High taxes on cloudy days - Dynamic state-induced price components in power markets

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FCN | Future Energy Consumer Needs and Behavior | E.ON Energy Research Center | RWTH AACHEN UNIVERSITY

Background and Motivation

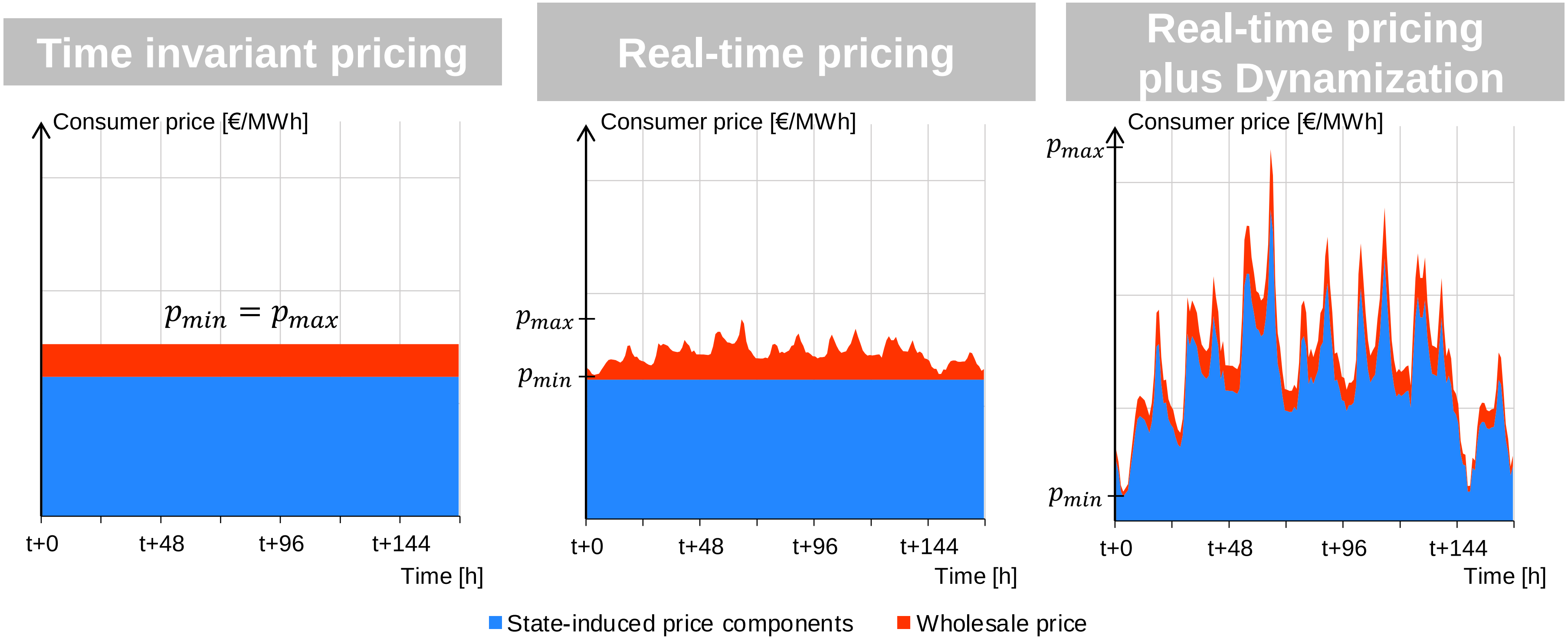
- **Energy policy objectives**
  - cut emissions to 80-95% below 1990 levels by 2050 *(European Commission, 2011)*
  - expansion of power generation from renewable sources, especially variable renewables like wind and solar

- **Economic consequences**
  - decreasing utilisation of variable renewables
  - unchanged demand for thermal backup capacities

→ Dynamization of state-induced price components aims to address these adverse effects

Fundamental Idea of Dynamization

Example for dynamization based on German power market data



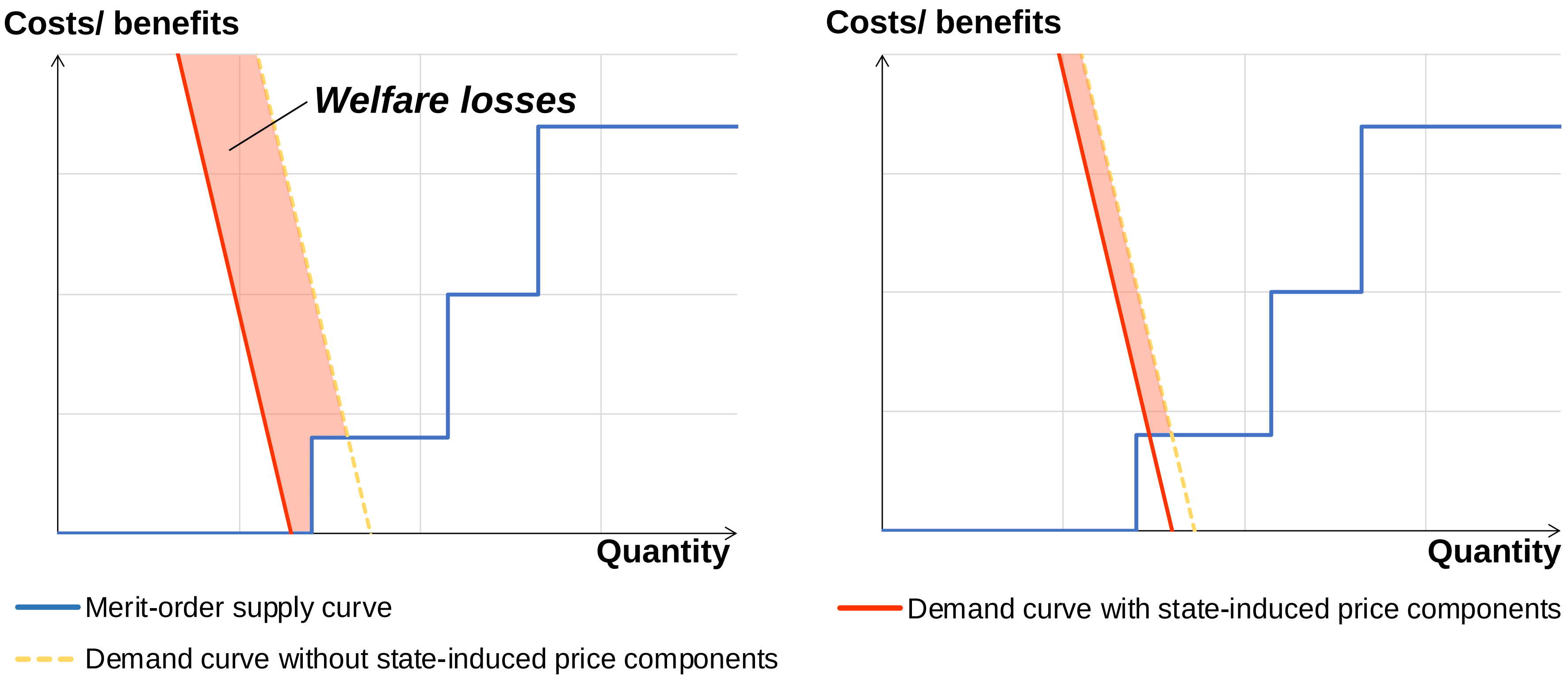
Germany 20.11.2013 - 27.11.2013, Source: Open Power Data

- In case of dynamization state-induced price components are set proportional to wholesale prices

Qualitative analysis

Low demand and high supply from VRE → low state-induced price components

No Dynamization	Dynamization

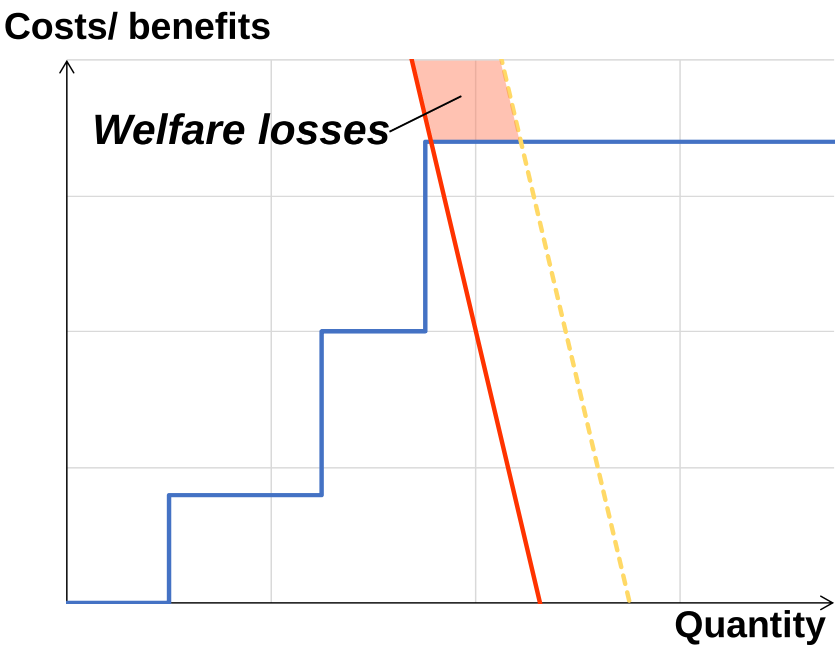


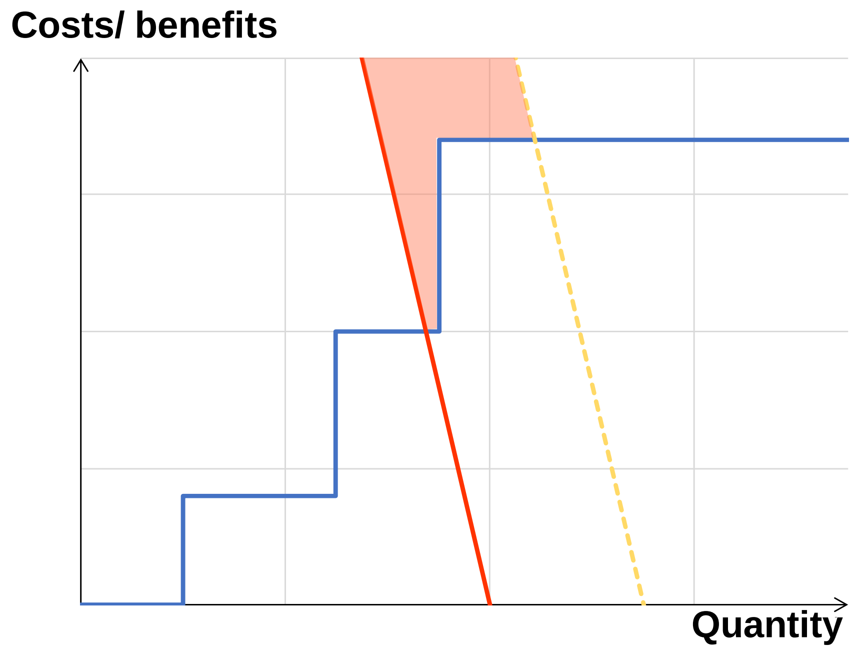
- **Advantages:** Curtailment is avoided and welfare losses are decreased
- **Disadvantages:** Increased thermal generation from mid-load plants

Qualitative analysis

High demand and low supply from VRE → high state-induced price components

No Dynamization	Dynamization





Merit-order supply curve

Demand curve with state-induced price components

Demand curve without state-induced price components

- **Advantages:** Decreased demand for peak-load capacities
- **Disadvantages:** Welfare losses increase

Quantitative analysis

Model of the power market incorporating effects of taxation

(Stylized) bilevel optimization problem

Decision Variables

$sup_{g,t}$: Supply of generator g in time period t

$dem_{c,t}$: Demand of consumer c in time period t

eeg_t: level of levy to finance renewables in period t

$cap_{g \in TH}$: Capacity of thermal technology g

Bilevel problem

$$\underset{sup,dem,eeg}{\boldsymbol{max}} \sum_{c,t} (MU_{c,t} - eeg_t) * dem_{c,t} - \sum_{g,t} MC_g * sup_{g,t}$$

$$s.t.\ balancing\ equation$$

$$technical\ constraints\ incl.\ storage,\ DSM,\ trade\ etc.$$

$$\sum_{g \in RE} revenue_g + \sum_{c,t} eeg_t * dem_{c,t} = 0$$

$$cap_g \in \underset{g\ \in\ Thermal}{\boldsymbol{argmin}} \{revenue_g, revenue_g \geq 0\}$$

Quantitative analysis

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Bilevel problem

Linear

$$\max_{sup,dem,eeg} \sum_{c,t} (MU_{c,t} - eeg_t) * dem_{c,t} - \sum_{g,t} MC_g * sup_{g,t}$$

$$s.t.\ balancing\ equation$$

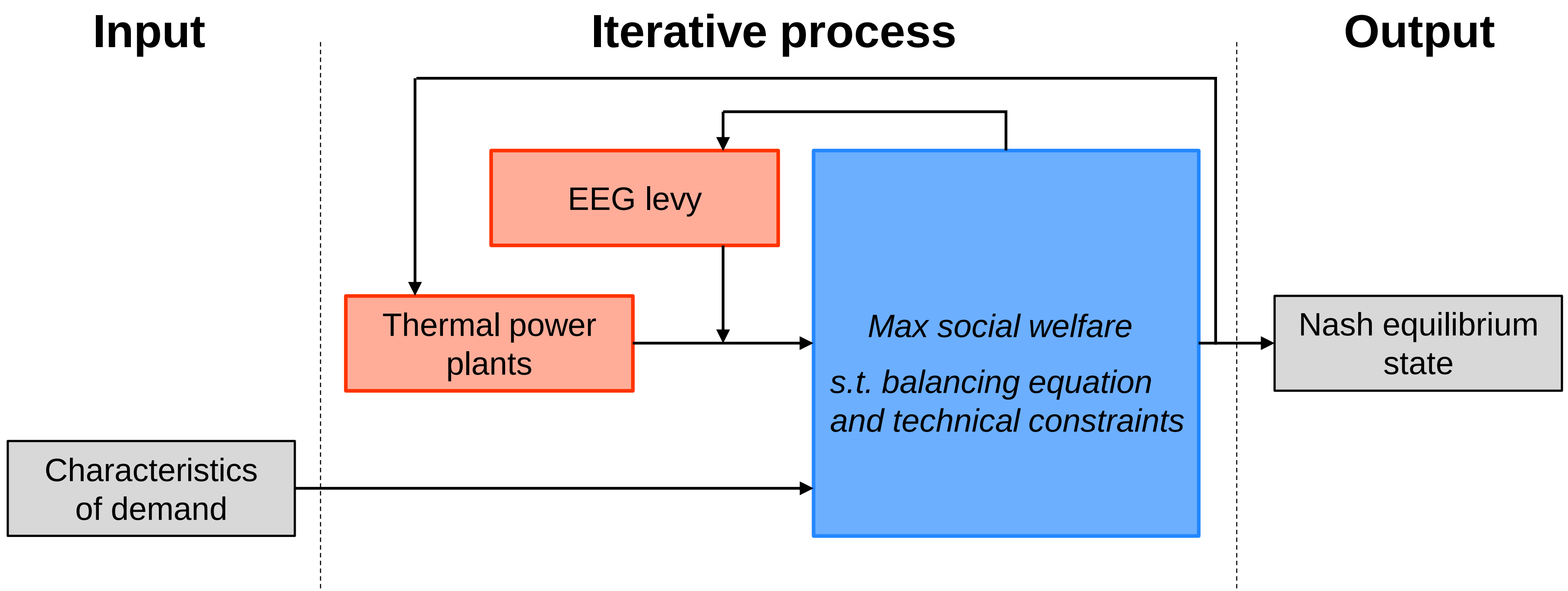
$$technical\ constraints\ incl.\ storage,\ DSM,\ trade\ etc.$$

Non-linear
NP-hard

$$\sum_{g \in RE} revenue_g + \sum_{c,t} eeg_t * dem_{c,t} = 0$$

$$cap_g \in \operatorname*{argmin}_{g\ \in\ Thermal} \{revenue_g, revenue_g \geq 0\}$$

Iteration algorithm to solve non-linear parts of the model



- Linear programming to simulate decisions on dispatch and consumption
- Iterative approach to simulate investment decisions

Quantitative analysis

Application of the model

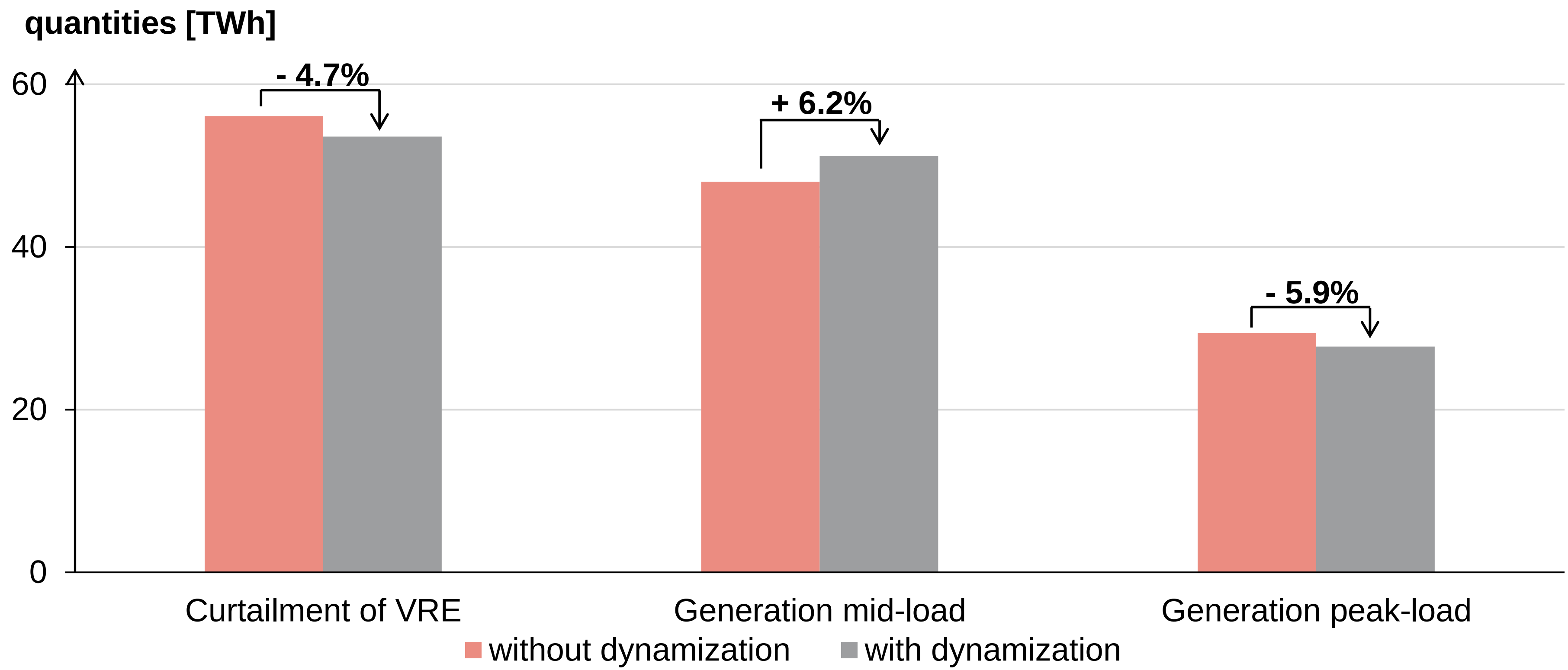
- **Policy framework**
  - Energy-only-market and carbon price
  - Scarcity pricing when demand reaches maximum supply capacity
  - For dynamization this levy is adjusted proportionally to hourly wholesale prices

- **Parameterization**
  - Largely decarbonized German energy system in 2050 according to *Gerhardt et al., 2015*

- **Computed indicators**
  - Integration costs: costs incurred by VRE on a system level *(Hirth, 2013)*
  - Decarbonisation costs: costs of avoiding greenhouse gas emissions

Results

Change in generation quantities at a carbon price of 100 €/tCO2 and -0.05 own-price elasticity of demand

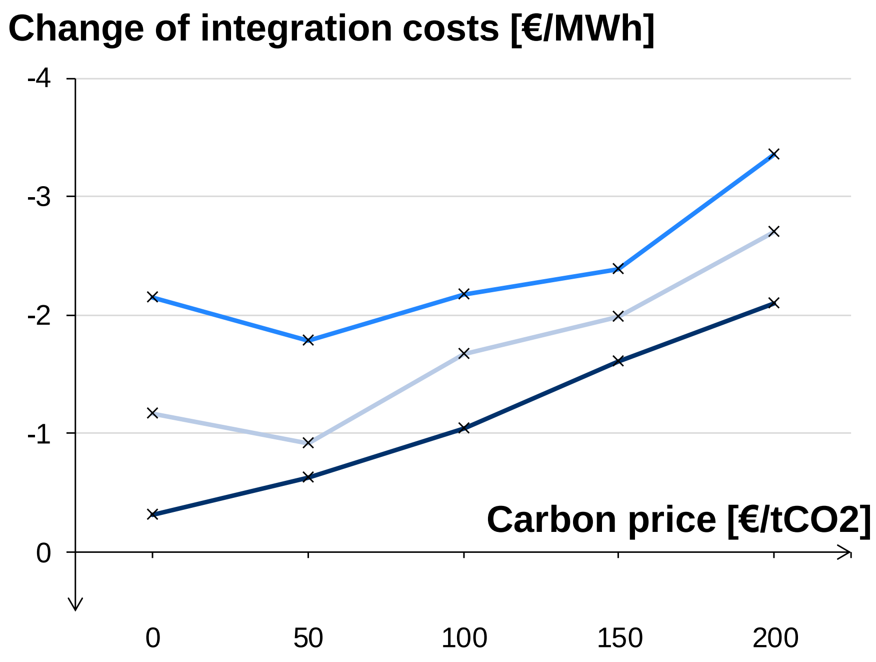


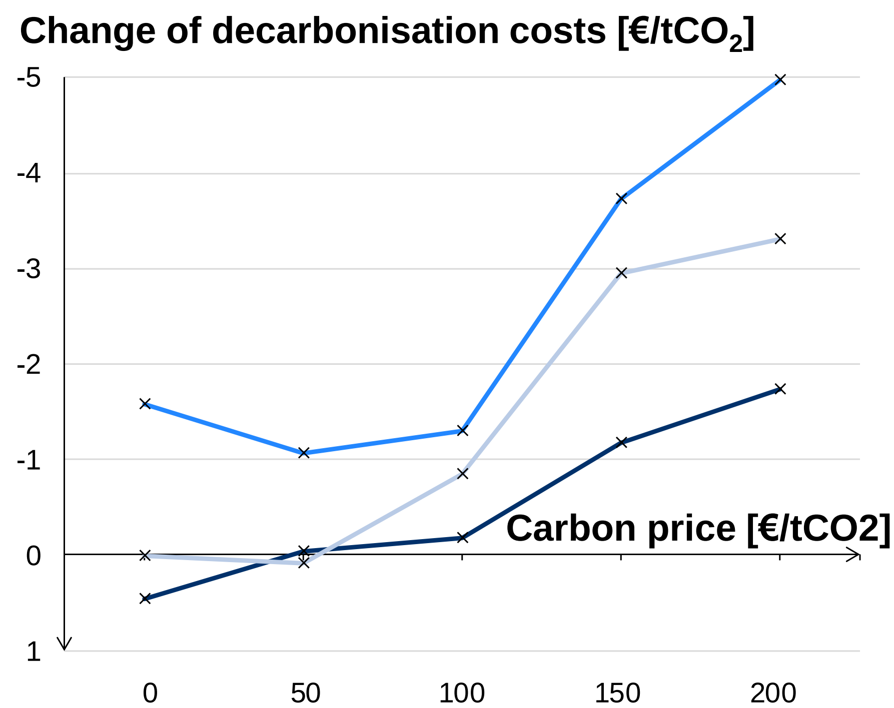
- Curtailment and generation from peak-load power plants is decreased
- Overall generation increases by 5.2 TWh and emissions might increase

Results

Impact for different carbon prices and own-price elasticities of demand

Integration Costs	Decarbonisation Costs



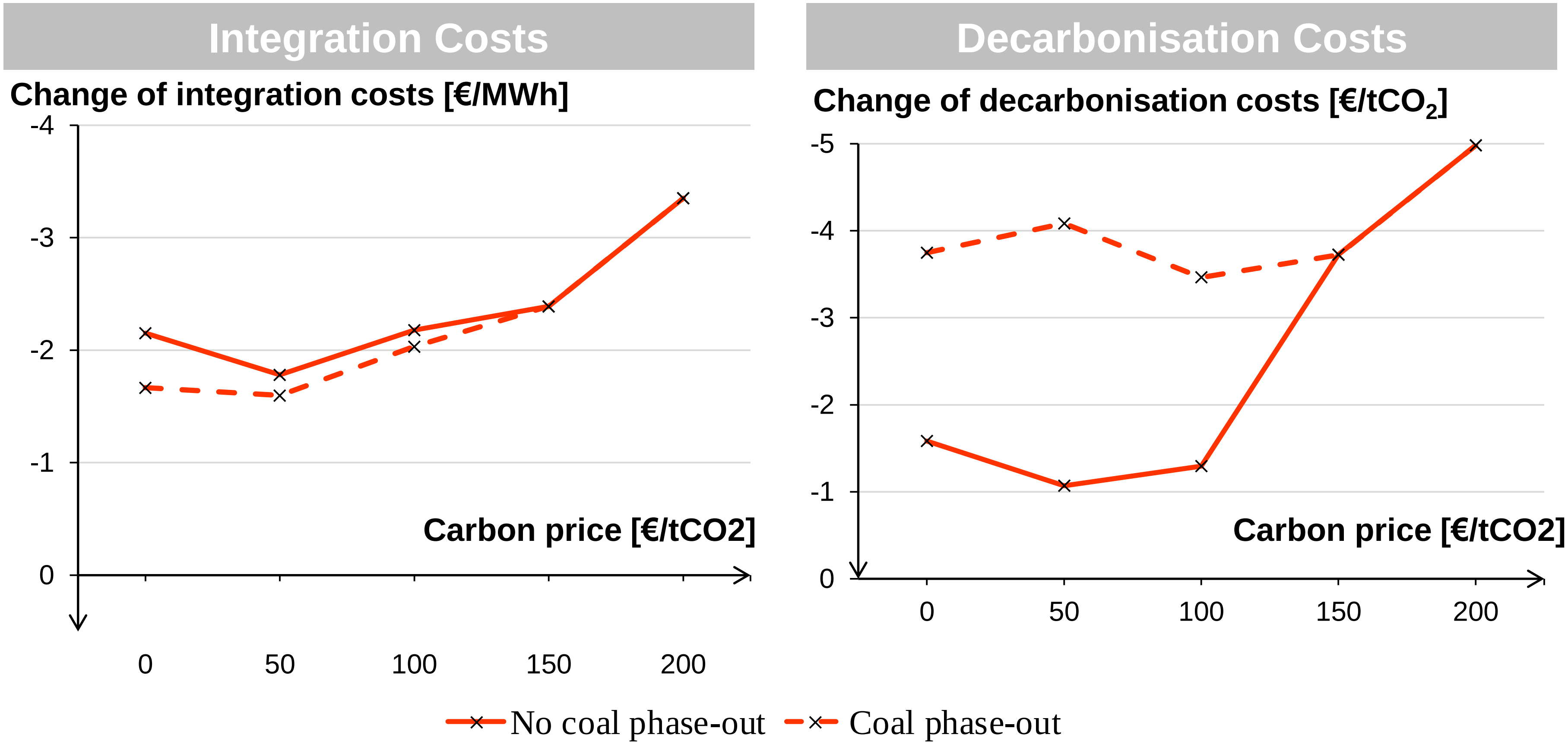


$\varepsilon = -0.0029$ $\varepsilon = -0.025$ $\varepsilon = -0.05$

- Effects increase with the own-price elasticity of demand
- Effects on decarbonisation costs are highly dependent on the respective mid- and peak-load technologies

Results

Impact of coal phase-out



- Adverse effects on emissions from shift towards mid-load power plants is avoided, if coal power plants are phased out

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Conclusion

- **Findings**
  - Dynamization generally supports the integration of variable RE into the energy system
  - Dynamization supports the overarching target of decarbonisation given the right policy framework

- **Outlook**
  - Potential of dynamization to avoid grid congestions and optimize grid utilisation (Smart-Grid)

Thank you for your attention.

Contact

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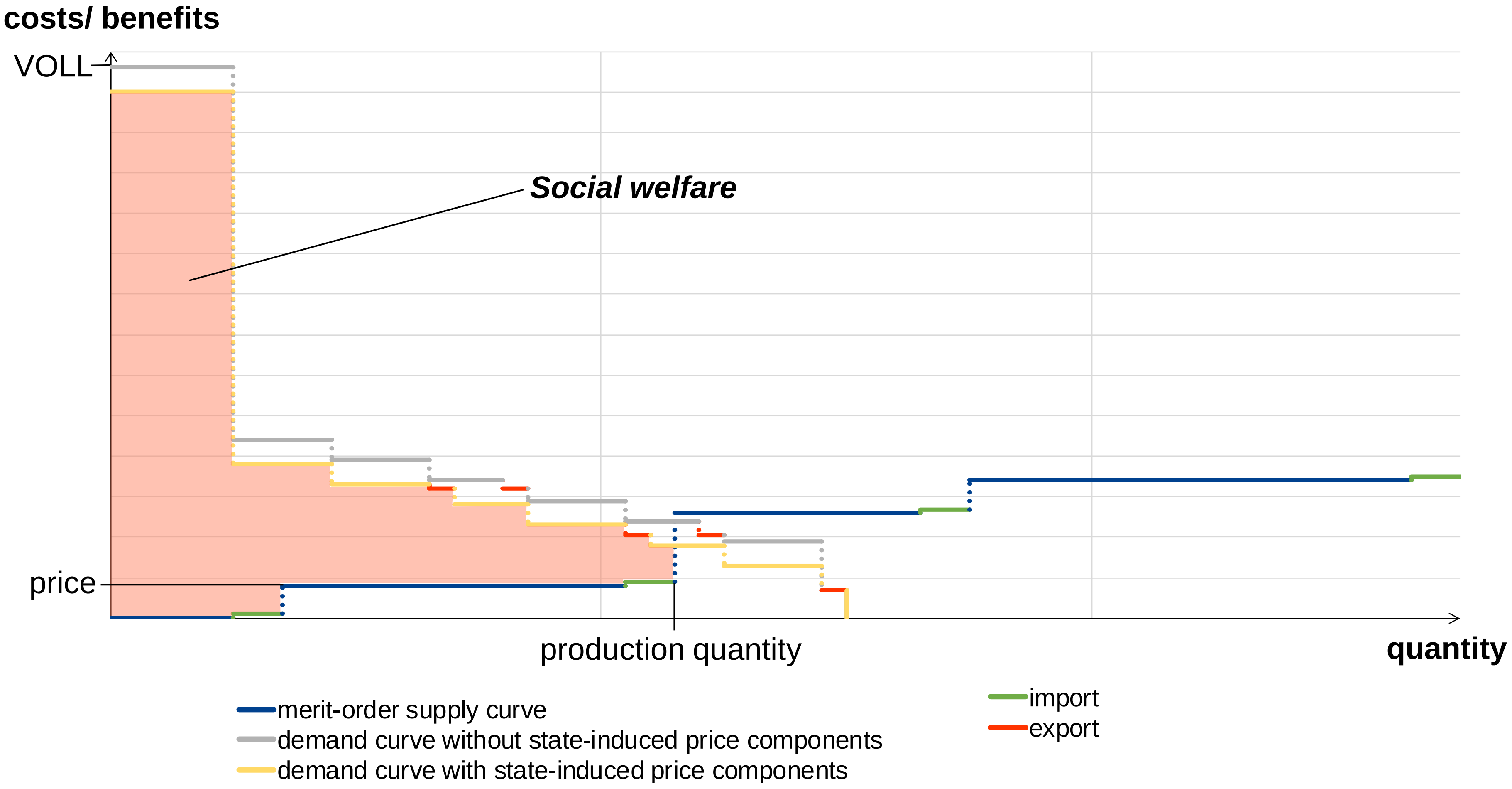
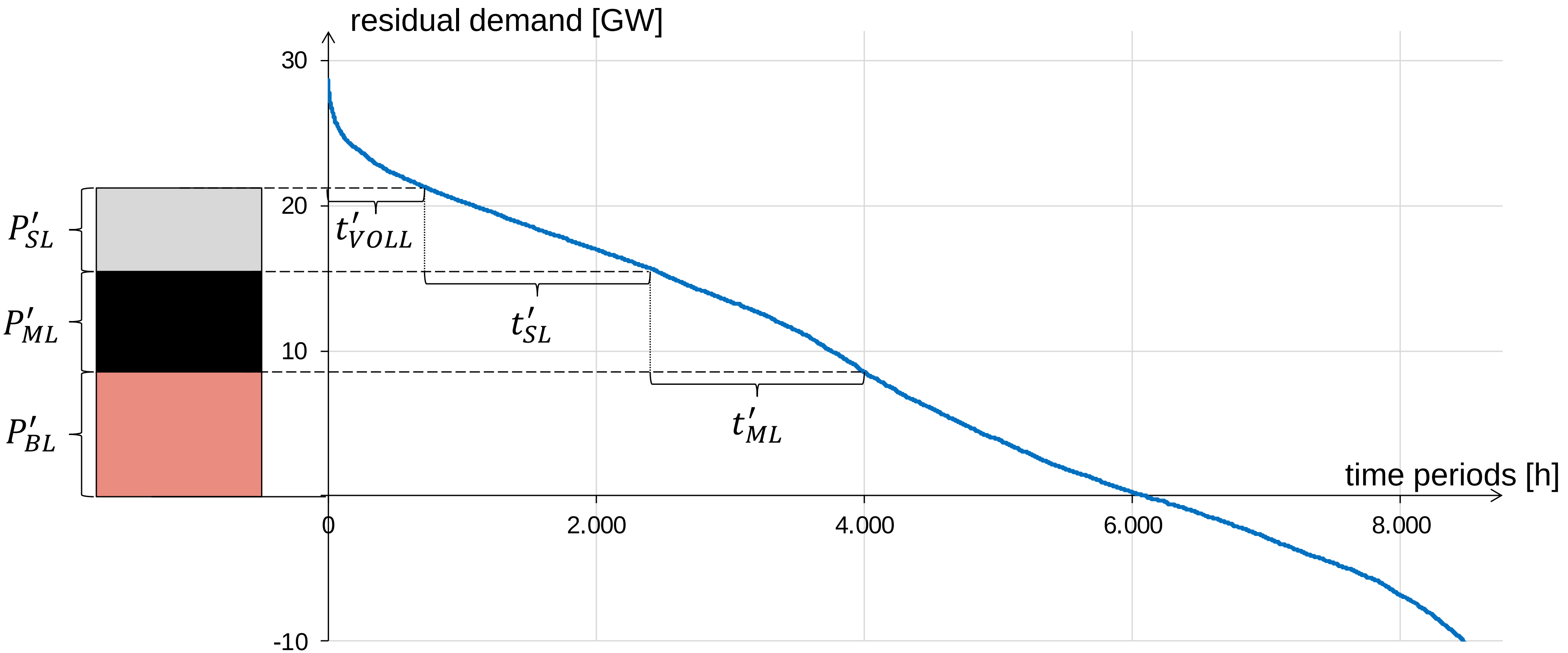
Mechanics of the short-term market simulation



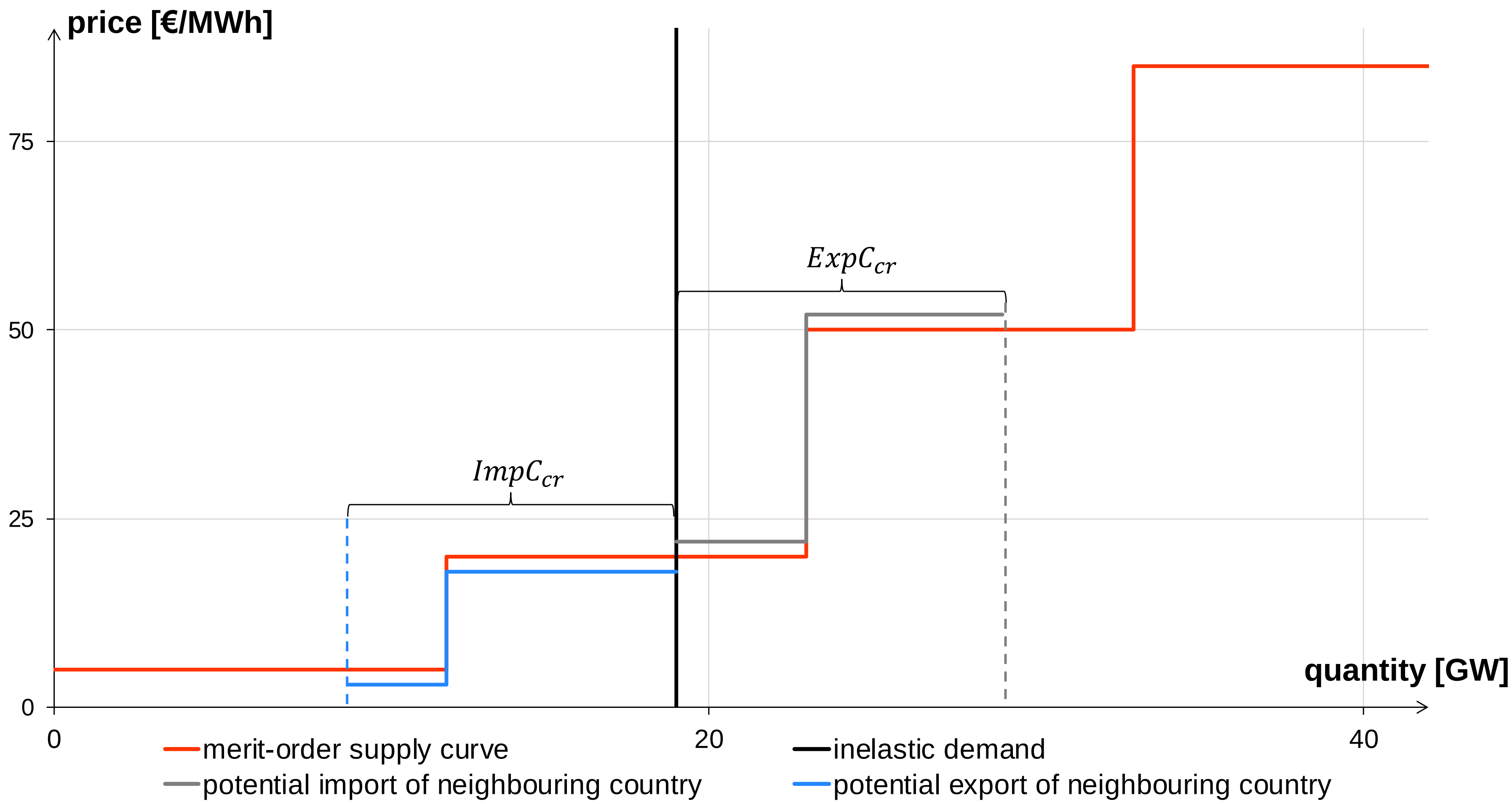
Backup

Long-term equilibrium of the thermal power plant portfolio



- Residual demand represents the share of demand covered by thermal power plants
- At a Nash equilibrium the revenue of every technology takes the smallest non-negative value possible

Import and Export in the Short-Term Model



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