A parsimonious model for the complex German electricity system – what lessons to be learnt

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Motivation

- Fundamental electricity system and market models have been in use for more than a decade
- Models include increasing number of details
  - All European Countries
  - Multiple generation technologies (thermal, hydro, renewables, CHP…)
  - (partly) unit-wise modelling
  - Operation restrictions and costs (minimum operation times, start-up cost…)
  - Multiple markets (spot, several reserve qualities, …)
- ➢ Huge data needs
- ➢ Limited transparency on impact of data on results
- ➢ Backtesting model quality gets cumbersome

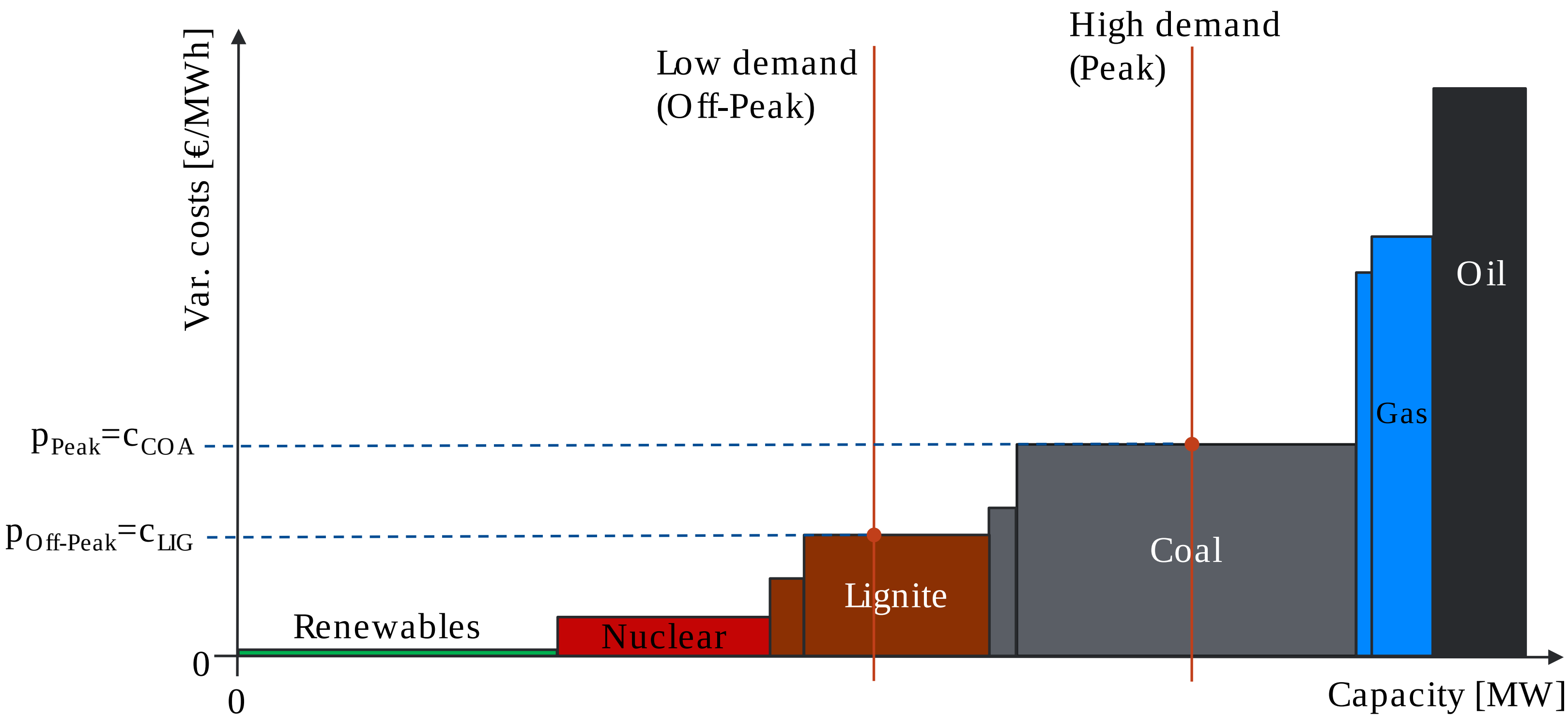
- ➢ Use of a parsimonious model?

Agenda

General approach

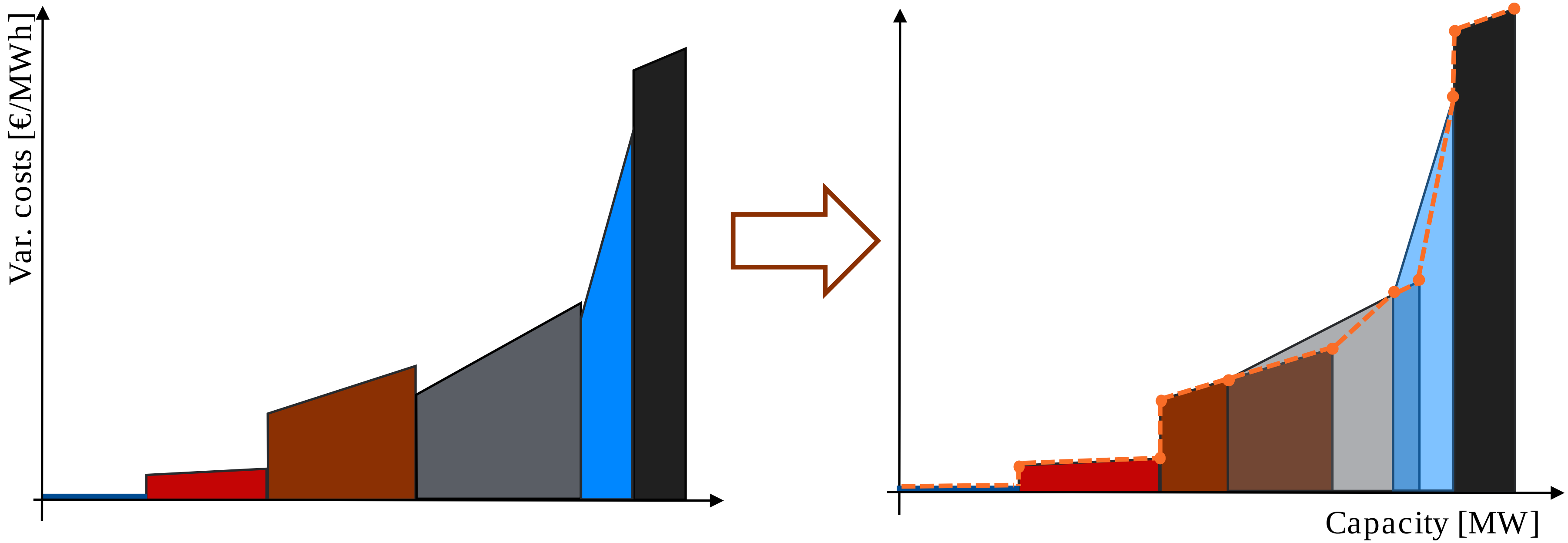
- Starting point:
  „"Merit order" (supply-stack) model
- Approximations for
  - Varying power plant efficiencies
  - CHP power plants
  - Hydro pump storage plants
- Detailed data on:
  - Load
  - Renewable infeed
  - Capacities
  - Imports & Exports
  - Availabilities

Parsimonious fundamental model



- "Merit order" model
- Price results from the intersection of the supply and demand curve
- To reflect the actual situation better we adjust supply and demand side

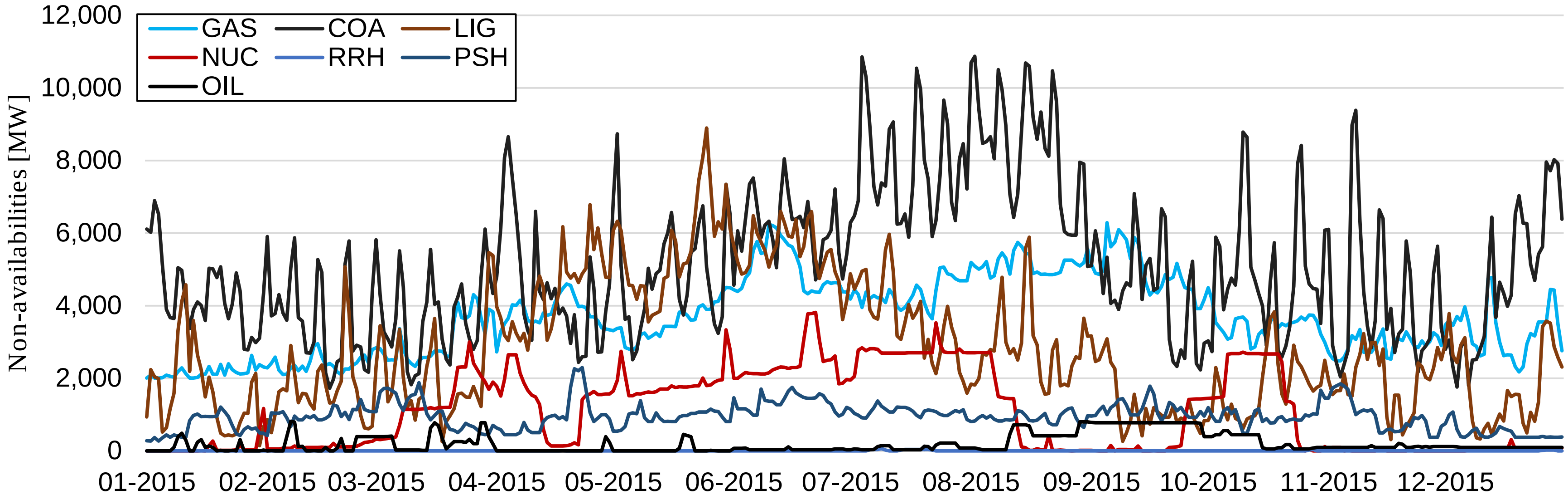
Supply side: piecewise linear supply stack



- We consider heterogeneity of technology classes by estimates on minimum and maximum efficiency resulting in intervals of ascending costs.
- Piecewise linear supply stack with mixed capacity intervals

Supply side: power plant availabilities

2 Parsimonious Model



- Power plant non-availabilities
  - Scheduled: $Unav_{pl,t}^{sched}$
  - Unscheduled: $Unav_{pl,t}^{unsched}$
  - Installed capacity: $Cap_{pl,t}$
- Availability factor
  - $Av_{pl,t} = 1 - \frac{Unav_{pl,t}^{sched} + Unav_{pl,t}^{unsched}}{Cap_{pl,t}}$
  - $AvCap_{pl,t} = Av_{pl,t} \cdot Cap_{pl,t}$
  - $AvCap_{pl,t}^{CHP} = Av_{pl,t} \cdot Cap_{pl,t}^{CHP} - CHP_{pl,t}^{MustRun}$

Demand – residual load

- Residual load

  $D_t = L_t - W_t - S_t - CHP_t^{MustRun} - TB_t$

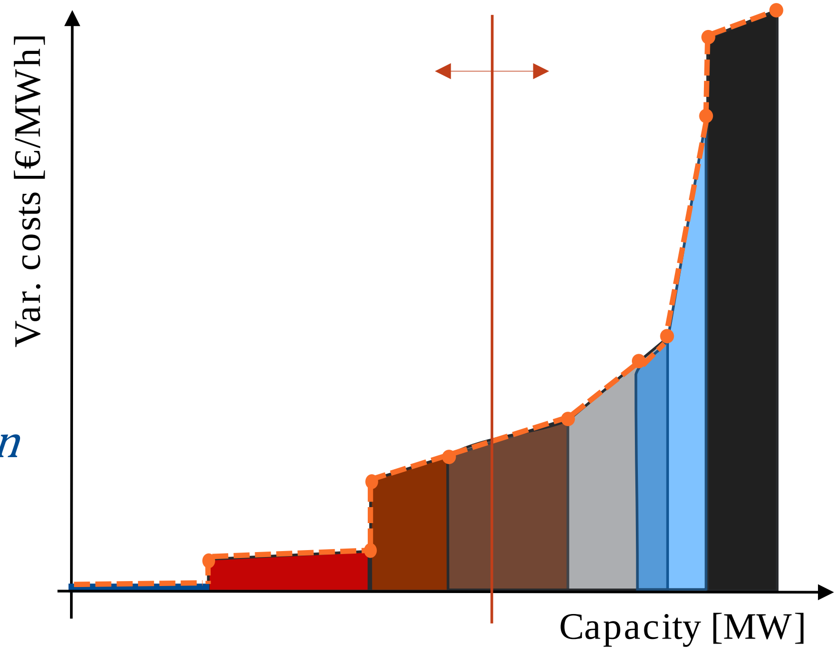
  – $L_t = Demand$

  – $W_t = Wind\ infeed$

  – $S_t = Solar\ infeed$

  – $CHP_t^{MustRun}$ = Must-run CHP production

  – $TB_t = Transmission\ balance$



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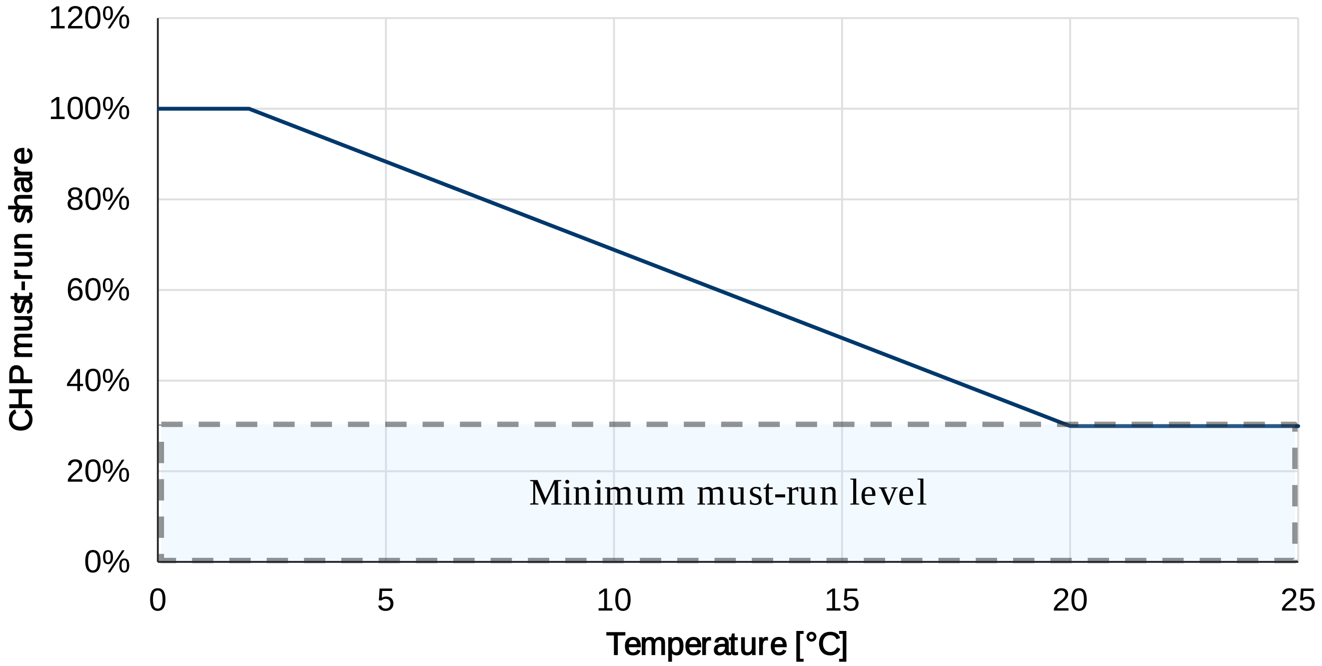
Demand – CHP must-run power plants

- Residual load

  $D_t = L_t - W_t - S_t - \boldsymbol{CHP_t^{MustRun}} - TB_t$

  – Temperature driven CHP plants create a must-run production independent from power prices: $CHP_t^{MustRun}$

  – Temperature-dependent must-run level

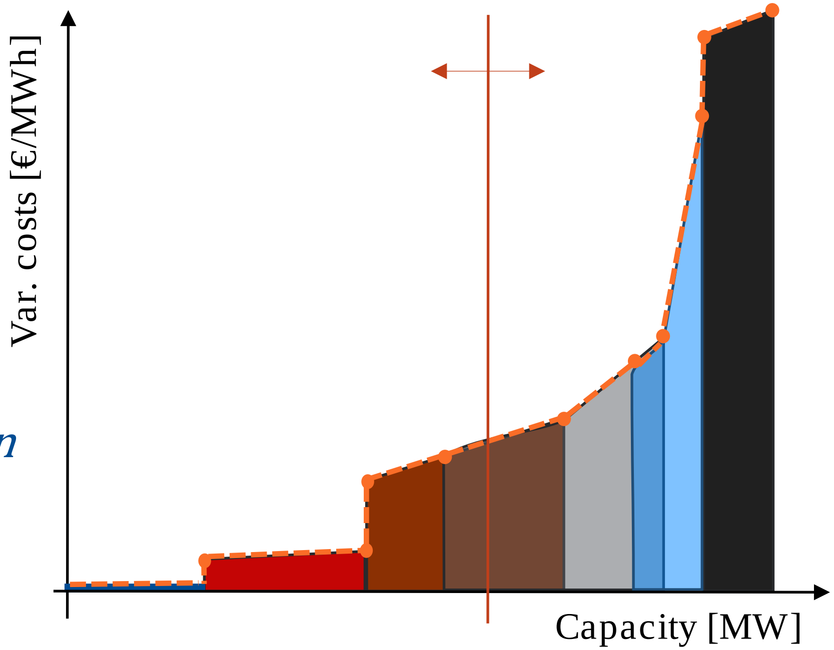


Demand – transmission balance

- Residual load

  $D_t = L_t - W_t - S_t - CHP_t^{MustRun} - \boldsymbol{TB_t}$

  - $L_t = Demand$
  - $W_t = Wind\ infeed$
  - $S_t = Solar\ infeed$
  - $CHP_t^{MustRun}$ = *Must-run CHP production*
  - $\boldsymbol{TB_t}$ = ***Transmission balance***
    - Ex-post analysis: Available as data
    - Ex-ante analysis: ?
      - → Use of an auxiliary model on past data



Demand – Transmission balance

2 Parsimonious Model

- Explaining German transmission balance with a multiple regression model:

$$TB_t = \beta_0 + \beta_1 Wind_t + \beta_2 PV_t + \beta_3 Temp_t + \beta_4 FS_t + \beta_5 L_t + \beta_6 AvCap_{LIG,t} + \beta_7 AvCap_{NUC,t} + \beta_8 CO_2 Preis + \varepsilon_t$$

Regression result				
Variable	Estimate	SA	tStat	pValue
(constant) [MWh]	6124,1300	635,6297	9,6347	0,0000
Wind-infeed [MWh]***	-0,3548	0,0086	-41,0770	0,0000
Solar-infeed [MWh]***	-0,4652	0,0090	-51,9271	0,0000
Temperature [°C]***	146,5702	7,5380	19,4443	0,0000
Filling level of Scand. reservoirs [GWh]**	-0,0044	0,0020	-2,2555	0,0241
Load [MW]***	0,0862	0,0035	24,2831	0,0000
Available lignite capacity [MW]***	-0,4337	0,0286	-15,1606	0,0000
Available nuclear capacity [MW]***	-0,5448	0,0222	-24,5539	0,0000
CO_2-price [€/t]***	183,5405	12,4692	14,7195	0,0000
# observations	26304	Mean dependent variable		-2313
adjusted R^2	0,650691	Akaike Info Criterion		18,24908
F-statistics	6126	Schwarz Criterion		18,25188

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Motivation	1
Parsimonious model	2
Key differences between large fundamental and parsimonious models	**3**
Data & Validation	4
Implications for validating fundamental models	5
Final remarks	6

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Key differences

3 Key differences between large fundamental and parsimonious models

	Parsimonious model	Full fundamental model
Spatial coupling	Single market area ➢ Exogenous imports/exports	Multiple market areas ➢ Endogenous imports/exports
Temporal coupling	Uncoupled time periods ➢ No start-up costs or min-operation times ➢ Hydro and PSW: Shadow prices or exogenous quantities	Coupled periods ➢ (approximate) modelling of start-up costs and min-operation times ➢ Endogenous quantities and shadow prices for hydro and PSW
Technology classes	Linearly increasing variable cost ➢ Differentiated prices inside one technology class	Constant variable cost ➢ Price levels correspond to technology classes
Availabilities	Detailed data ➢ Improved back-testing qualities	Rough data

Implications

3 Key differences between large fundamental and parsimonious models

Parsimonious model:

- Search for approximations for
  - Imports/exports
  - Impact of start-up costs

Full fundamental model:

- For backtesting
  - Detailed data for availabilities
  - Separate steps
    - Backtesting single country and single time steps
    - Backtesting single country with intertemporal constraints
    - Backtesting full model

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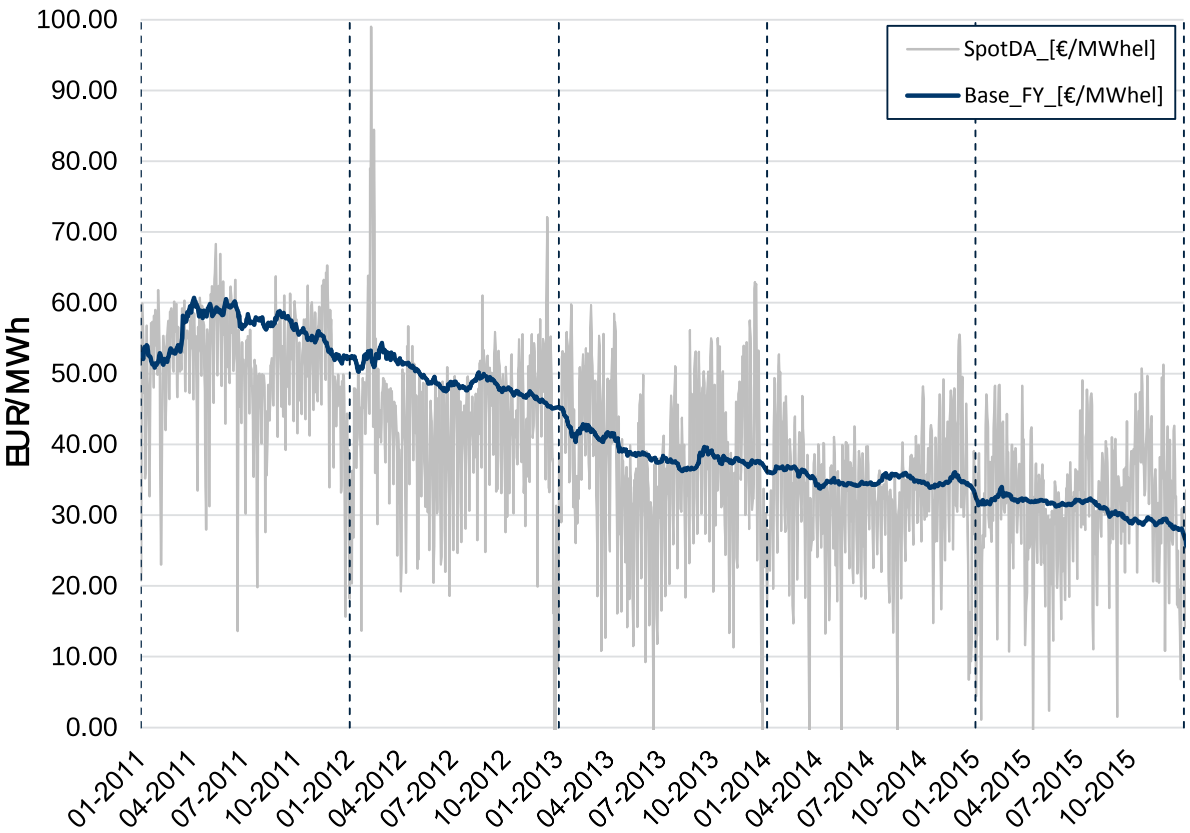
Plunge in German electricity wholesale prices



- German electricity spot market price
  - 2011: 51.12 €/MWh
  - 2015: 31.63 €/MWh
  - Decrease of 38%
- What caused the price drop?
  - CO_2 price drop
  - Cheap fuel prices
  - Expansion of Renewables
  - Nuclear phase out
  - …

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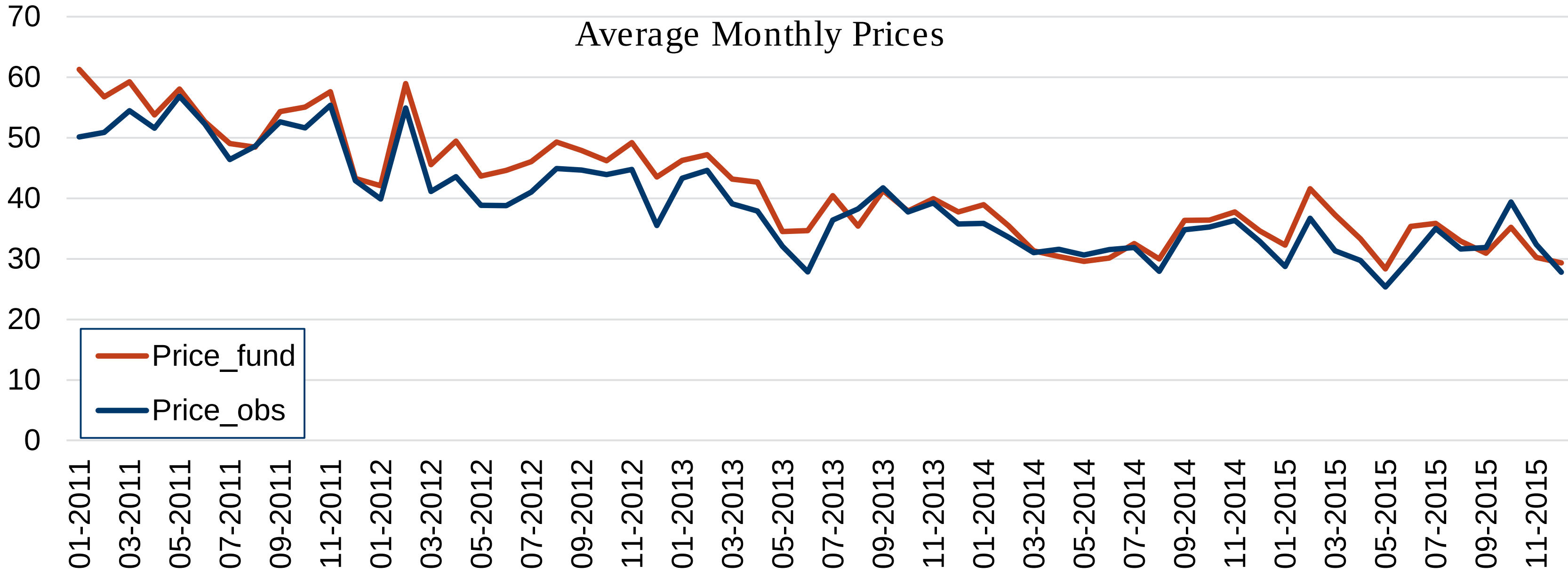
Data

Type	Dataset	Source	Data manipulation & Remarks
Fuel prices	Coal price (API#2) Gas price (OTC TTF DA) Oil price (ICE Brent Index) CO2 price (EUA)	Energate.de	
Load	Hourly load values for a specific country and year Monthly electricity statistics	Entso-e transparency platform & entso-e.eu + IEA	Scaling of Entso-e hourly load data to IEA monthly electricity supplied
Renewable Infeed	Wind-feed-in (DA-Forecast) PV-feed-in (DA-Forecast)	German TSOs	
Transmission balance	Scheduled commercial exchanges	Entso-e transparency platform	
CHP factors	Share of must-run CHP production Temperature data	DeStatis + BMWi + DWD	Based on turbine types and
Capacities	Installed hourly capacity Installed CHP capacity	EEX Transparency platform +BnetzA	Hourly power plant capacities from EEX scaled to net installed capacity of BNetzA Kraftwerksliste
Availabilities	Scheduled and unscheduled unit unavailability	EEX Transparency	Hourly availability factor for each technology class (cf. above)

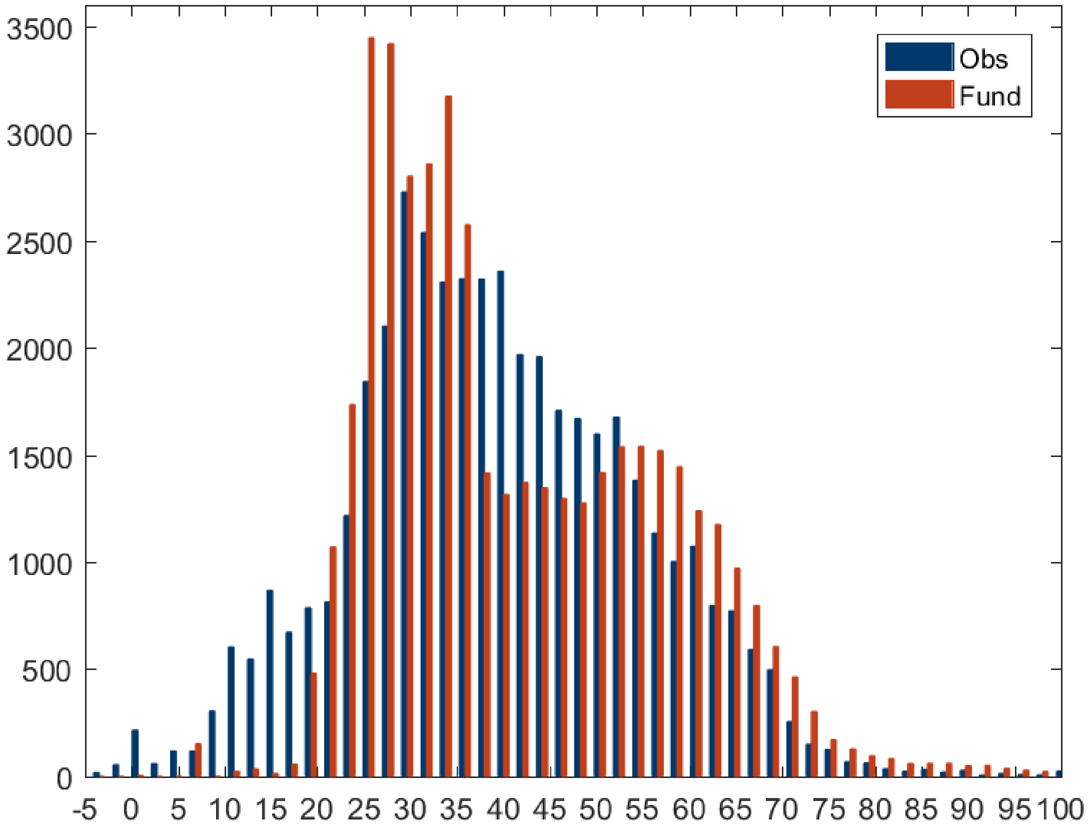
Price validation I

3 Data & Validation



[€/MWh]	2011		2012		2013		2014		2015		Overall	
	Obs	Fund	Obs	Fund	Obs	Fund	Obs	Fund	Obs	Fund	Obs	Fund
Mean	51,12	54,10	42,60	47,14	37,79	40,04	32,76	33,61	31,63	33,96	39,18	41,77
S.D.	13,60	14,17	18,68	16,06	16,45	15,79	12,77	10,15	12,67	9,66	16,63	15,60
# neg.	15	0	56	12	63	0	64	0	126	0	324	12
Min	-36,82	20,75	-221,99	-10,00	-100,03	6,76	-65,03	6,70	-79,94	6,50	-221,99	-10,00
Max	117,49	162,15	210,00	210,90	130,27	94,43	87,97	70,59	99,77	68,01	210,00	210,90

Price validation II



- Model prices are higher than observed prices
- High price concentration in price range 25-35 €/MWh.
- Rarely low model prices
- No negative model prices

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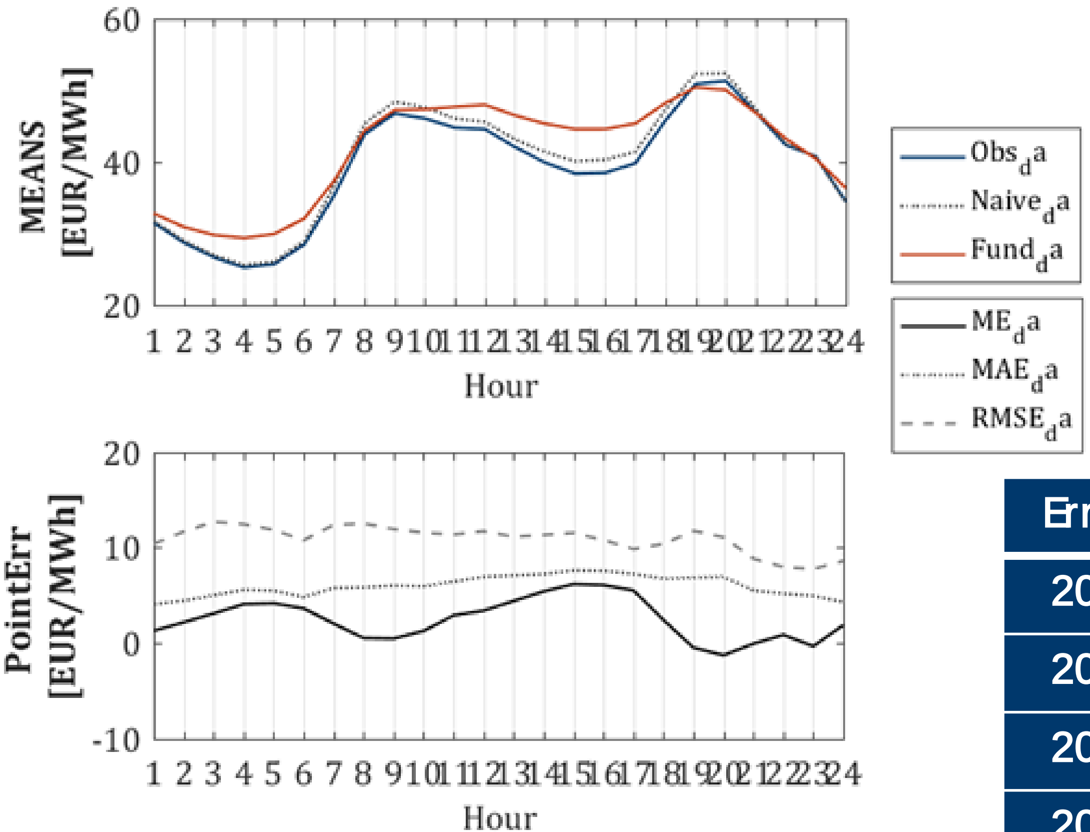
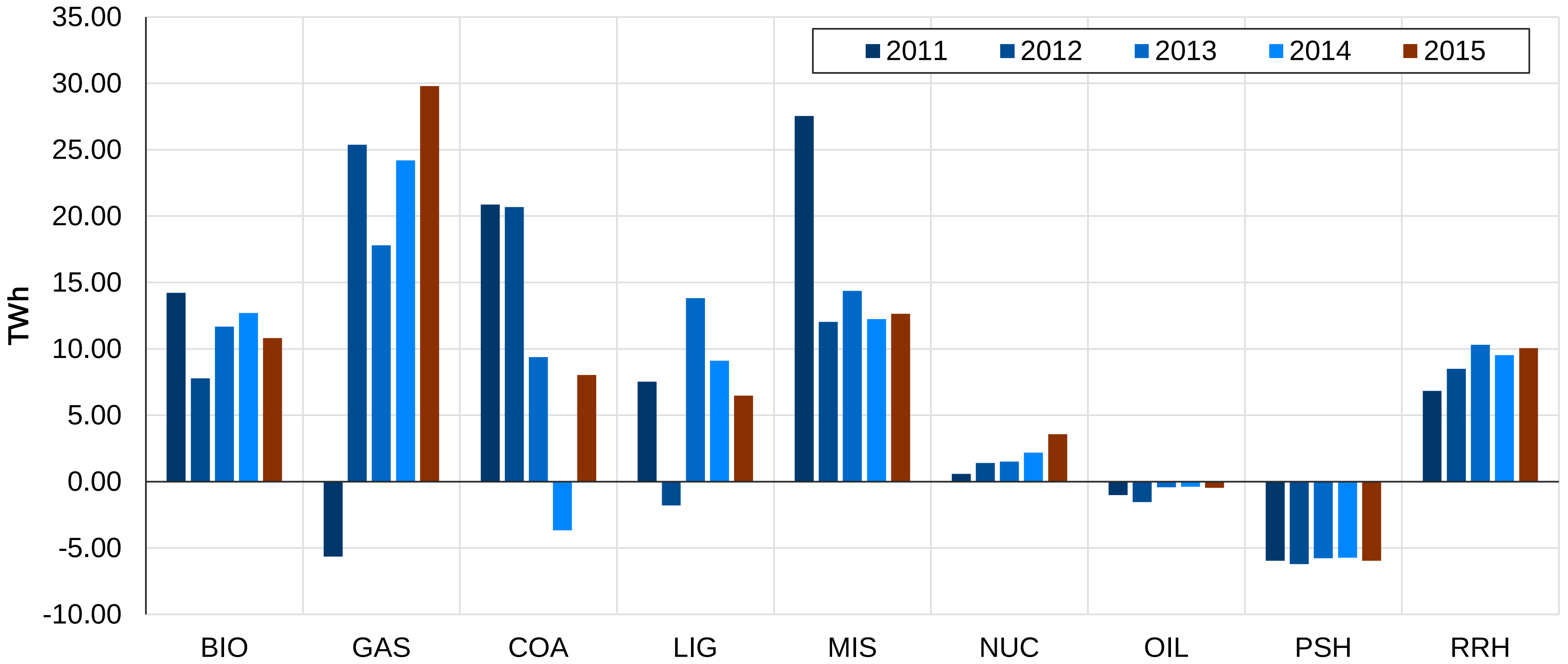
Price validation III



- Model prices are on average higher than observed prices.

Errors	ME	MAE	RMSE	R^2
2011	2.98	5.91	8.72	0.59
2012	4.54	7.00	12.3	0.57
2013	2.26	7.04	9.75	0.65
2014	0.84	4.55	6.7	0.72
2015	1.86	5.45	7.41	0.66
Overall	**2.50**	**5.99**	**9.19**	**0.69**

Production validation



- Good results for most combustible fuels (Coal, Lignite, Nuclear and Oil).
- Problems with modelling gas and renewables with unclear costs

Conclusion validation parsimonious model

- The parsimonious fundamental model is a simple modelling approach for describing fundamental coherences for prices and production volumes.
  - Fundamental price differs on average by 2.50 €/MWh.
  - MAE is 5.99 €/MWh
  - Suitable determination of production volumes of lignite, nuclear and coal
- Shortcomings
  - Problems with modelling extreme prices (pos./neg.) → no fundamental negative prices
  - Price volatility is too low
  - Problems modelling gas fired production volumes and production from technologies without "standard" cost structures (biomass, run-of-the-river, pumped- and seasonal storage)

Agenda

Lessons to be learnt

5 Implications for validating fundamental models

- Good data = good modelling results!
- Not only yearly quantities and yearly average prices matter

- Stepwise backtesting strategy for large fundamental models (cf. above)
  - Backtesting single country and single time steps
  - Backtesting single country with intertemporal constraints
  - Backtesting full model

- Validity of future scenarios established based on non-validated models?

- Careful reflection of modelling of regulatory distortions
  - Renewable remuneration schemes (notably market premia)
  - CHP operation and regulation context (e.g. self-consumption)

Agenda

Conclusions

- Backtesting is time-consuming
  - Even for smaller models
- Rewards for backtesting have been low in the past
- Looking back does not replace the look ahead
- But:
  - We have now 25 years of experience with sustainability in electricity systems (FIT in Germany started 1990, Rio conference 1992)
  - We do not achieve core objectives of sustainability in 2020 (-40 % GHG emission reduction in Germany)
  - ➢ We have to learn from history to avoid errors in the future

Thank you for your attention!

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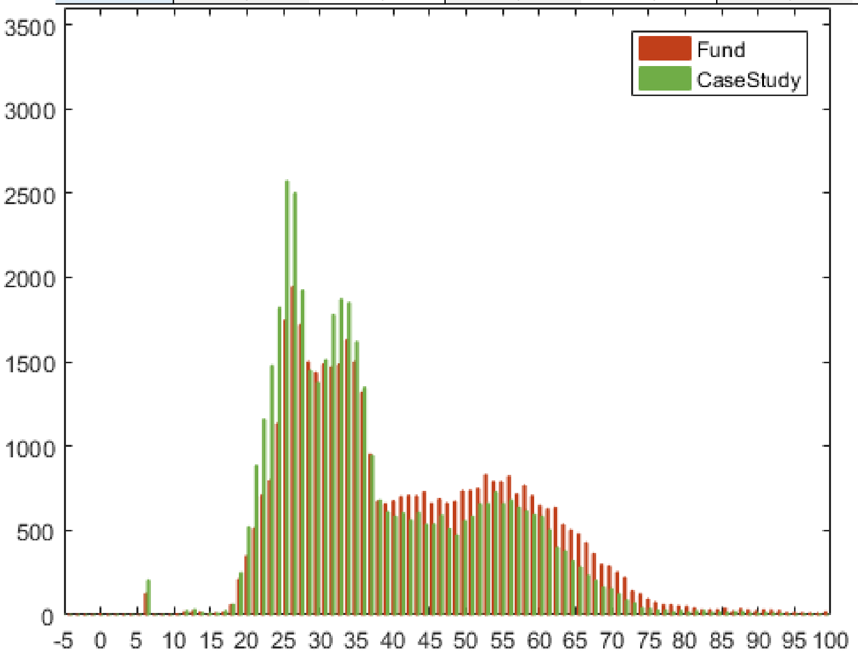
Backup I
Case Study – Counterfactual scenario

- Accelerated nuclear phase out
  - Fukushima accident on 11.03.2011
  - German government decided to phase out nuclear power generation
  - As a result 12 GW nuclear capacity were shut down
  - ➢ How would the German electricity market look like without the accelerated nuclear phase-out?
- Counter factual scenario
  - For the counterfactual analysis a non-observable case is designed to compare with the actual situation.
- Construction of counterfactual situation
  - Direct influence: Installed nuclear capacity
  - Indirect influence: CO_2-price, electricity export balance

Backup II
Case study - price results

[€/MWh]	Overall		2011		2012		2013		2014		2015	
	FundM	CaseS	FundM	CaseS	FundM	CaseS	FundM	CaseS	FundM	CaseS	FundM	CaseS
Min	-10,0	6,5	20,8	15,3	-10,0	6,5	6,8	6,8	6,7	6,7	6,5	6,7
Max	210,9	127,7	162,2	127,7	210,9	100,2	94,4	84,8	70,6	65,4	68,0	59,9
# neg.	12	0,0	0	0,0	12	0,0	0	0,0	0	0,0	0	0,0
Mean	41,7	37,7	54,1	51,1	47,1	42,7	40,0	35,2	33,6	30,1	33,5	29,7
S.D.	15,6	13,9	14,2	12,5	16,1	13,5	15,8	13,8	10,1	7,7	9,6	6,9

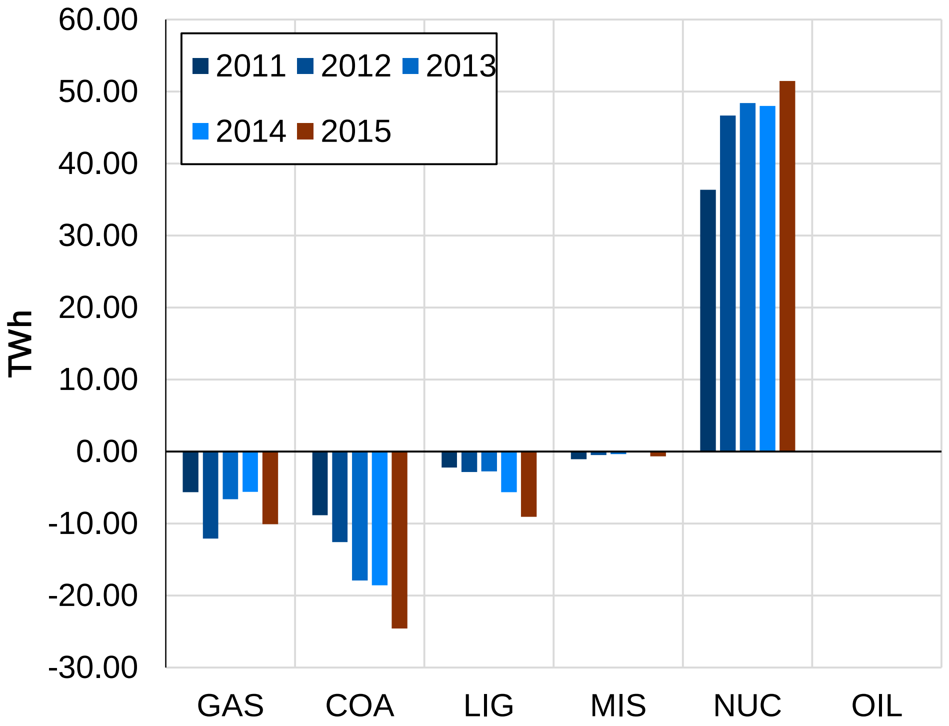


- Prices would have declined on average by 4.02 €/MWh.
- In 2015 price would have been on average below 30 €/MWh.
- Lower price volatility

Backup III
Case study - production results

- Increased nuclear production in GER (+ 45 TWh/a)
- Lower production from other combustible fuels (-28 TWh/a)

  Of which..
  - Coal -16 TWh/a
  - Lignite -4.29 TWh/a
  - Gas -7.73 TWh/a
- Difference between additional nuclear and lower combustible production (17 TWh/a) is exported.
  - In 2015 Germany would have achieved an export surplus of 62 TWh.



[TWh]	2011	2012	2013	2014	2015
Actual Exchange	-4,1	-20,3	-34,3	-35,6	-55,5
Counterfact. Exchange	-22,4	-38,9	-54,9	-53,6	-62,5