in a perfect capacity market there are no additional cost for electricity consumers in times of overcapacity
- opposes the disadvantage of peak-load power plants induced by the merit order effect of RES by comparative advantages with an increasing share of RES

For further information about capacity markets you may read Vázquez *et al.* (2002) for the first paper dealing with a capacity market with reliability options, Hobbs *et al.* (2001); Cramton *et al.* (2013) for an overview and Schäfer and Altvater (2019) for the analytic assessment used in the lecture.

Three days in June 2019

- Do you remember what you did in June 2019?
- On three days in June, 6th, 12th and 25th **unexpectedly** there was not enough electricity in the German electricity system to satisfy

$\rightarrow$ electricity from other European countries was requested

$\rightarrow$ emergency plan to keep the system stable

$\rightarrow$ keeping the system stable

$\Rightarrow$ ancillary services

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System stability of electricity supply

- voltage stability

→ compensation of transmission losses, reactive power

- frequency stability

→ balancing energy

- congestion management

→ redispatch, interruptible load, reserve capacity

- reconstruction of electricity supply

→ black start capability

Figure: Destroyed power lines in winter 2005; photo: Jürgen Peperhowe

Frequency stability

- every supplier with more than 100,000 clients has two obligations

1. forecast your clients' electricity demand for time slices of 15 minutes for the next day until 2 pm
2. guarantee that this demand is always covered by a respective supply

$\Rightarrow$ a wrong forecast might be partially balanced by other wrong forecasts

$\Rightarrow$ the rest is balanced by the TSO who is responsible to contract balancing energy

Balancing energy in Germany

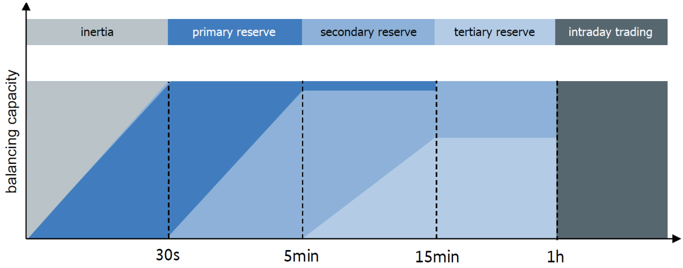

Figure: Schematic illustration of the different types of balancing energy used in the German electricity system; source: translation from Bundesnetzagentur and Bundeskartellamt (2021), Monitoringbericht 2021.

- Primary reserve $\widehat{=}$ Frequency Containment Reserve (FCR)
- Secondary reserve $\widehat{=}$ Automatic Frequency Restoration Reserve (aFRR)
- Tertiary reserve $\widehat{=}$ Manual Frequency Restoration Reserve (mFRR)

Development of German electricity generation

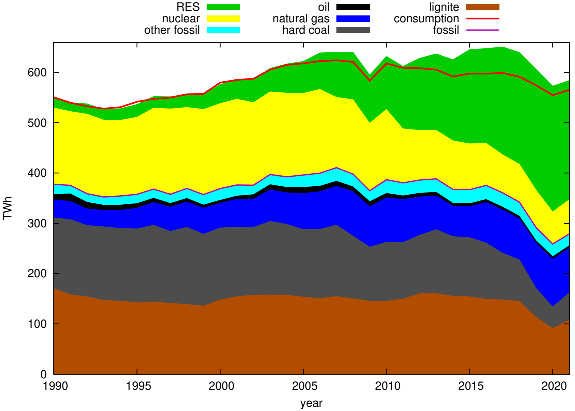

Figure: Stacked area chart illustrating the development of gross electricity output with respect to different energy sources in Germany between 1990 and 2021. The difference between gross electricity generation and gross electricity consumption (red line in the graph) corresponds to electricity exports; own illustration based on data provided by Working Group on Energy Balances (2018), Information Platform of the German Transmission System Operators (2018)

Electricity flow from aFRR and mFRR in Germany

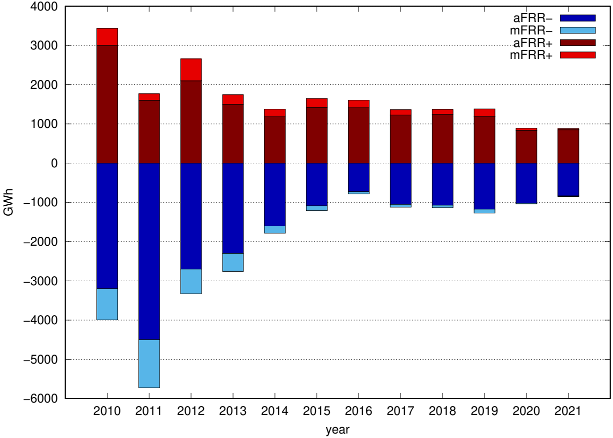

Figure: Development of the electricity flow from aFRR and mFRR in Germany between 2010 and 2021; own illustration based on www.smard.de, Bundesnetzagentur and Bundeskartellamt, Monitoringberichte 2012 – 2016.

Auction design for aFRR in Germany

Auction design 2011 – 2017

- weekly auctions
- two time slices: Mon-Fri, 8 am - 8 pm; rest
- bidders place bids for balancing capacity (€/MW) and delivery/consumption of electricity (€/MWh)
- bidders with lowest capacity bids are successful
- electricity flow is called in an ascending price-order from successful capacity-bidders

Illustration of the auction design for aFRR and mFRR

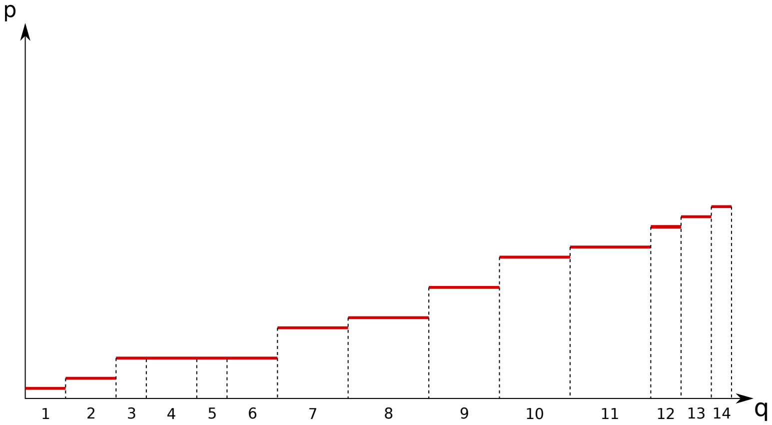

Figure: Schematic illustration of the merit order of capacity bids in the balancing market; own illustration.

Illustration of the auction design for aFRR and mFRR

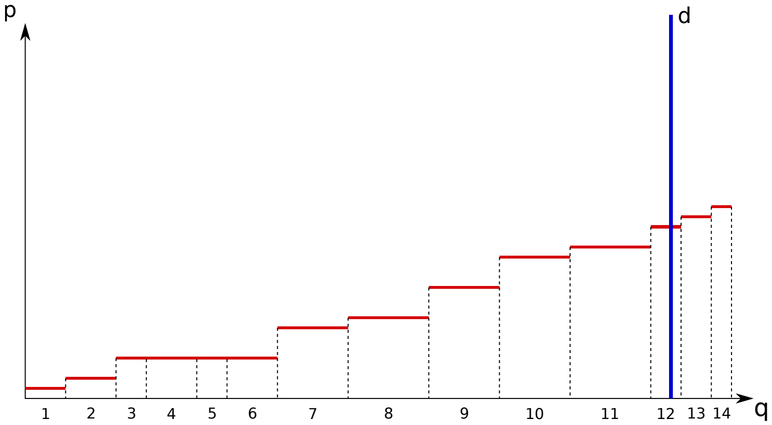

Figure: Schematic illustration of the merit order of capacity bids in the balancing market; own illustration.

Illustration of the auction design for aFRR and mFRR

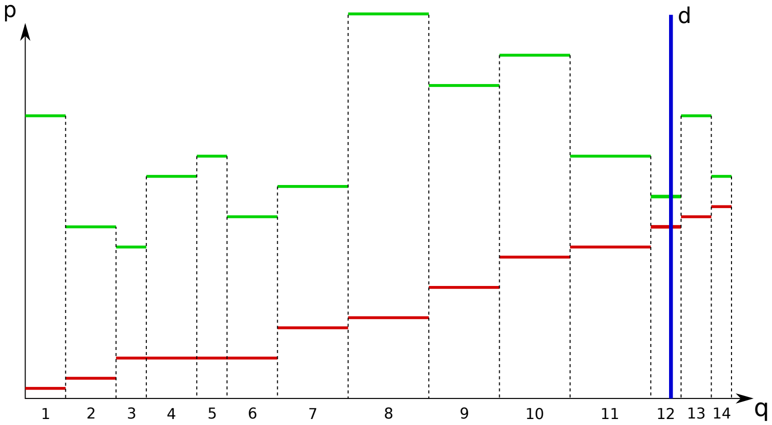

Figure: Schematic illustration of the merit order of capacity bids (red) in the balancing market with bids for electricity delivery (green); own illustration.

Illustration of the auction design for aFRR and mFRR

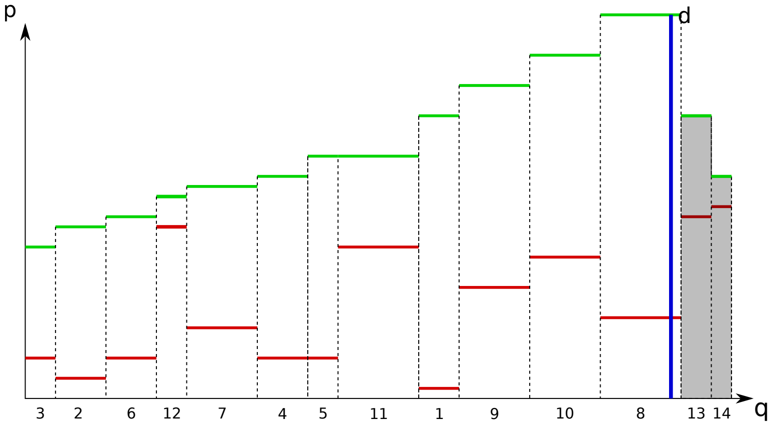

Figure: Schematic illustration of the merit order of bids for electricity delivery (green) in the balancing market with bids for capacity (red); own illustration.

Auction design update

Design change from 13 June 2017

- daily auctions
- six time slices per day
- bidders place bids for balancing capacity (€/MW) and delivery/consumption of electricity (€/MWh)
- bidders with lowest capacity bids are successful
- lowest bids for electricity from successful bidders are used

⇒ reduction of entry barriers for RES and small power plants

⇒ increasing competition

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Price cap and further design change

17 October 2017

- successful bid with 77,777 €/MWh for electricity delivery
- Positive balancing energy reached almost 25,000 € between 7.15 pm and 7.45 pm

⇒ price cap 9,999.99 € introduced on 2 January 2018

⇒ introduction of a "mixed bid auction" on 12 July 2018

$$p_{bid} = p_{cap.} + \rho \cdot p_{flow}$$

→ ρ is a weighting factor calculated by the ratio of delivered/consumed electricity and requested capacity

Illustration of the auction design for aFRR and mFRR

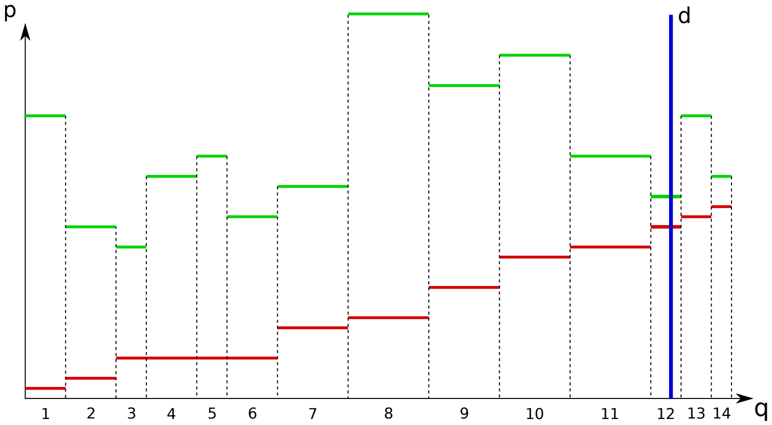

Figure: Schematic illustration of the merit order of capacity bids (red) in the balancing market with bids for electricity delivery (green); own illustration.

Exercise

- Calculate the weighting factor for 2019.

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

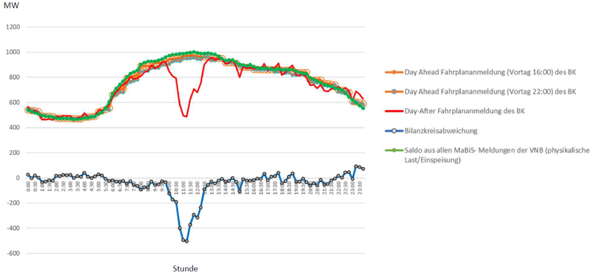

Figure: Deviation of electricity supply and demand in an exemplary balancing group; source: 50hertz, Amprion, Tennet, TransnetBW (2019), Investigation on system imbalances in June 2019.

References

Cramton, P., Ockenfels, A. and Stoft, S. (2013). Capacity market fundamentals. *Economics of Energy & Environmental Policy*, **2**, 27–46.

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.

Hobbs, B. F., Iñón, J. and Stoft, S. E. (2001). Installed capacity requirements and price caps: Oil on the water, or fuel on the fire? *The Electricity Journal*, **14**, 23–34.

Information Platform of the German Transmission System Operators (Informationsplattform der deutschen Übertragungsnetzbetreiber – netztransparenz.de) (2018). EEG-Jahresabrechnungen. Available at: `https://www.netztransparenz.de/EEG/Jahresabrechnungen`, accessed April 1, 2018.

Nicolosi, M. and Fürsch, M. (2009). The impact of an increasing share of RES-E on the conventional power market–the example of Germany. *Zeitschrift für Energiewirtschaft*, **3**.

Schäfer, S. and Altvater, L. (2019). On the functioning of a capacity market with an increasing share of renewable energy. *Journal of Regulatory Economics*, **56**, 59–84.

Sensfuss, F., Ragwitz, M. and Genoese, M. (2008). The merit-order effect: A detailed analysis of the price effect of renewable electricity generation on spot market prices in Germany. *Energy Policy*, **36** (8).

Vázquez, C., Rivier, M. and Pérez-Arriaga, I. J. (2002). A market approach to long-term security of supply. *IEEE Transactions on Power Systems*, **17** (2), 349–357.

Working Group on Energy Balances (Arbeitsgemeinschaft Energiebilanzen e.V) (2018). Bruttostromerzeugung in Deutschland ab 1990 nach Energieträgern. Available at: `https://ag-energiebilanzen.de/index.php?article_id=29&fileName=20171221_brd_stromerzeugung1990-2017.xlsx`, accessed September 4, 2018.