technische universität dortmund

Institute of Energy Systems, Energy Efficiency and Energy Economics

A market-oriented stochastic optimization framework and its application in the energy domain

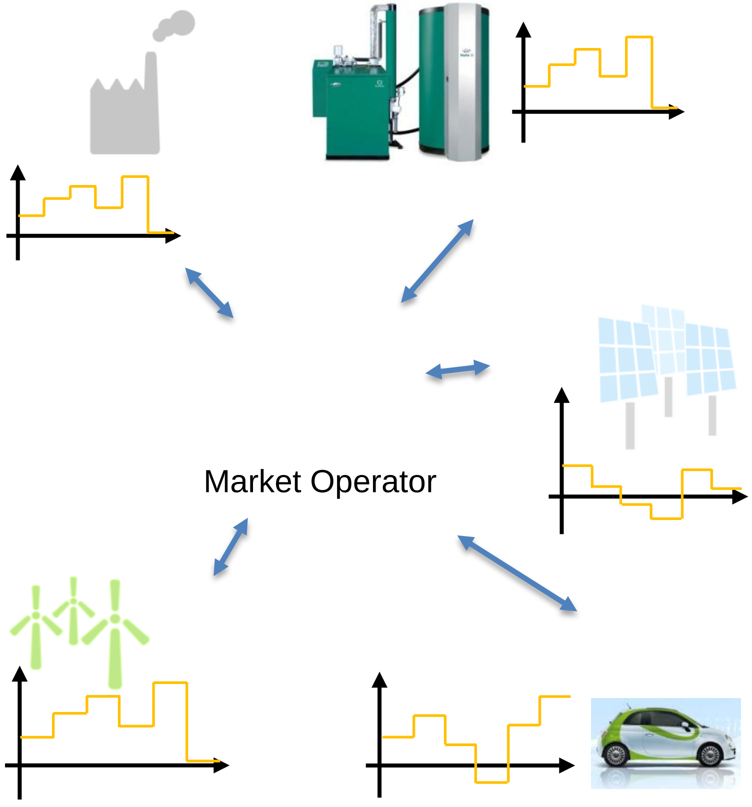
Dipl.-Inf. Sebastian Ruthe | Vienna, 13.11.2013

Agenda

- Introduction
- Model and problem formulation
- Motivation for a stochastic market model
- Stochastic market optimization framework
- Preliminary simulation results

Introduction

- Motivation/ Assumptions
  - Increase in renewable energy generation
  - Increasing amount of DG and DRR
  - Trend towards smaller units
  - Trend towards locally distributed units
- Characteristics of DG and DRR
  - Individual cost function
  - Local device restrictions
  - Represented by a software agent that participates in the market system
- Problem domain:
  - Optimization of unit commitment
  - **Goal:** Increase overall welfare by reducing the energy generation costs



Model and problem formulation

- Each prosumer agent $i \in I := \{i \mid 1 \leq i \leq n, i \in \mathbb{N}\}$ has a …
  - Preferred energy allocation vector $x = (x[1], \ldots, x[k])^T$
    - $x[j] > 0$: consumption in period j
    - $x[j] \leq 0$: production in period j
  - Individual cost function $\mathrm{cost}(\cdot) : \mathbb{R}^k \mapsto \mathbb{R}$
  - Local device restrictions $\mathfrak{R} \subseteq \mathbb{R}^k$
  - Typical values: $k = 96,\ n \geq 1\mathrm{Mio.}$

- Definition **Unit Commitment Problem** (UCP): The UCP comprises the task of computing $n = |I|$ energy schedules $x_i \in \mathbb{R}^k$, such that

$$\underset{x_i \in \mathfrak{R}_i}{\mathrm{argmin}} \sum_{i \in I} \mathrm{cost}_i(x_i)$$

$$s.t. \quad \boxed{\sum_{i \in I} x_i[j] = 0;} \quad \forall j : 1 \leq j \leq k$$

Lagrange Relaxation → General Equilibrium Problem

- Lagrange Relaxation

$$\mathrm{L}_{\mathrm{Dual}} := \max_{\lambda \in \mathbb{R}^k} \left\{ L(\lambda) := \operatorname*{argmin}_{x_i \in \mathfrak{R}^k} \left\{ \sum_{i \in I} \mathrm{cost}_i(x_i) \boxed{- \sum_{i \in I} \lambda \cdot x_i} \right\} \right\}$$

Lagrange Multiplier

eparable

  - Note: $$\max_{\boldsymbol{\lambda} \in \mathbb{R}^{\boldsymbol{k}}} \quad \Leftrightarrow \quad \boldsymbol{\partial L / \partial \lambda = 0} \quad \Leftrightarrow \quad \sum_{\boldsymbol{i \in I}} \boldsymbol{x_i = 0}$$

- Definition **General Equilibrium Problem (GEP)**: *The GEP comprises the task of finding a price vector* $\boldsymbol{p} = (p_1, \ldots, p_k)$ *such that:*

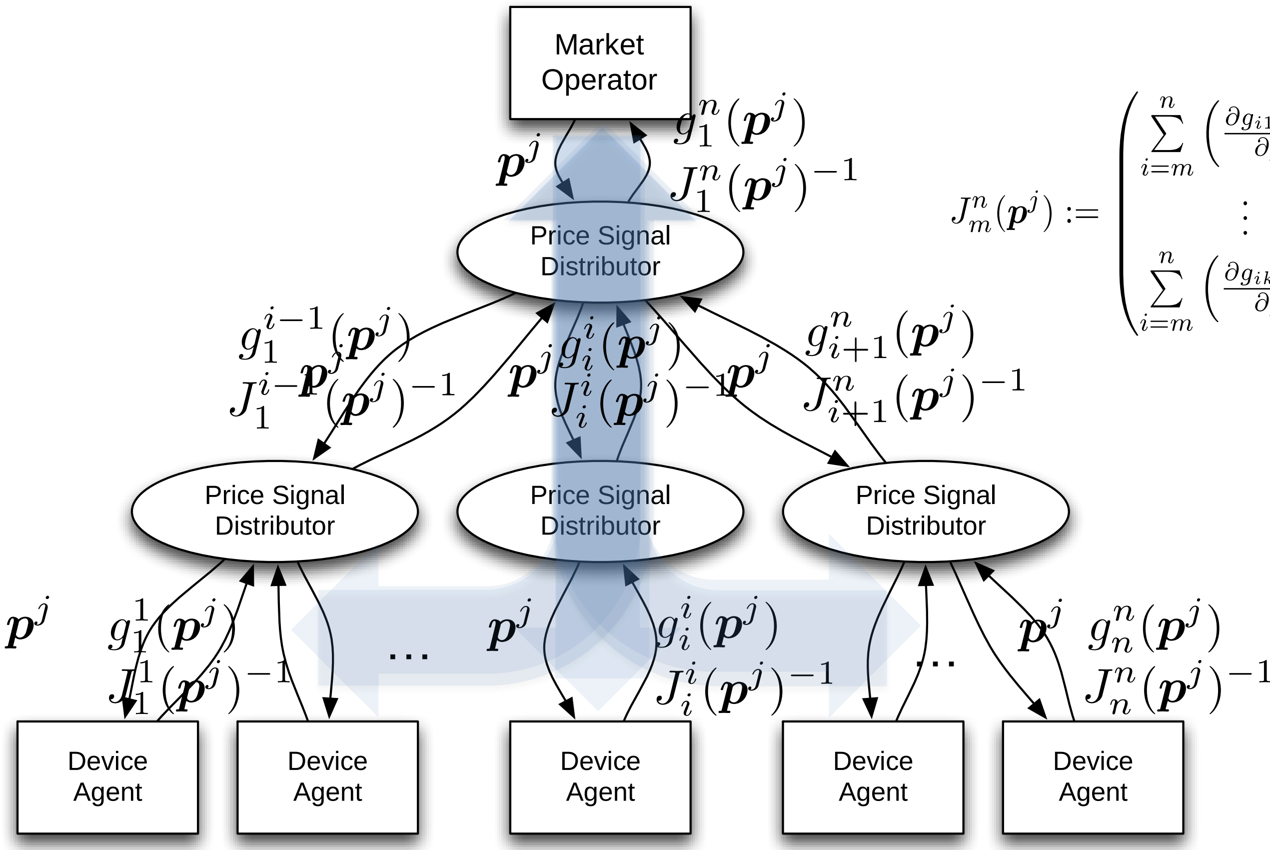
$$\boxed{\sum_{i \in I} g_i(\boldsymbol{p}) = 0}$$

Root finding of k non-linear equations

$$g_i(\boldsymbol{p}) := \operatorname*{argmin}_{\boldsymbol{x}_i} \ \mathrm{cost}(\boldsymbol{x}_i) + \boldsymbol{p} \cdot \boldsymbol{x}_i \qquad \forall\, i \in I$$

Newton Raphson solution/ Hierarchical information flow

$$\boldsymbol{p}^{j+1} = \boldsymbol{p}^{j} - J_1^n(\boldsymbol{p}^j)^{-1} \cdot g_1^n(\boldsymbol{p}^j)$$



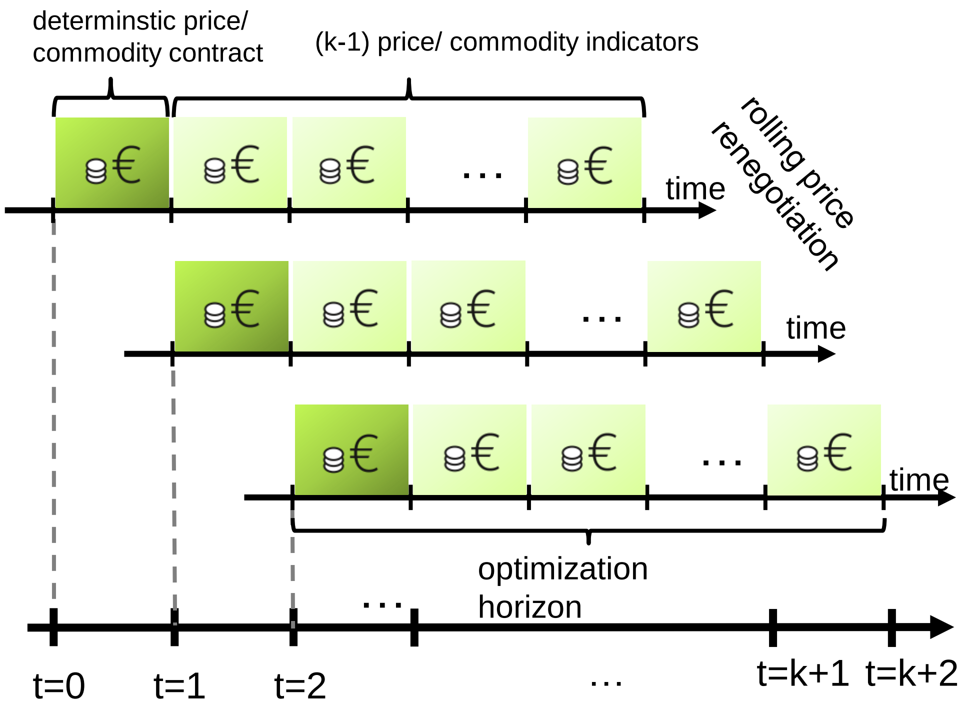
$$g_m^n(\boldsymbol{p}^j) := \sum_{i=m}^{n} g_i(\boldsymbol{p}^j)$$

$$J_m^n(\boldsymbol{p}^j) := \begin{pmatrix} \sum_{i=m}^{n} \left(\frac{\partial g_{i1}(\boldsymbol{p}^j)}{\partial p_1}\right) & \cdots & \sum_{i=m}^{n} \left(\frac{\partial g_{i1}(\boldsymbol{p}^j)}{\partial p_k}\right) \\ \vdots & \ddots & \vdots \\ \sum_{i=m}^{n} \left(\frac{\partial g_{ik}(\boldsymbol{p}^j)}{\partial p_1}\right) & \cdots & \sum_{i=m}^{n} \left(\frac{\partial g_{ik}(\boldsymbol{p}^j)}{\partial p_k}\right) \end{pmatrix}$$

$$\boldsymbol{p}^j = \begin{pmatrix} p_0^j \\ p_1^j \\ \vdots \\ p_k^j \end{pmatrix}$$

Summary deterministic market model

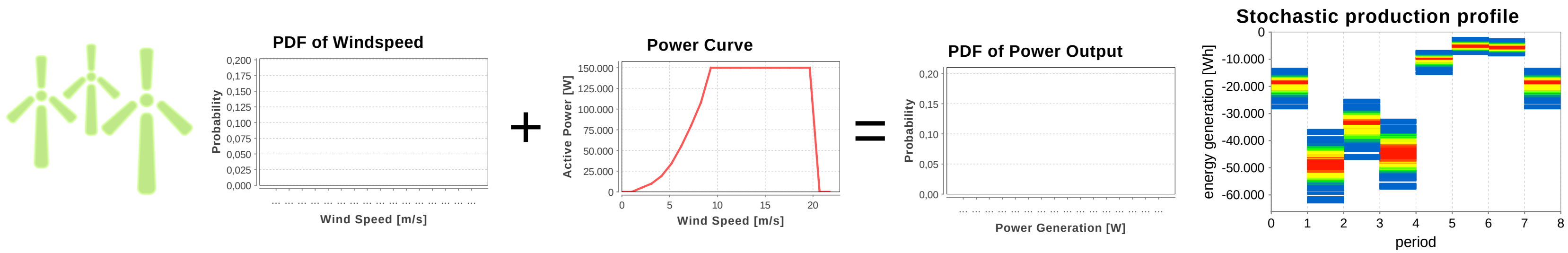
- Fix optimization horizon (typically 96 - ¼h periods)
- (De)centralized deterministic market model ➔ iterative NR based price protocol determines market clearing price
- Autonomous software agents negotiate energy schedules
- Each unit has an individual gain function $g_i(\cdot) : \mathbb{R}^k \mapsto \mathbb{R}^k$ that models the reaction on the price signal
- Rolling horizon implementation



Motivation stochastic market framework

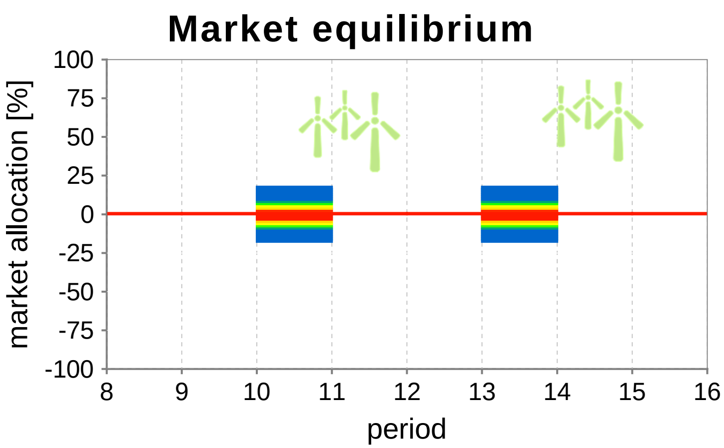
- An increasing amount of market participants have stochastic consumption/ production profiles:

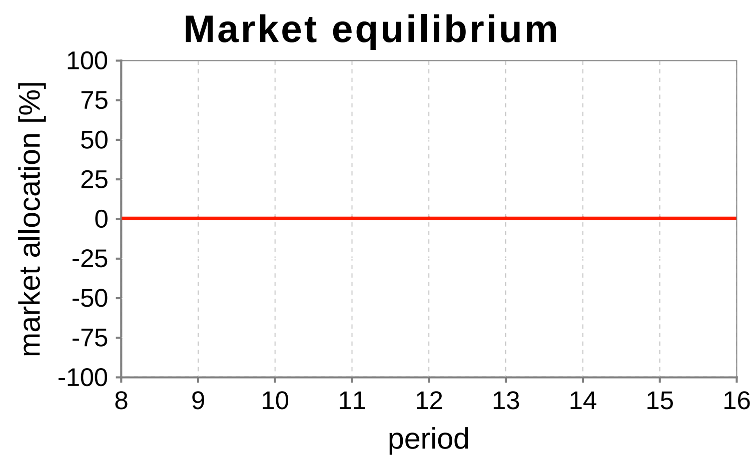
- Example wind farm:

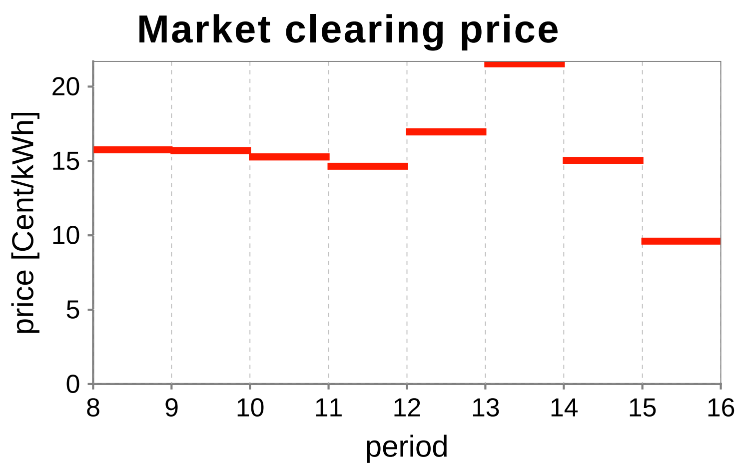


- Example electric vehicle as DRR:

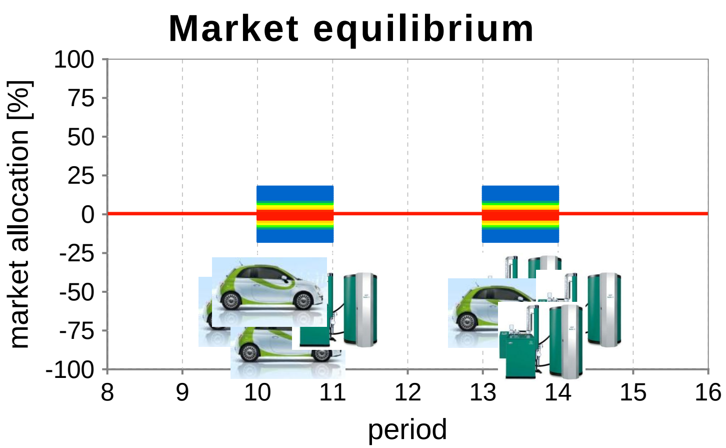
Insufficient incentives

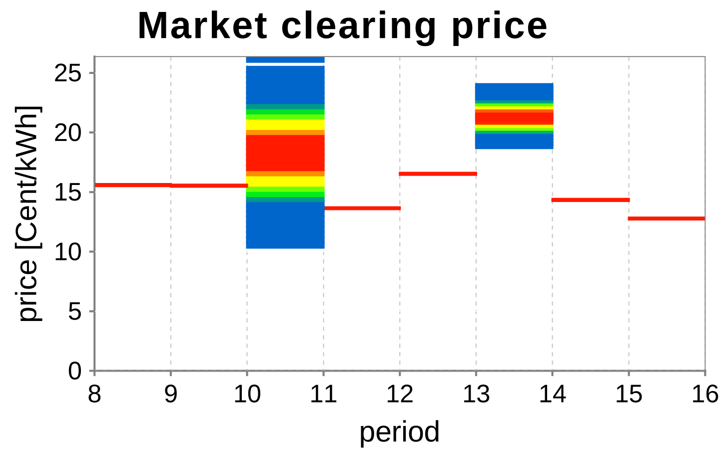


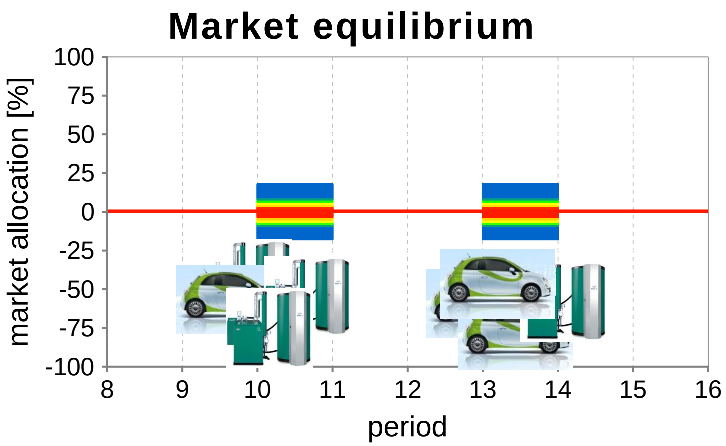


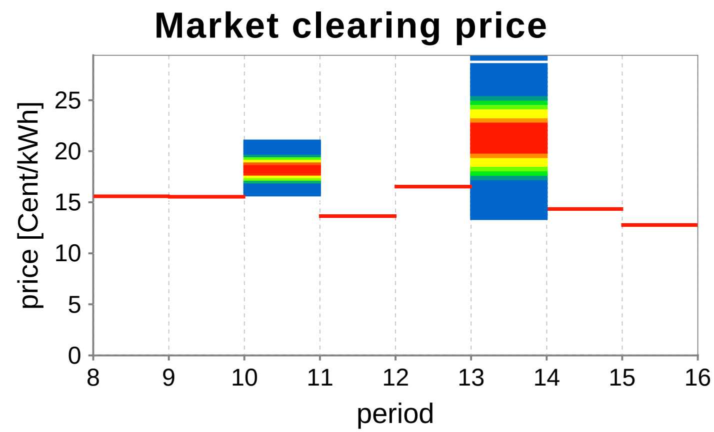


New incentives for flexibilities



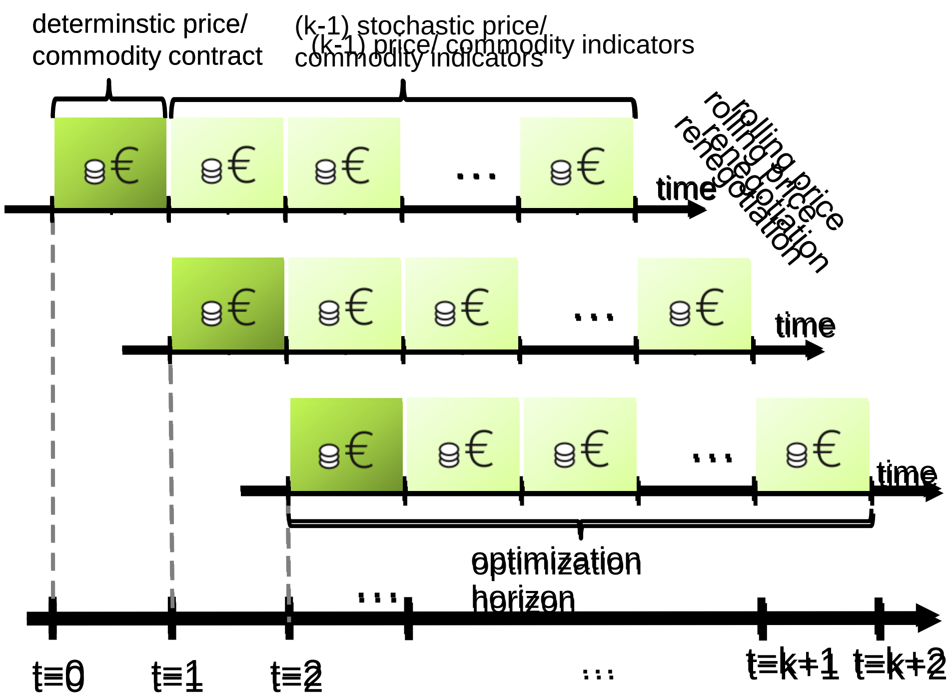






Stochastic multi commodity market model

- Extended Model
  - Stochastic commodity allocations (PDF for each commodity)
  - Commodity uncertainties are mapped to price uncertainties
- Assumptions:
  - Stochastic independence among multiple consumer/ producer
  - No intermediate forecast updates



Problem formulation

- Definition **Stochastic General Equilibrium Problem (SGEP)**: *The SGEP comprises the task of finding a stochastic price vector* $\boldsymbol{P} = (P_1, \dots, P_k)$ *where* $P_i : \Omega \to \mathbb{R}$ *are Random Variables such that*:

$$\mathbb{E}\left[\sum_{i=1}^{n} g_i(\boldsymbol{P})\right] = 0$$

Local stochastic optimization

$$g_i(\boldsymbol{P}) := \max_{\boldsymbol{X}_i} \ \mathrm{cost}(\boldsymbol{X}_i) + \mathbb{E}[\boldsymbol{P}] \cdot \mathbb{E}[\boldsymbol{X}_i]$$

$g_i(\boldsymbol{\rho}) = (X_{i1} = g_{i1}(\boldsymbol{P}), X_{i2} = g_{i2}(\boldsymbol{P}), \dots, X_{ik} = g_{ik}(\boldsymbol{P}))$ *denotes the stochastic commodity vector.* $X_{ij} : \Omega \to \mathbb{R}$ *are Random Variables which indicate the stochastic demand / supply of the i-th market participant (Agent) in the j-th period.*

Mapping commodity uncertainties to price domain

- How can we approximate the influence of an uncertain allocation deviation in period m on market prices?
  - We may sample the rebalancing response on a given price incentive.

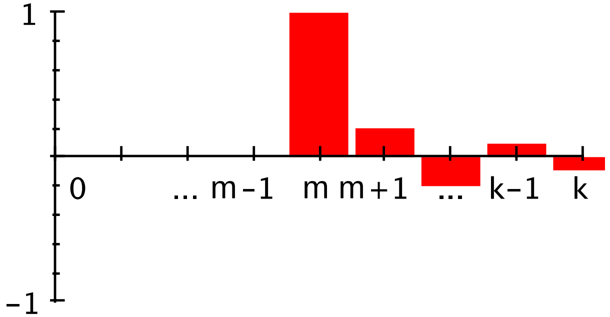
- Definition **Rebalancing Price Response (RePR)**: *For each market participant* i*, the constant price deviation* Δp *in period* m *of the current stochastic price vector* $\boldsymbol{P}$ *an the existing commodity allocation* $\boldsymbol{X}_i = g_i(\boldsymbol{P})$ *the Rebalancing Price Response* $g_{\mathrm{RPR},i}$ *is defined as:*

Market participant

$$g_{\mathrm{RPR},i}(\boldsymbol{P}, m, \Delta p) := \max_{\boldsymbol{X}'_i} \ \mathrm{cost}_i(\boldsymbol{X}'_{\boldsymbol{i}}) + \boldsymbol{X}'_{\boldsymbol{i}} \cdot \boldsymbol{P}'$$

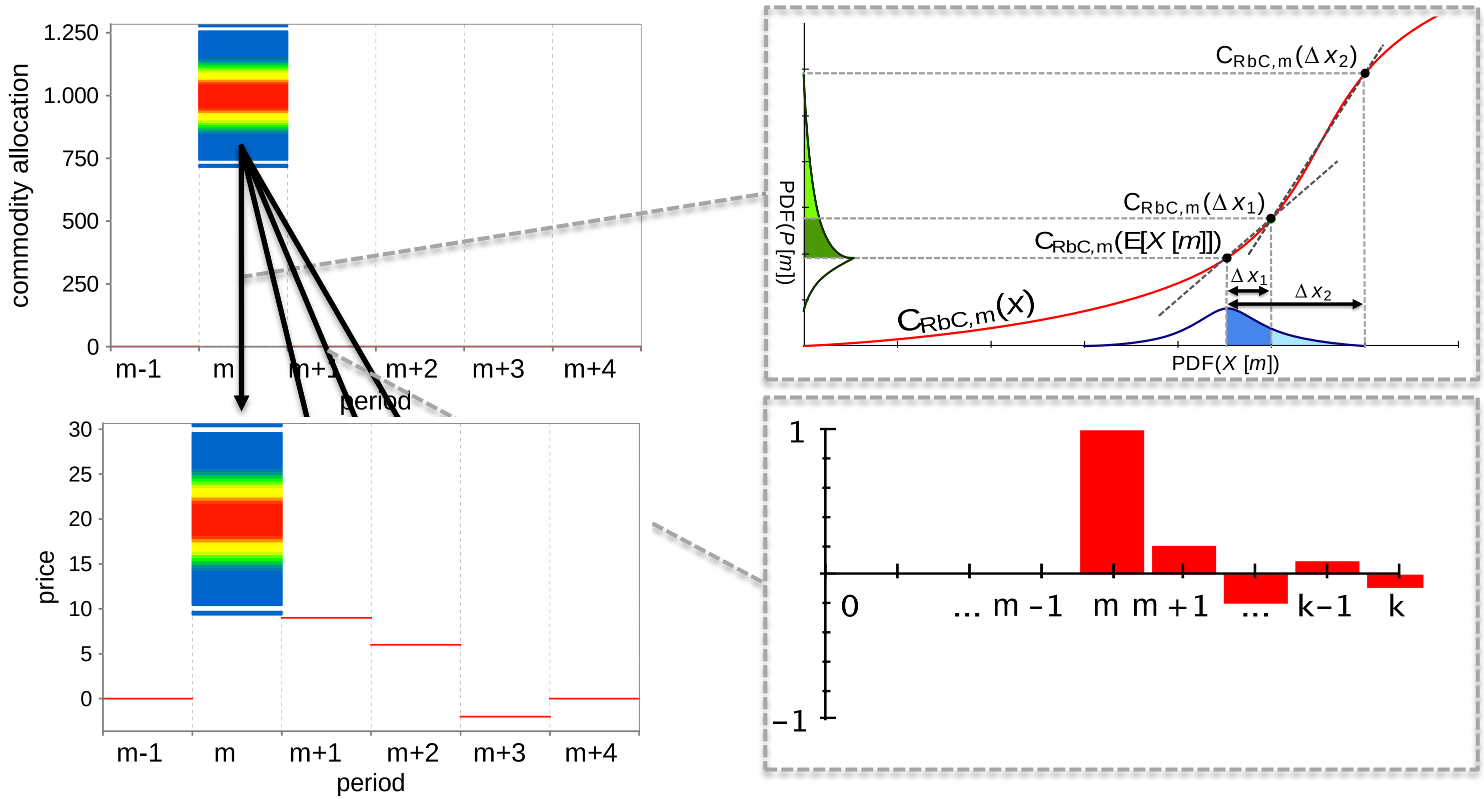
$$s.t. \quad \forall j < m : \boldsymbol{X}'_{\boldsymbol{i}}[j] = \boldsymbol{X}_{\boldsymbol{i}}[j]$$

$$\boldsymbol{P}' := (\boldsymbol{P}_1, \ldots, \boldsymbol{P}_{m-1}, \boldsymbol{P}_m + \Delta p, \boldsymbol{P}_{m+1}, \ldots, \boldsymbol{P}_k)^T$$



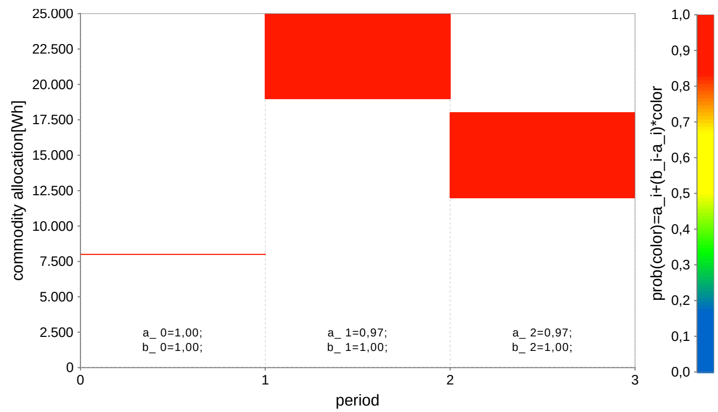
Mapping commodity uncertainties to price domain

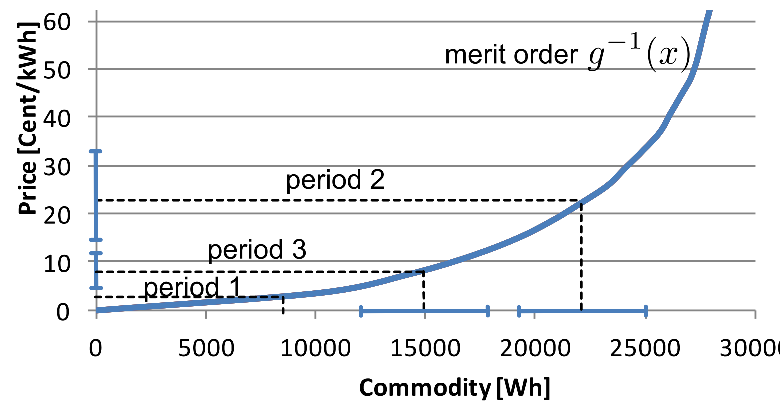
- Given a well chosen set of Rebalancing Price Responses we are now able to approximate the merit order of all market participants.



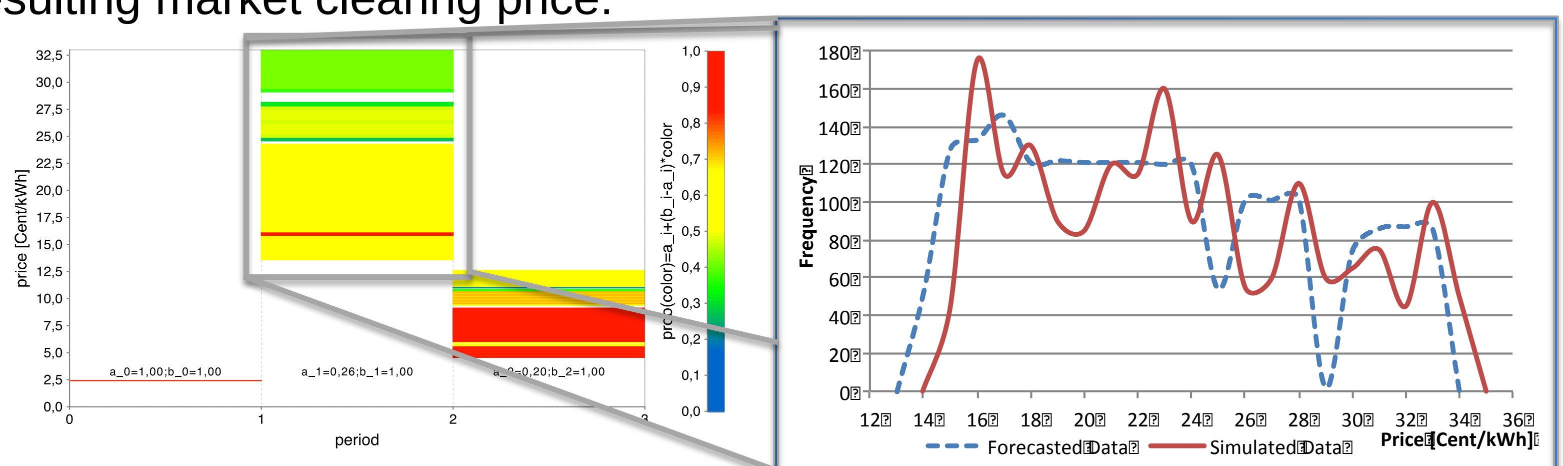
Results: Simple test scenario

- Market setup: stochastic demand (left) merit order of supply (right):



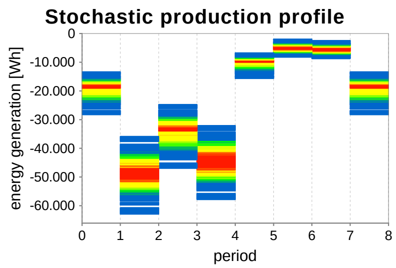


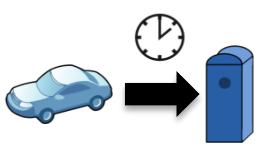
- Resulting market clearing price:

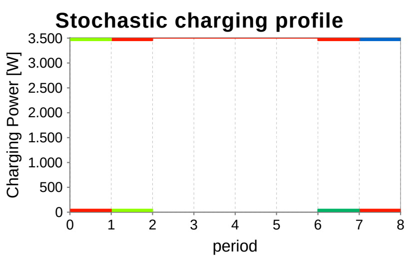


Expected future results

- Modeling of Grid operator → integration of grid constraints
- More robust unit commitment
- New incentives for demand response resources and storage devices
- Better integration of renewables, DG and DRR







Thank you for your attention!