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Competence Center: Supply of Electricity

Key factors of future wholesale electricity prices in Switzerland

Task 4.2: Global observatory of electricity resources

Martin Densing, Evangelos Panos
Energy Economics Group
Paul Scherrer Institute (PSI)

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In cooperation with the CTI

Energy
Swiss Competence Centers for Energy Research

Schweizerische Eidgenossenschaft
Confédération suisse
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Swiss Confederation

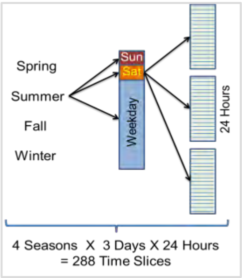
Commission for Technology and Innovation CTI

Energy Economics Group activities in SoE

Elec. generation capacity → **Electricity prices** → **Optimal profit against prices**

European capacity expansion modeling

- Long-term capacity expansion in Europe under policy scenarios
- Scope: CH+EU

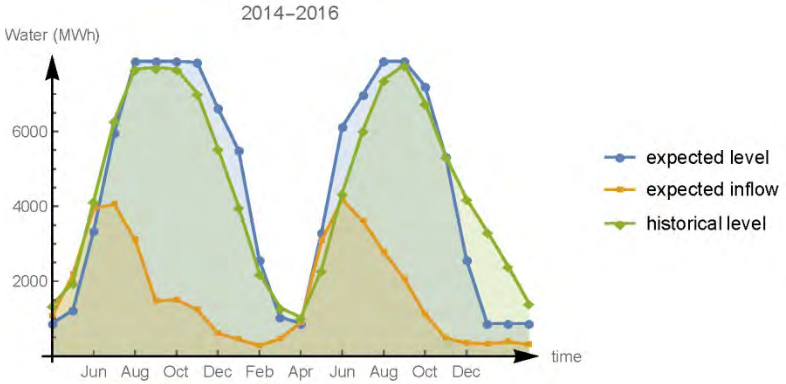


Electricity market modeling

- Future wholesale price ranges under policy scenarios
- Scope: CH+surrounding countries

Hydropower stochastic dispatch modeling

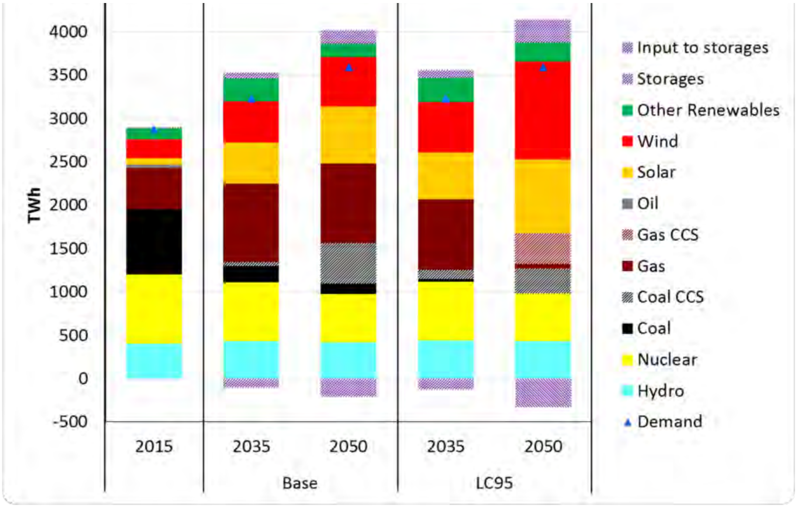
- Optimal production and pumping thresholds under exogenous prices
- Scope: Single utility



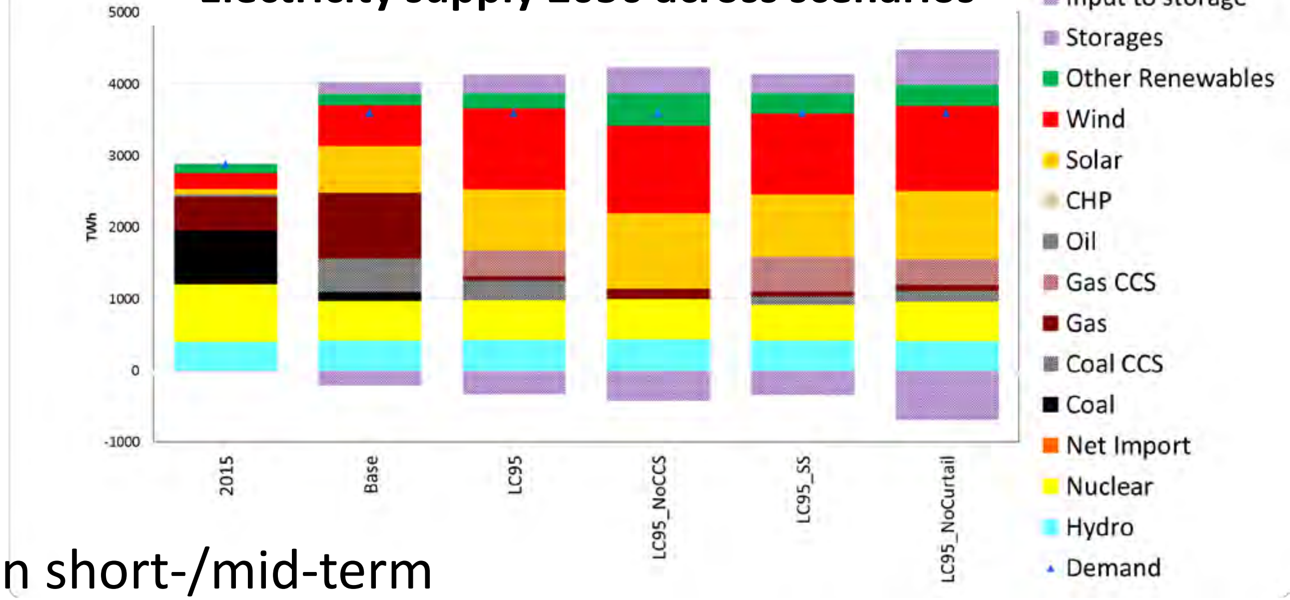
EU production capacity expansion modeling (poster)

- Multi region, cost-optimization model of electricity system of Europe: Long time horizon (2050), hourly time resolution (typical days)
- Near-term EU energy polices implemented (with new electricity storage options)

Electricity supply in 2015, 2035, and 2050



Electricity supply 2050 across scenarios



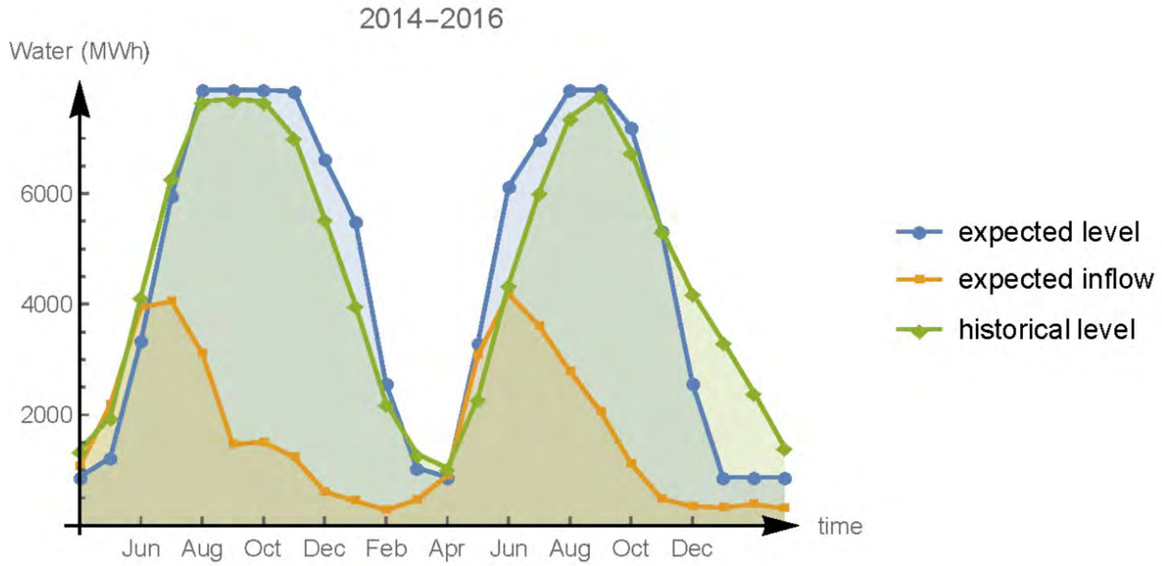
- **Gas power** becomes transitional technology in short-/mid-term
- **Baseline scenario:** EU polices reduce power sector’s CO_2 emission in 2050 by 60% (w.r.t. 2010)
- **Further decarbonization** requires high share of renewable (> 40% of generation) and gas-based CCS technology. In 2050, the new renewables require 250-450 TWh (=5-10% of electricity load) shifted daily by **storage with 125-355 GW capacity**

Optimal stochastic control of hydro dispatch (poster)

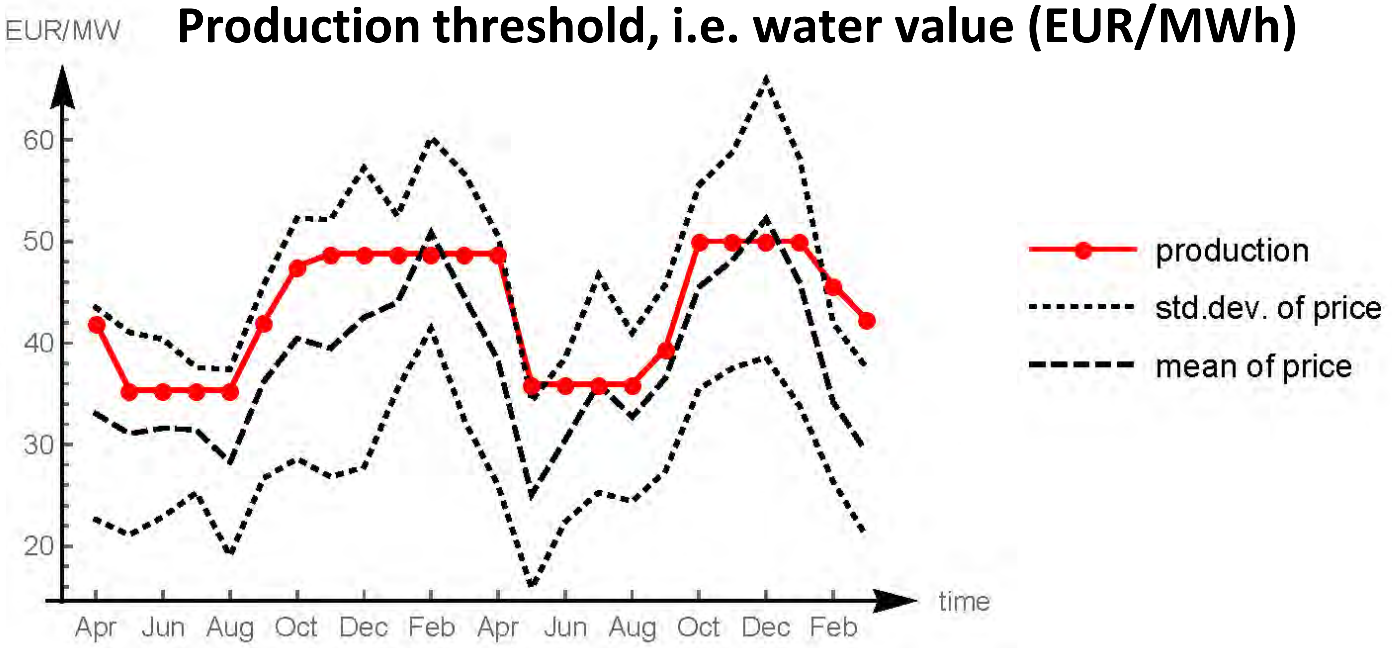
- Stochastic multi-period control model of stored (pumped) hydropower that optimizes expected profit under expected water inflow
- Input: Electricity-price probability distribution at each time step

Example: Switzerland aggregated into 1 plant, monthly time steps, over two years:

Storage level (MWh)



Production threshold, i.e. water value (EUR/MWh)



- First milestone within SCCER-SoE achieved: Replication of historical patterns

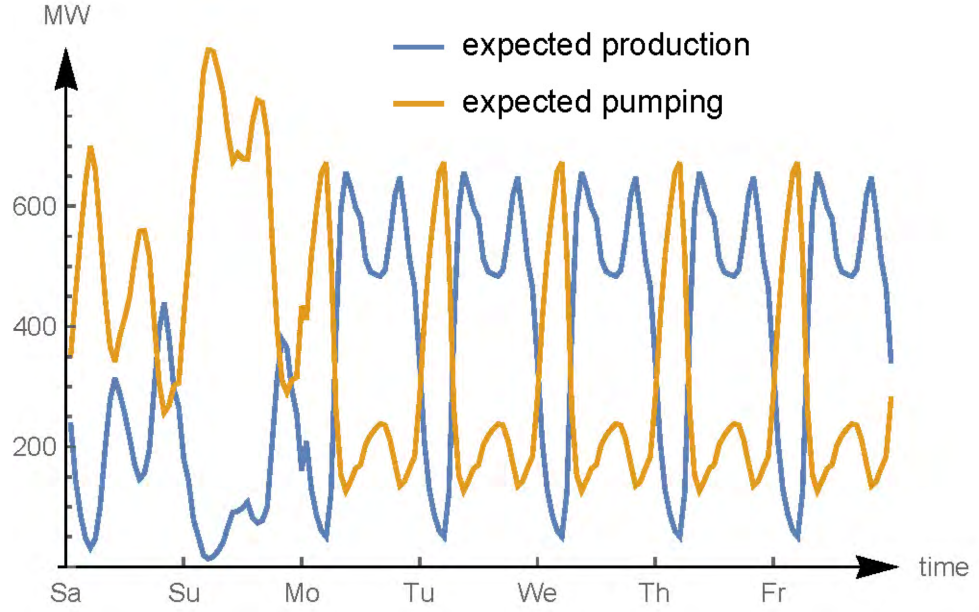
Optimal Stochastic Control of Hydro-Dispatch (poster)

SCCER SoE

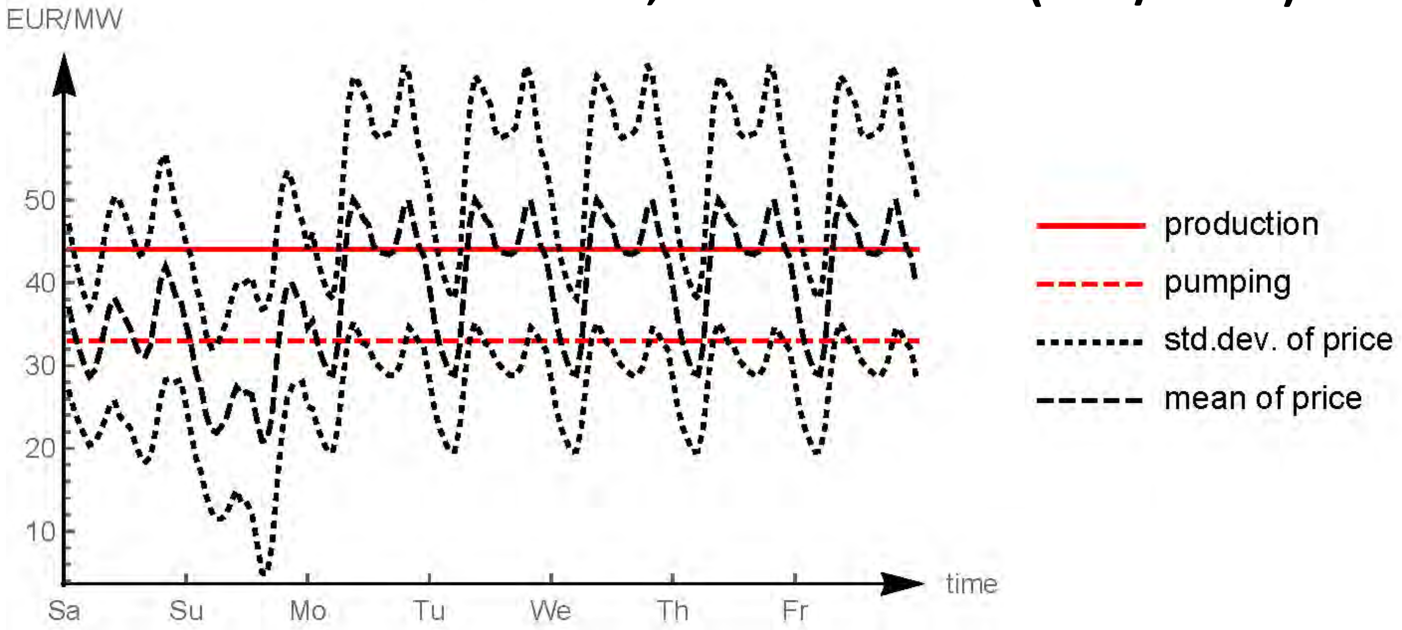
- Stochastic multi-period control model of stored (pumped) hydropower that optimizes expected profit under expected water inflow
- Input: Electricity-price probability distribution at each time steps

Example: Pumped-storage plant (1 GW) over a week:

Production (weekend/weekday)



Production threshold, i.e. water value (EUR/MWh)



- Optimal production thresholds → Expected profit calculations (tbd)

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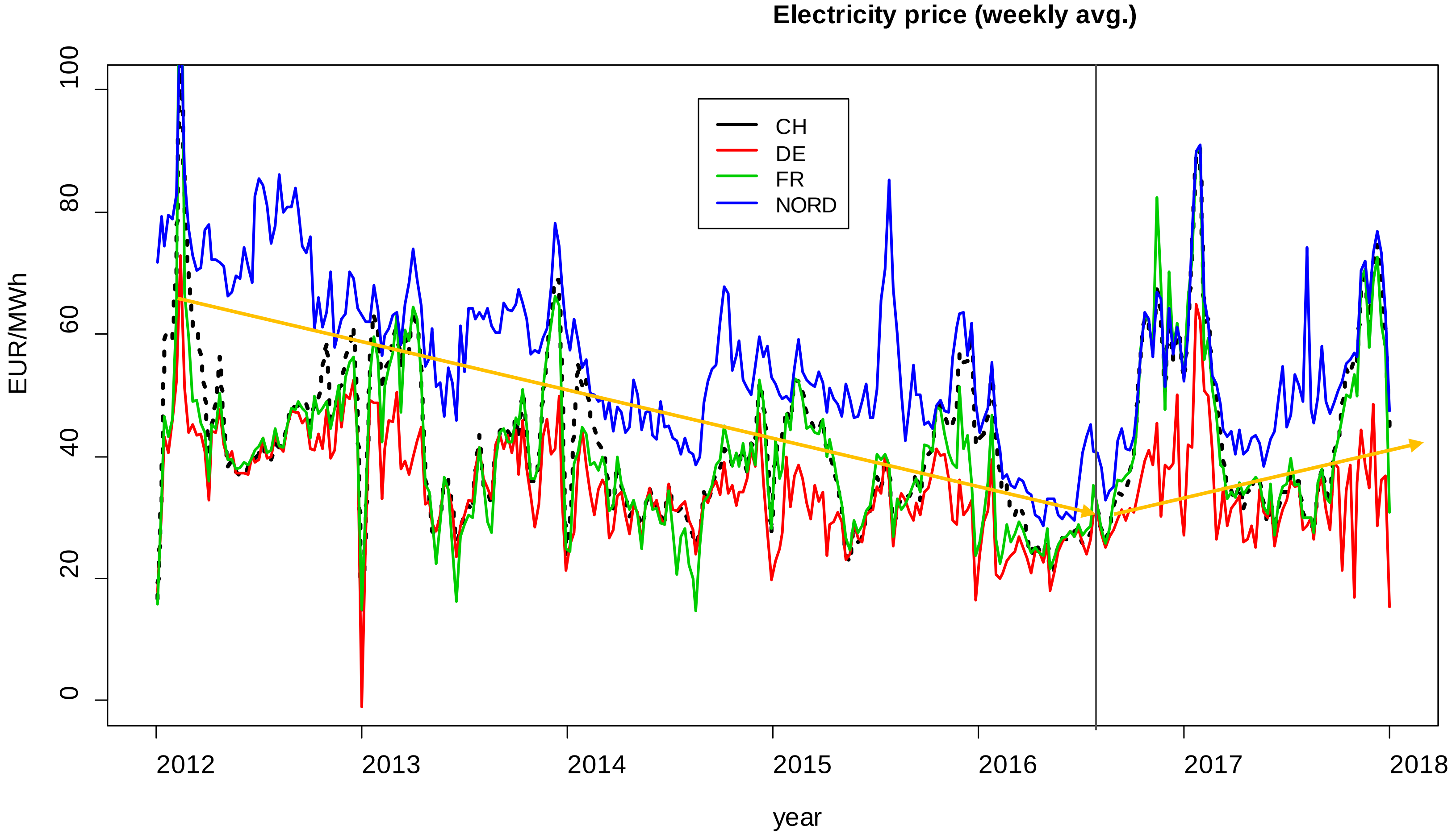
Main research question

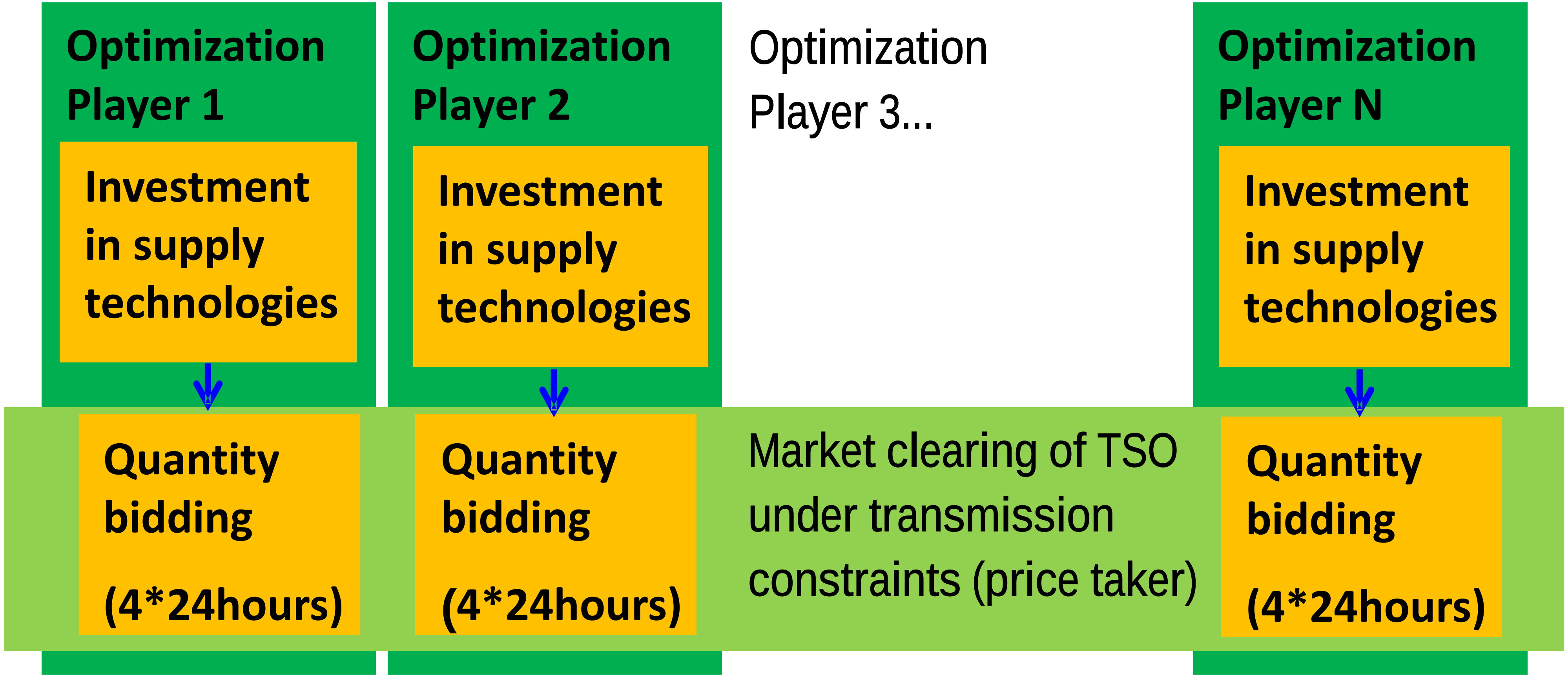
Can electricity prices rise again?

Especially under the implementation of the “Clean Energy for all Europeans Package”



Cross-Border Electricity Market (BEM) model

Nash-Cournot game to understand price formation & investments



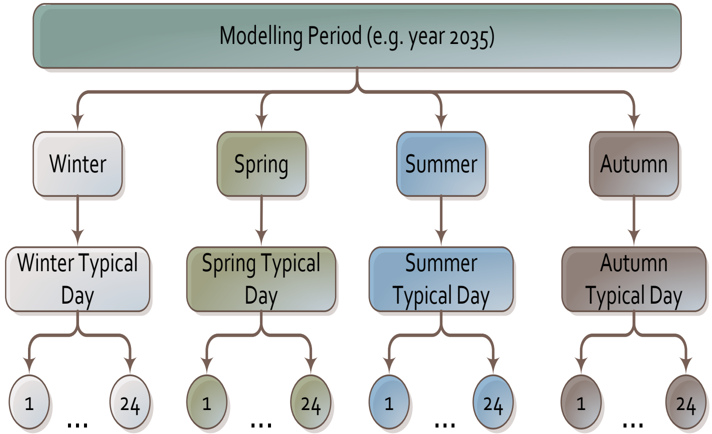
- The model can also run in different modes: (i) Deterministic or Stochastic; (ii) Social welfare maximization

Main features of the BEM model (I)

01

Long term horizon & high intra-annual resolution

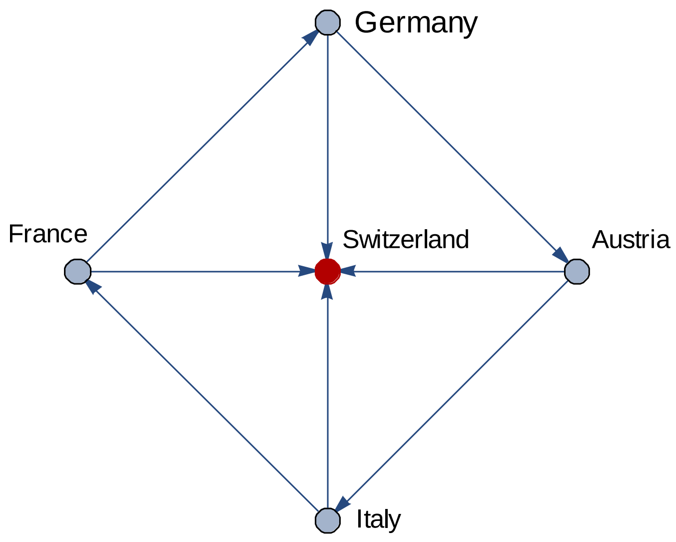
Each modelling period is divided into 96 typical operating hours, corresponding to 1 typical day per season; the framework is flexible allowing for defining more types of days within a season



02

Grid Transmission constraints between the players

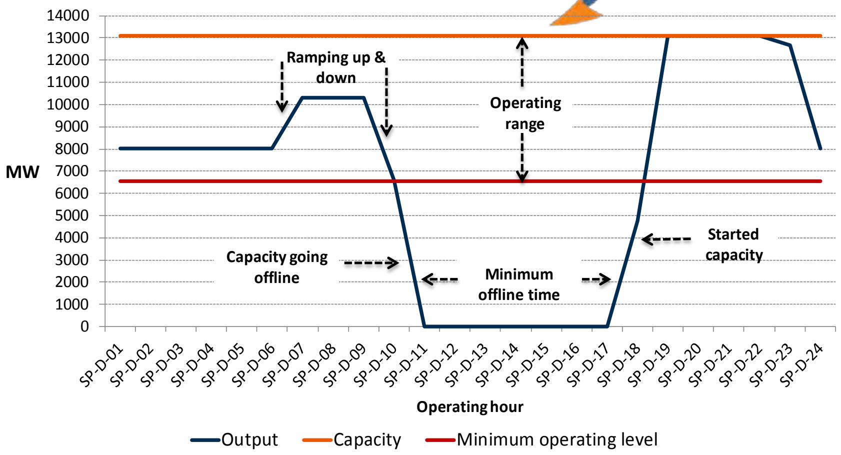
A DC power flow approximation is modelled for representing the grid transmission constraints between the nodes/players; in each node power plants can be located belonging to player(s); **in the current setup of the model the players are Switzerland and its neighbouring countries**



Main features of the BEM model (II)

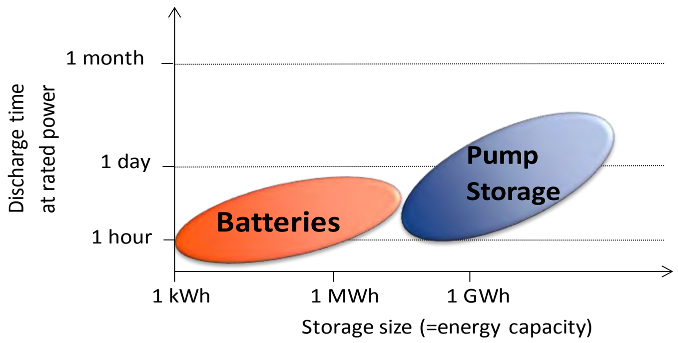
03 Operating constraints for power plants

A linearized approximation of the unit commitment problem is formulated based on clustering of similar units to represent: part load efficiency losses, ramping constraints, minimum operating levels, online/offline times, start-up costs, etc.



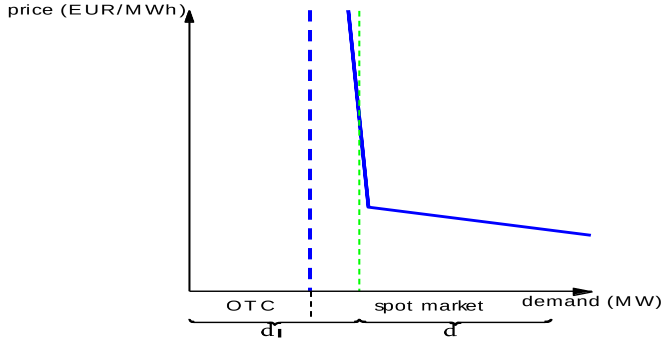
04 Representation of RES variability & storage

Based on a historical sample of solar and wind generation the model ensures that there is enough storage and dispatchable capacity to accommodate residual load curve variations and curtailment.



05 Elastic and inelastic electricity markets

The model can represent both elastic (i.e. traded) electricity demand and inelastic (i.e. over the counter - OTC) demand; the OTC demand is considered to be perfect competitive to avoid an exponential demand function representing both markets



Calibration within the BEM model

- The model has an estimation mode for the conjecture of a player regarding the aggregated reaction of its rivals, which is used to reproduce the historical prices

In a quantity offering setting q_i, each producer i tries to maximise its own profit (sales at price $p(q_i, q_{-i})$ minus production costs $C_i(q_i)$):

$$\max_{q_i \in R^+} p(q_{tot}) \cdot q_i - C_i(q_i)$$

The first order condition of the above problem is:

$$p(q_{tot}) - \frac{\partial q_{tot}}{\partial q_i} \cdot \frac{\partial p(q_{tot})}{\partial q_{tot}} \cdot q_i - C_i'(q_i) \leq 0 \perp q_i \geq 0$$

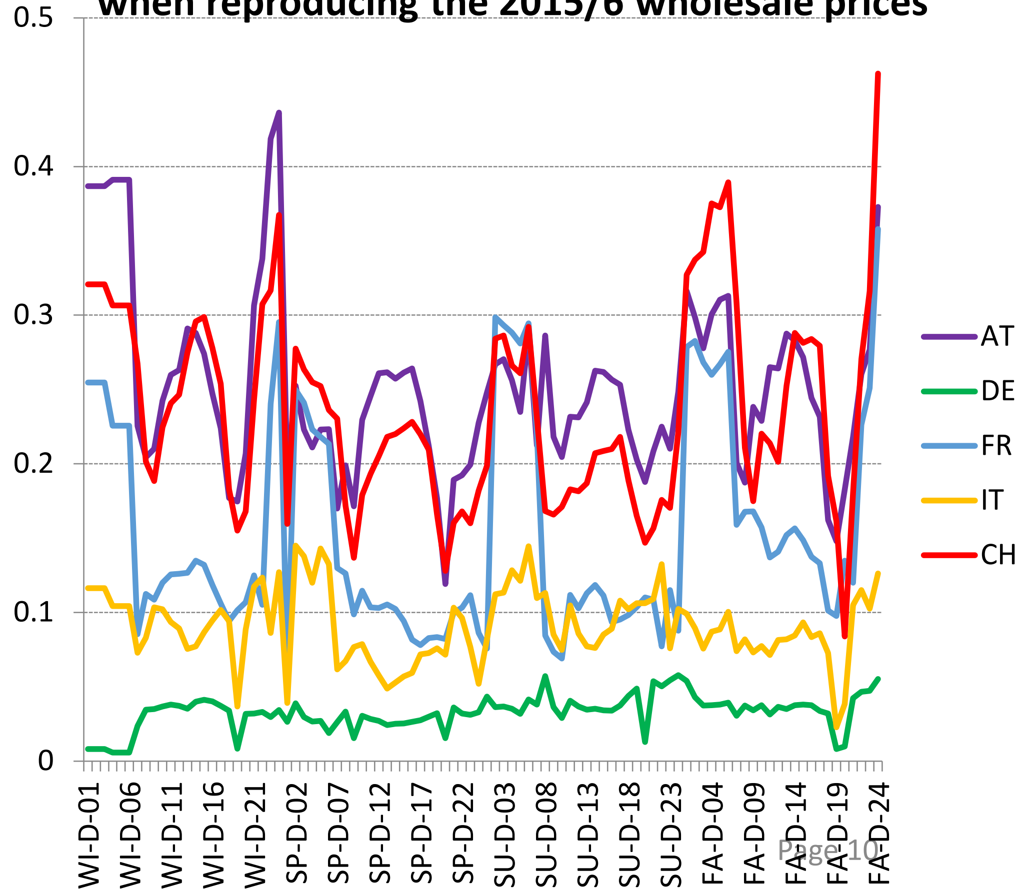
$\theta_i := \frac{\partial q_{tot}}{\partial q_i}$ conjecture of producer i

$\theta_i = 0$ perfect competition conjecture

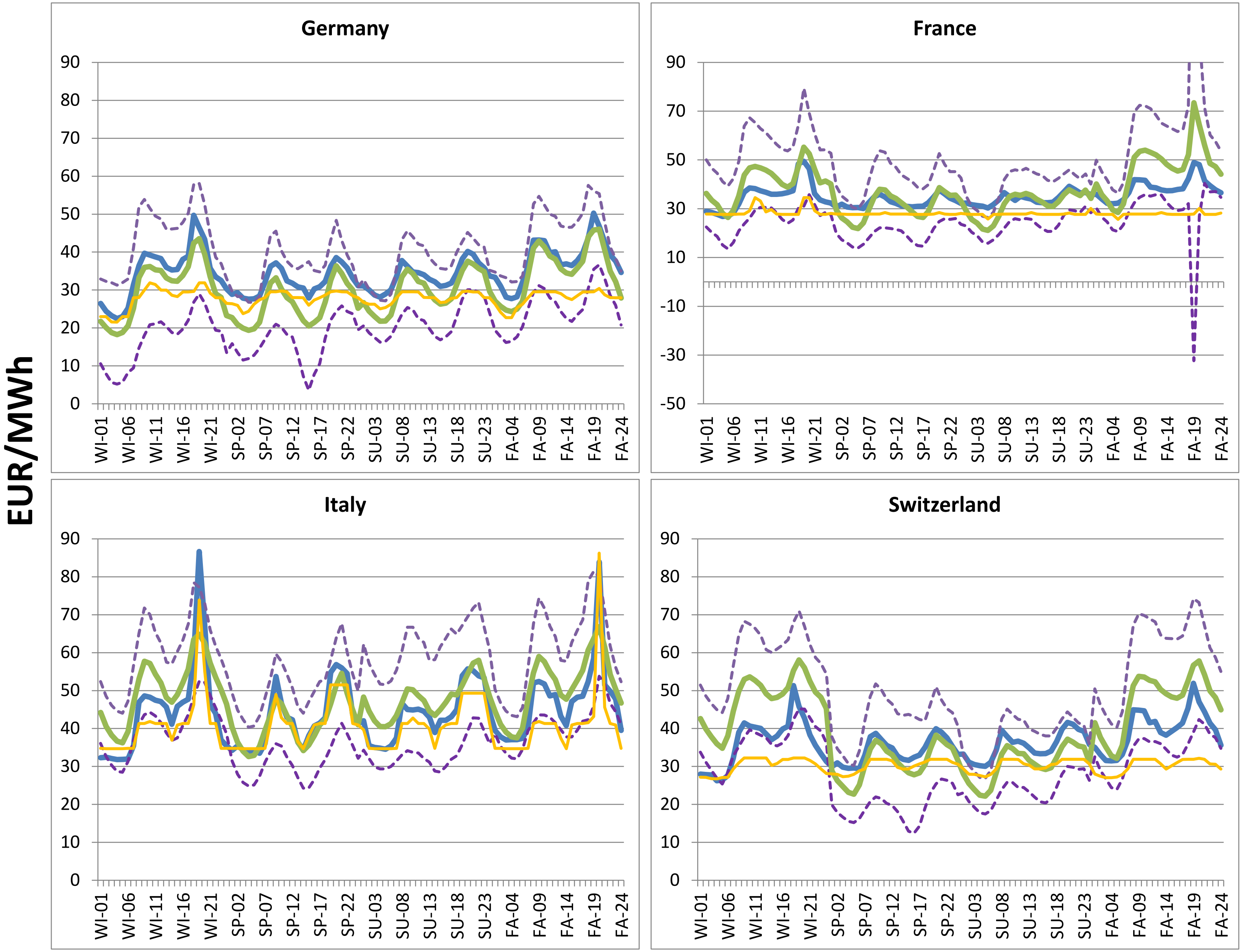
$\theta_i = 1$ Nash conjecture

$\theta_i \in (0, 1)$ Intermediate imperfect competition conjecture

Estimated deviation of θ_i from the model's cost-curve when reproducing the 2015/6 wholesale prices



Calibration of the BEM model to 2015/16 prices



Average wholesale day-ahead price 2015/6

BEM model price 2015/2016 (Game-theoretic formulation)

BEM model price 2015/2016 (Social Welfare formulation)

1 std. dev. of the historical prices 2015/2016

Definition of the scenarios

- Two core scenarios for year 2030 are assessed:

	Base	Low Carbon
Description	Reference scenario, based on EU TRENDS 2016 Scenario of EC	Climate scenario -40% reduction of CO_2 in 2030 from 1990 levels ("Clean Energy for All Europeans")
Fuel prices in 2030 (1)	Gas: 28 €/MWh, Coal: 12 €/MWh (in EUR_{2015})	
CO_2 price in 2030	30 €/tCO_2	80 €/tCO_2 (2)

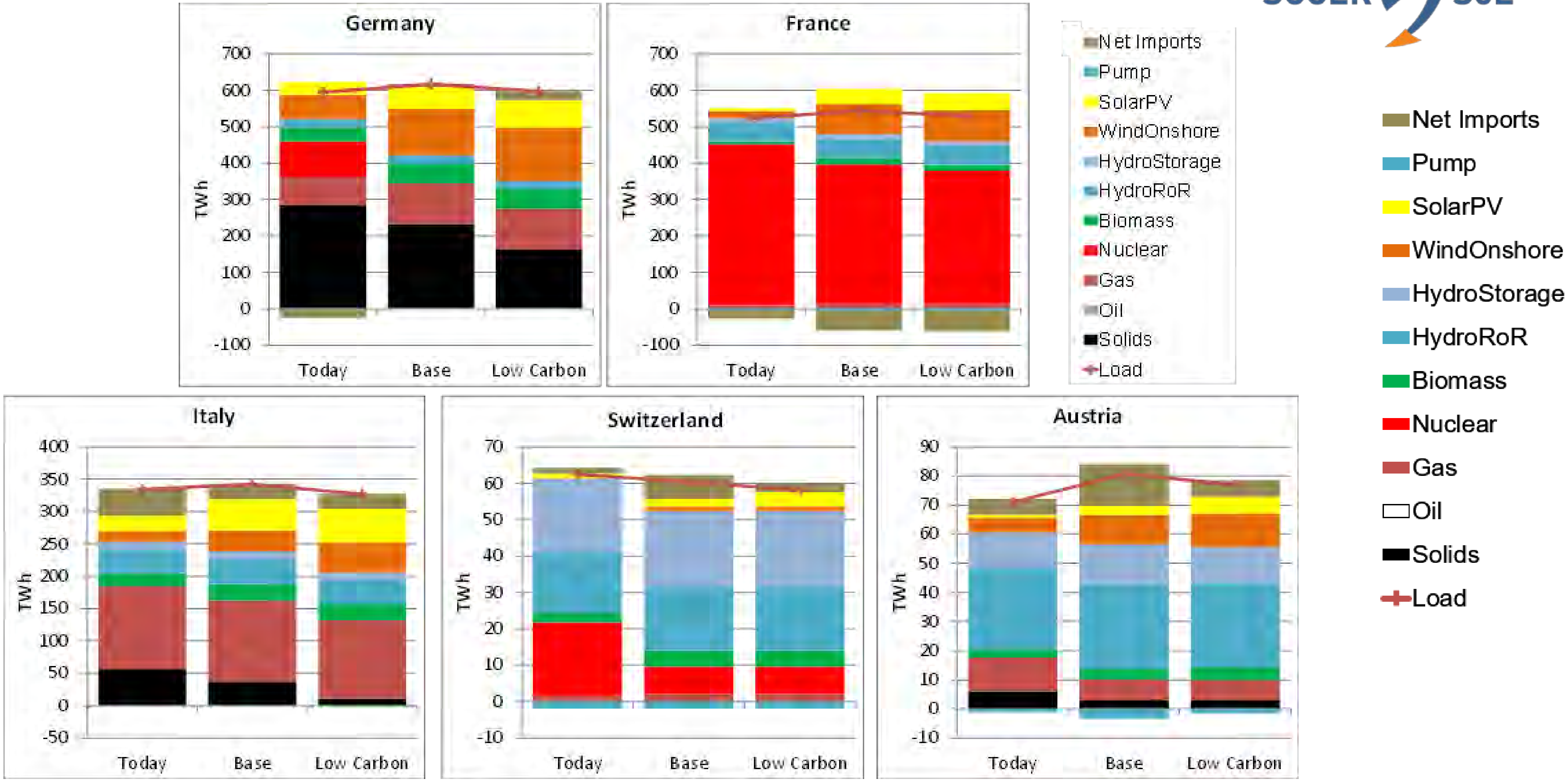
[1] IEA World Energy Outlook 2017, New Policies Scenario

[2] IEA World Energy Outlook 2017, Sustainable Scenario

Today's gas price (2015/6) 14 €/MWh, today's coal price 9 €/MWh

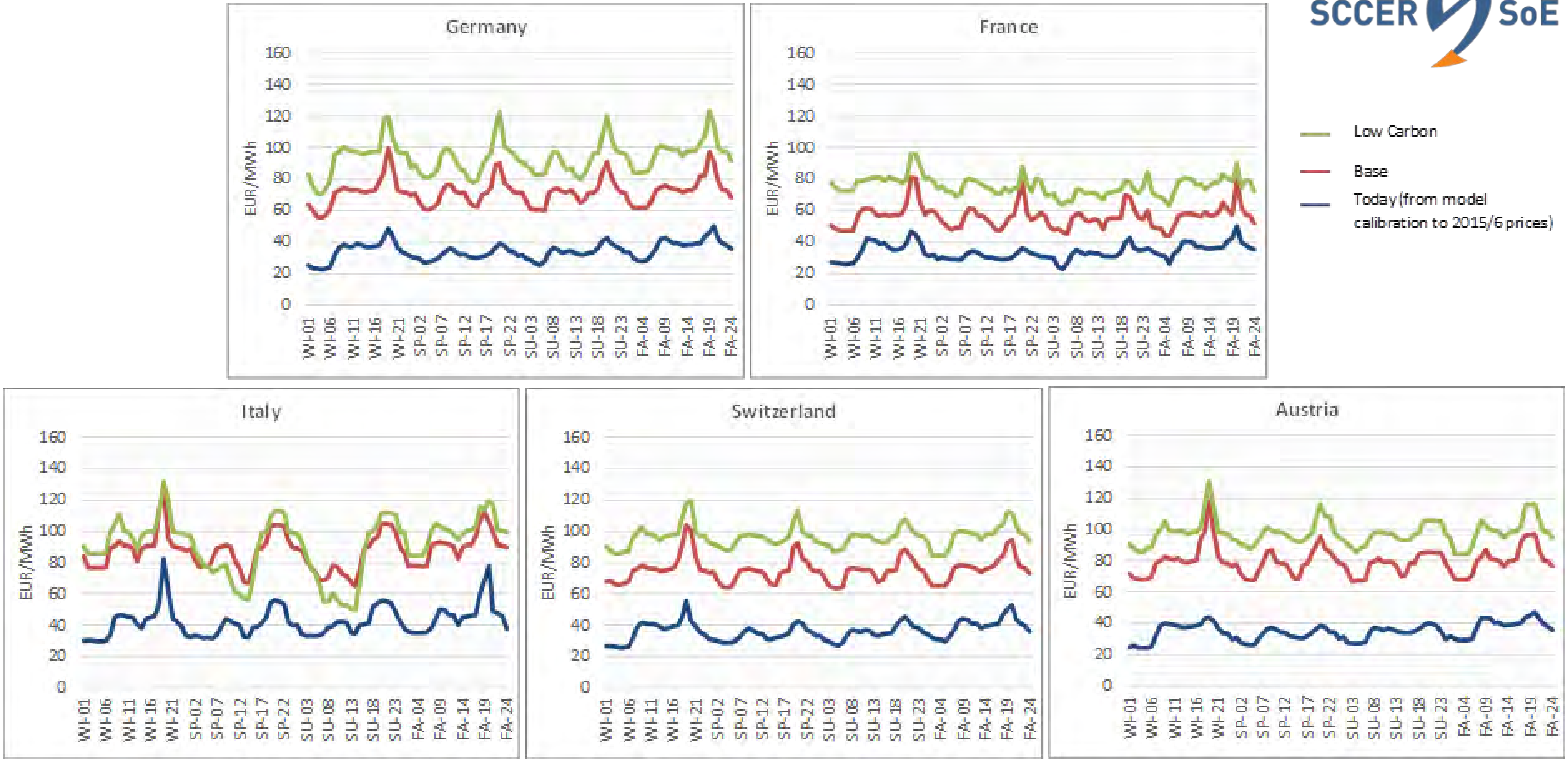
- Two additional variants:
  a) Enabling investment in batteries (transmission level) for additional flexibility
  b) Maintaining the fuel costs and CO_2 prices of today ("TodayCost")

Results: Electricity generation mix today & in 2030



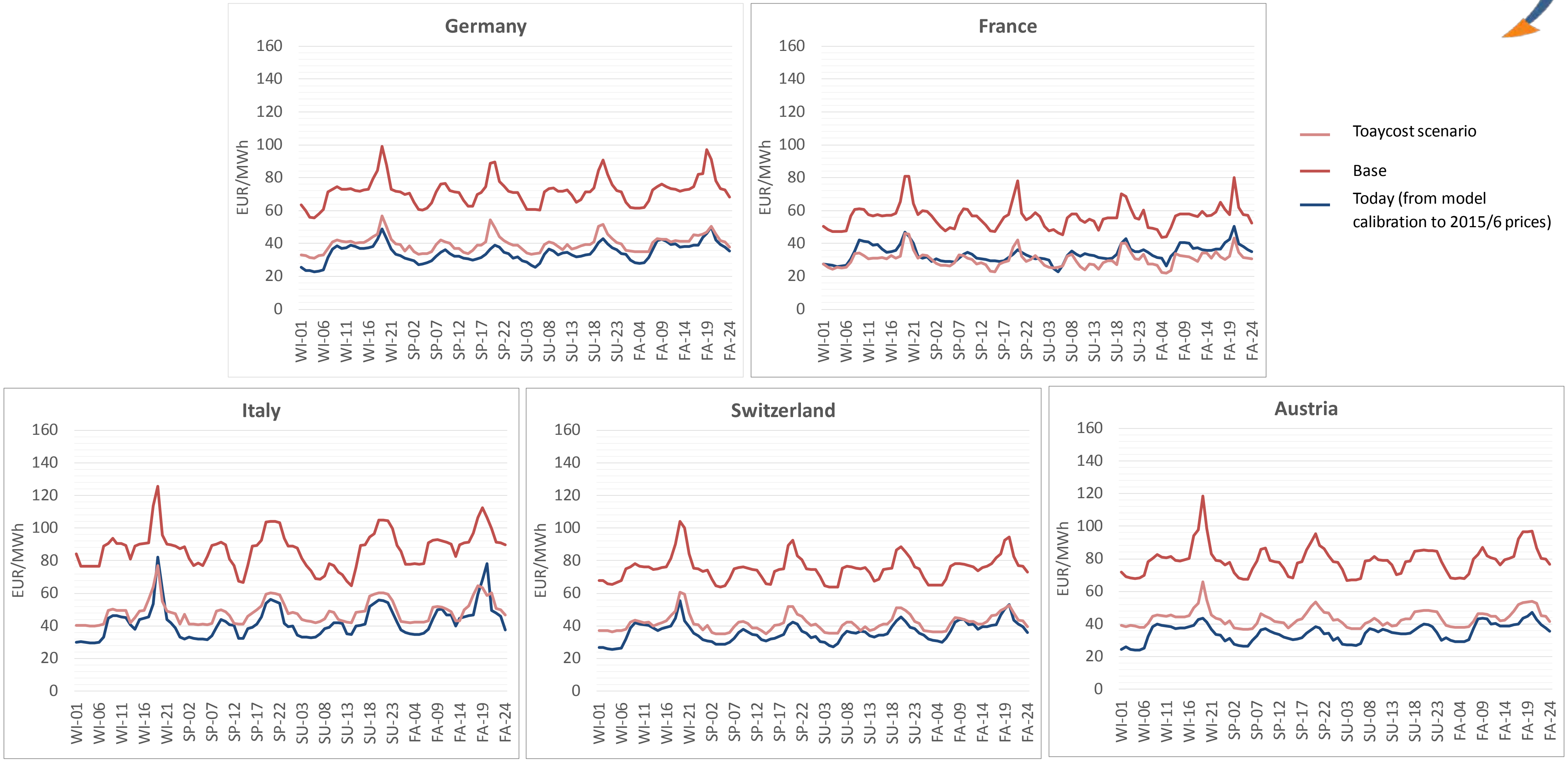
- new renewables given by scenario assumption (lower bounds)

Results: Electricity prices today and in 2030



- e.g. Germany: Prices driven by CO_2 and gas prices (despite more deployment of PV + wind)

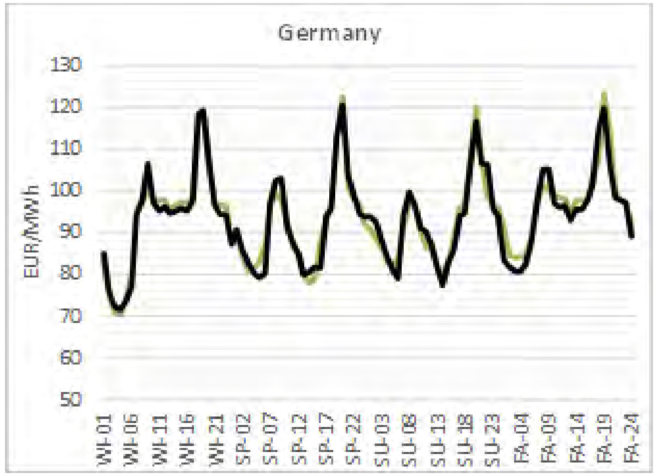
Variant of Base Scenario: 2015/16 fuel prices

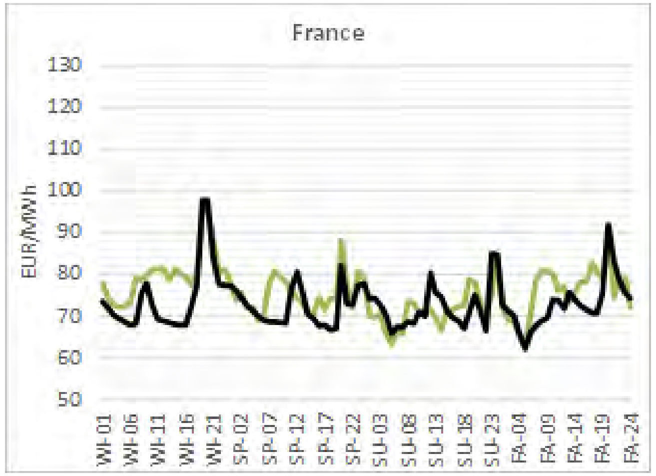


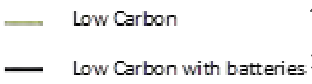
Electricity price increase key factors: **(1) Fossil fuel price, especially gas (indirectly CO_2 prices),** (2) Load levels, (3) Wind and solar penetration, (4) decommissioning of existing capacity (mainly nuclear power)

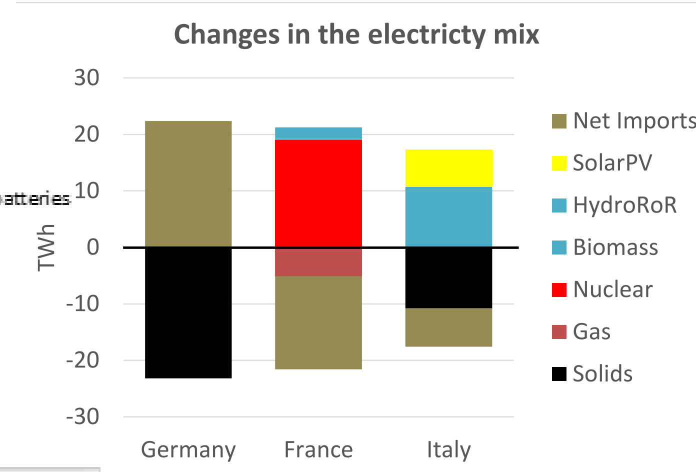
Results: Electricity prices and storage in 2030

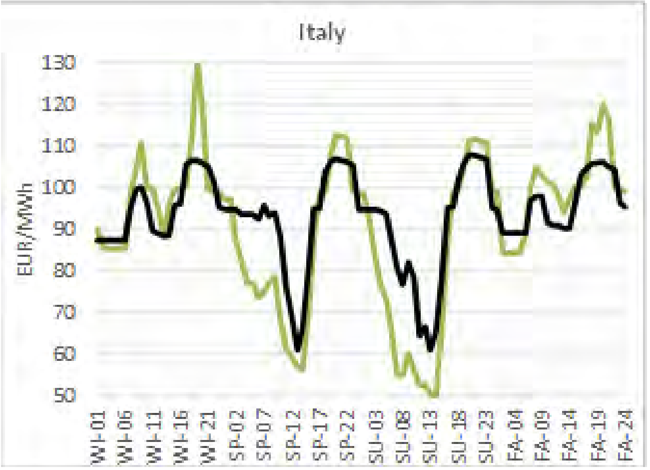
- Scenario variant: Low Carbon scenario with battery investments allowed

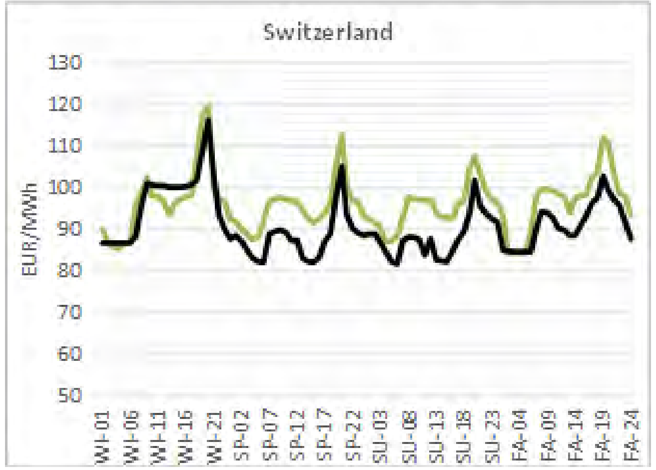


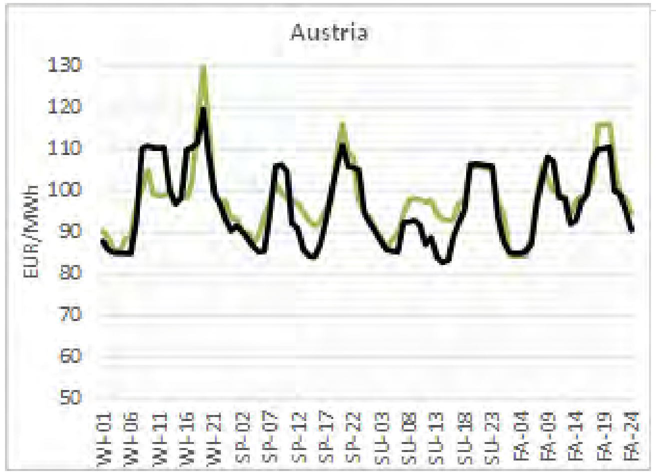






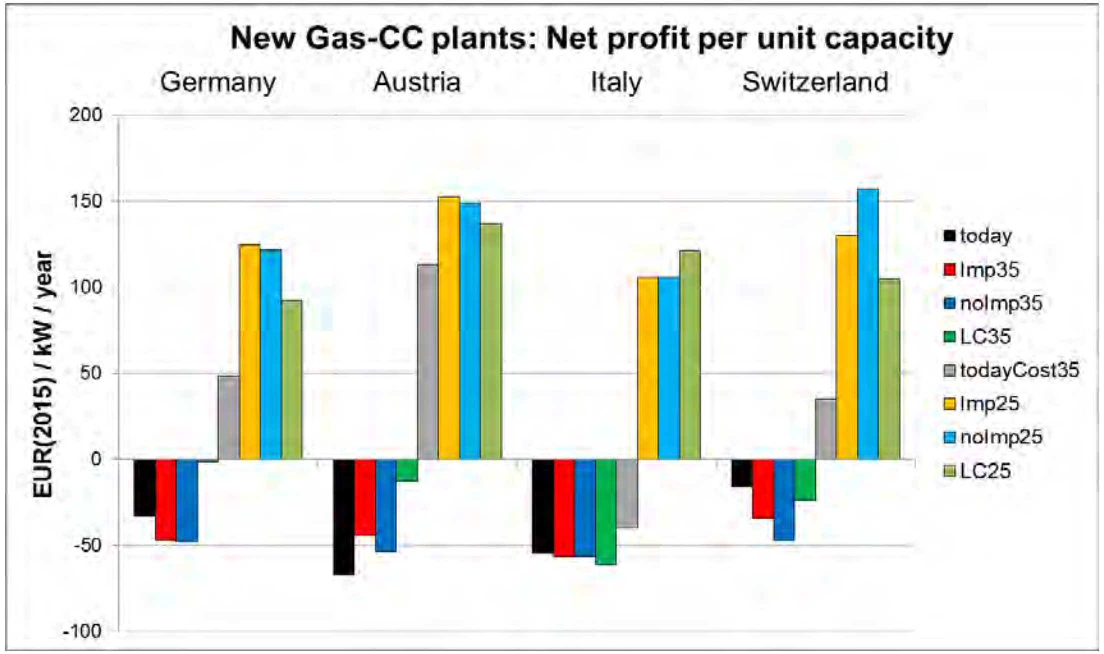


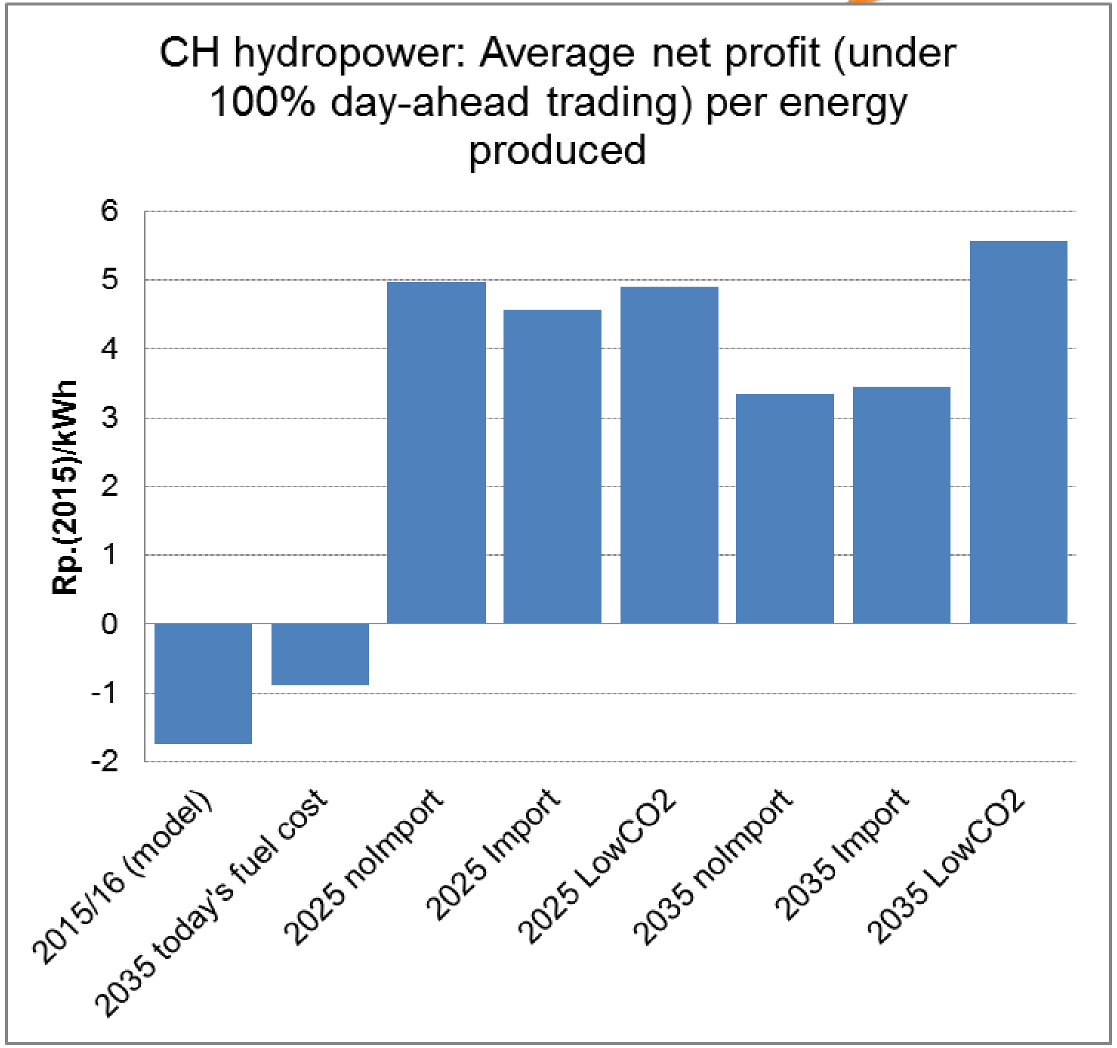




Investments in batteries:
Germany: 3 GW
France: 4 GW
Italy: 8 GW

Profits (preliminary results with other, similar scenarios)





- **Today**, building new gas plants seems not to be profitable
- Gas plants can be profitable, **Germany and Austria**, under today's cost assumption in 2035, where such gas plants can run in base load to replace the vanishing nuclear and coal base-load production.
- In **Italy in 2035**, gas plants cannot operate at enough load hours to produce enough operational profit in all scenarios.

Conclusions

- If **gas and CO_2 prices are rising** then electricity prices will raise again
  - In **Germany**, CO_2 prices have a greater impact on electricity prices than in the other countries due to the still remaining solid-based generation in the domestic supply mix
  - In **France**, prices follow the developments in the neighboring countries but remain the lowest
  - **Italy** remains a country with high prices due to the high domestic gas share; the high capacity factor of solar PV accentuates price dampening during noon
  - In **Switzerland**, prices closely follow the increase in gas price (even though the country does not build gas power plants; the country is a hub influenced by its neighbors)
- Intra-day **storage helps in mitigating peak prices and reduces volatility**, and in large scales can complement hydro storage (and participates in arbitrage trade)
- **Market integration** and **higher decentralization/non-dispatchable capacities** reduces the strategic behavior from producers

Publications & Other Support

- 2018 Submitted paper: ***“The future developments of the electricity prices in view of the implementation of the Paris Agreements: will the current trends prevail, or a reversal is ahead?”***
- 2017 Report: **“Oligopolistic capacity expansion with subsequent market-bidding under transmission constraints” -** co-financed by EWG-BFE research programme **https://www.aramis.admin.ch/Default.aspx?DocumentID=46075**
- 2018 Report on Profitability of Swiss Hydropower – co-financed by VSE-PSEL research programme