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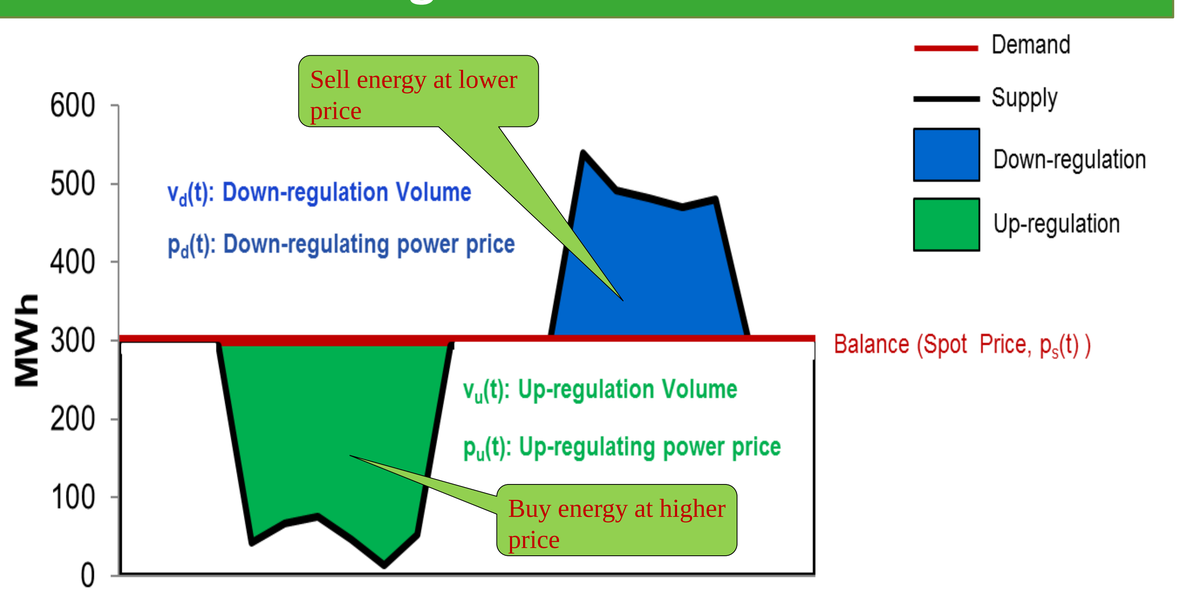
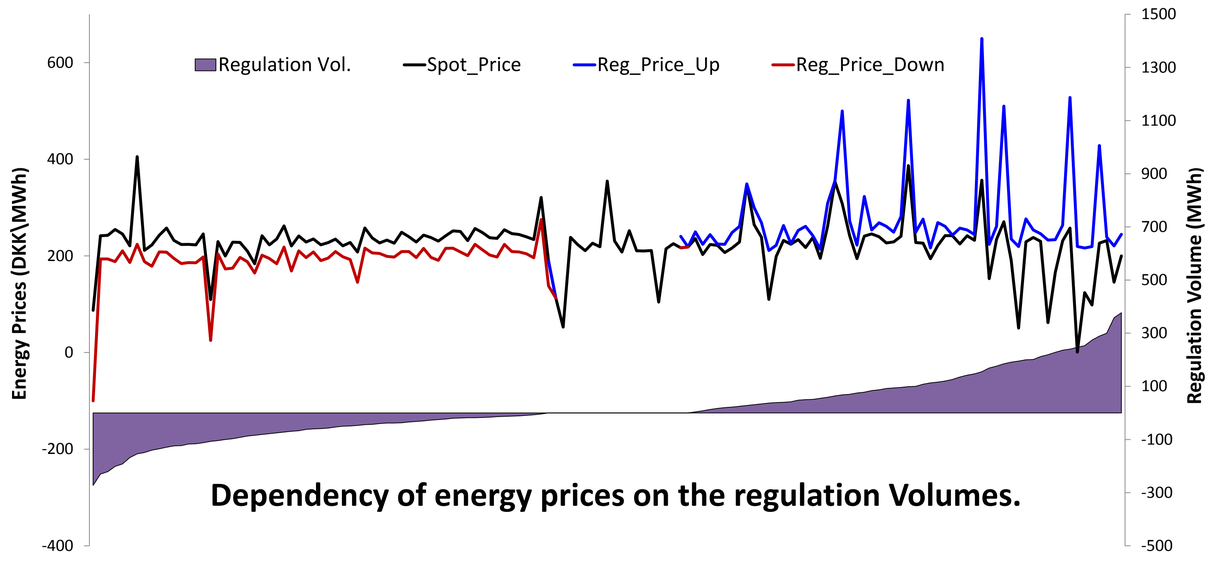
Evaluating the Value of Flexibility in Energy Regulation Markets

This work performs an econometric analysis of the benefits of introducing flexibility in the Danish/Nordic regulating power market. Here, the benefit is measured in terms of the reduction in regulation cost and/or regulation volume that a BRP (market) can achieve. The work investigates the relationships between market power prices and regulation volumes, in order to quantify the effects of flexibility on regulating power prices. Further, it analyzes the benefit for various types of flexibility and market objectives, to detect the type of energy flexibility that maximizes the benefits.

Regulation Market





Dependency of energy prices on the regulation Volumes.

Saving in Regulation Cost

- **Combined regulation cost:**

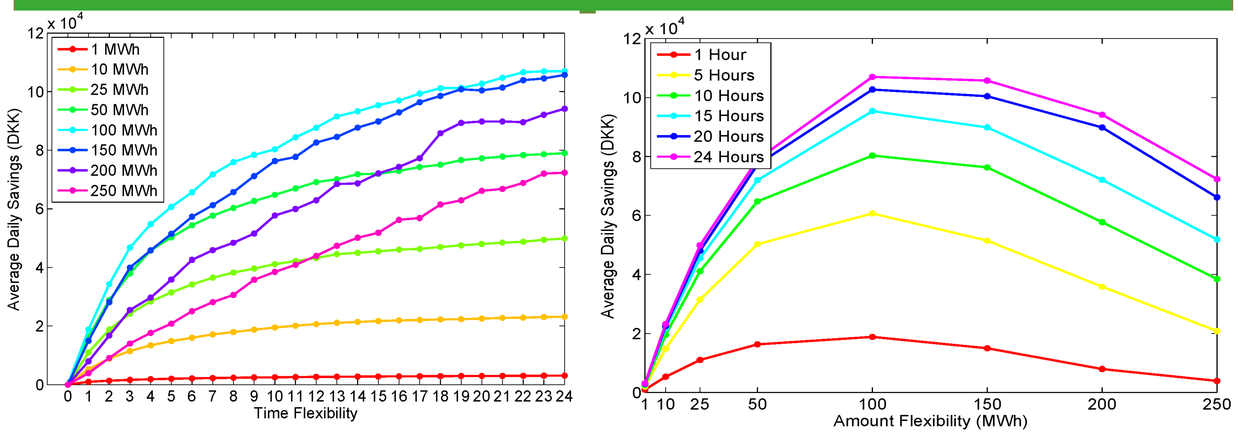
$$R(t,t') = v_{u/d}(t) * |p_{u/d}(t) - p_s(t)| + v_{u/d}(t') * |p_{u/d}(t') - p_s(t')|$$

- **Estimated price after shifting of flexible load**

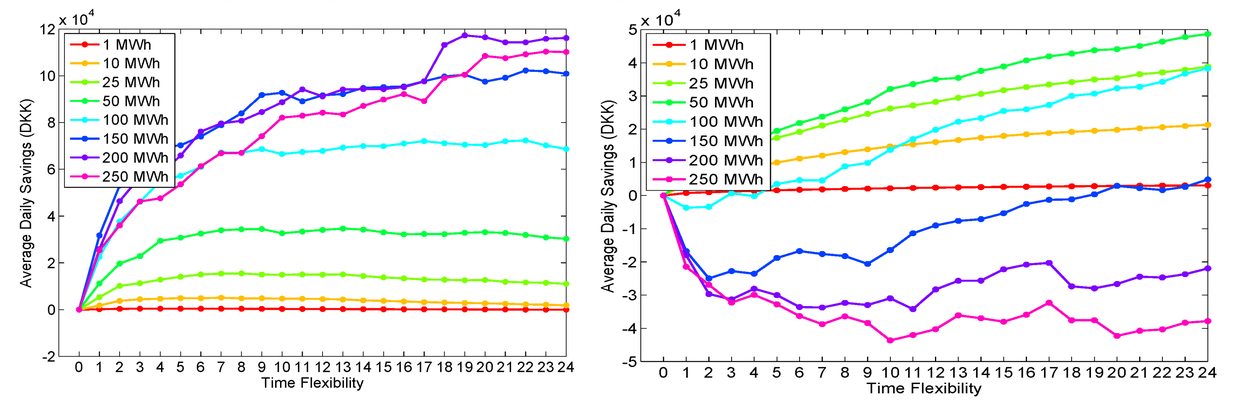
$$E(t,t') = \underline{v_{u/d}(t)} * \left|\underline{p_{u/d}(t)} - p_s(t)\right| + \overline{v_{u/d}(t')} * |\overline{p_{u/d}(t')} - p_s(t')|$$

- **Change in Regulation Cost:** $\Delta R(t,t') = R(t,t') - E(t,t')$

Results

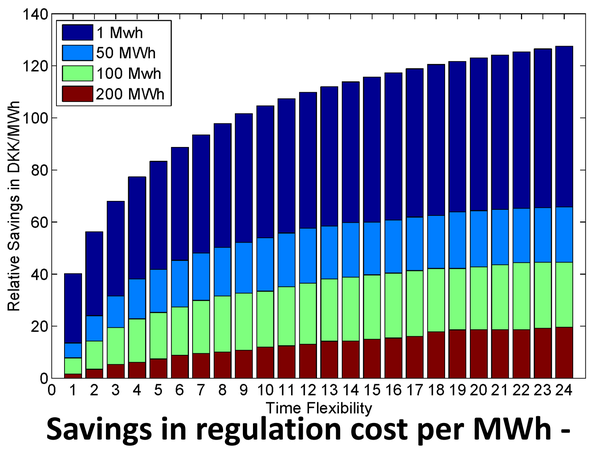


Savings in regulation cost - averaged across days (forward time flexibility).

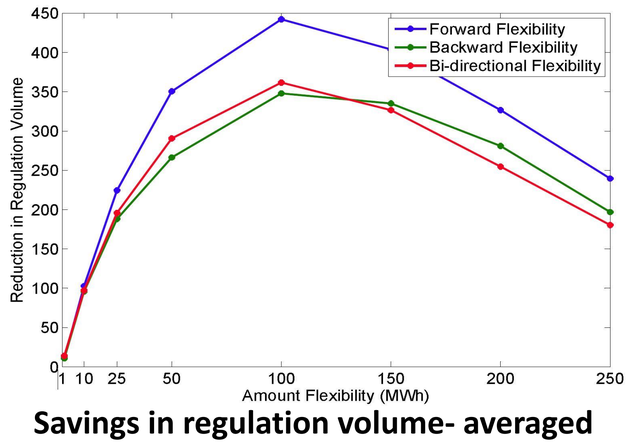


Direct savings from the volume of flexible amount - averaged across days.

Savings from side effects of shifting flexible demand-averaged across days.

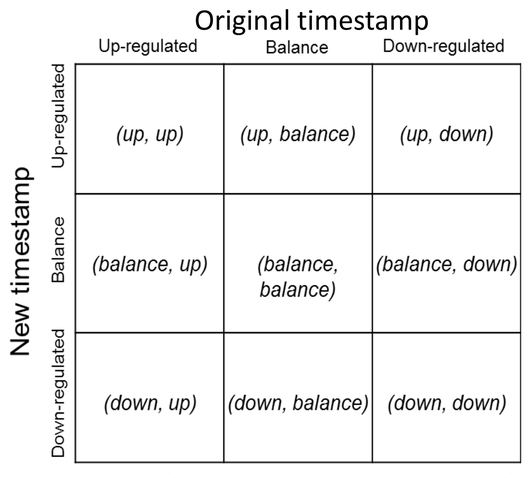


Savings in regulation cost per MWh - averaged over the days.

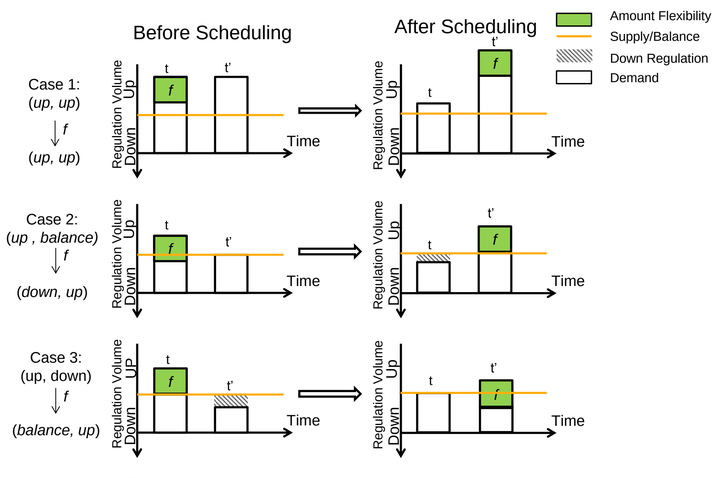


Savings in regulation volume- averaged across days (forward time flexibility).

ENERGY MARKET AND FLEXIBILITY



Possible market state at timestamps t and t'



Example of changes in market states due to utilization of energy flexibility.

Time Flexibility

- **Forward:** Energy demand can only be shifted forward in time
- **Backward:** Energy demand can only be shifted backward in time.
- **Bidirectional:** Energy demand can be shifted in both directions of time.

Regulation Cost and Market Objectives

- **Change in regulation prices:**

$$p_{u/d}(t) = 1.p_s(t) + 1_{v_u(t)<0}(-0.3362 \cdot p_s(t) + 0.0005\,(p_s(t) \cdot v_d(t)) + 1_{v_u(t)>0}(0.2378 \cdot p_s(t) + 0.0034\,(p_s(t) \cdot v_u(t))$$

- **Market Objectives**:

$$C(X;\tau) = \max(t'_1, \dots, t'_n) \sum_{i=1}^{n} C(t_i, t'_i; \tau)$$

Minimizing regulation cost: $C(t_i, t'_i; \tau) = \Delta R(t_i, t'_i; \tau)$

Minimizing regulation volume: $C(t_i, t'_i; \tau) = \left(v_{\underline{d}}(t) + v_{\underline{d}}(t')\right) - (\underline{v_{\underline{d}}(t)} + \overline{v_{\underline{d}}(t')})$

Analysis

- **Flexibility in energy demand/supply** can lead to:
  - **49% reduction in regulation costs** when just **3.87%** of total demand is flexible.
  - **Up-to 29.4% reduction in regulation volume.**
- Saving **increases** with **increasing time flexibility**.
- Total saving depends on the **size of the amount flexibility** traded in the market.
  - **Highest benefits** from amount flexibility of size **100 MWh**.
  - Saving **decrease** for amount flexibility **> 100MWh**
- **Up-to 100MWh** of amount flexibility, a market has both **direct and indirect benefits** of flexibility in energy demand.
- **Saving** and **threshold** value of amount flexibility depends on the **geographical location, size of the market, and the type of RES**.

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