Energie-Forschungszentrum Niedersachsen

Power to Compression: Electric and Gas Driven Compressor Optimization for Energy Cost Reduction and Renewable Electricity Storage in the Natural Gas Infrastructure

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Photo: Gascade

Structure

- Motivation and background
- The underlying theory
- Case study results
- Conclusions and Outlook

Motivation and Background

- Increasing demand for (long term) renewable power storage, indicated by periods with low power prices
- Gas turbines for compressor drives are among the least efficient natural gas appliances
- High economic cost for compressor fuel gas in gas importing countries
- Increasing import pipeline capacity demand for final customers
- CO_2 emissions certificate costs, and tightening air quality standards for gas turbines
- Reliable gearless high speed electric drives >25 MW have become available
- EU regulation requires efficiency audit for gas supply infrastructure by mid-2015

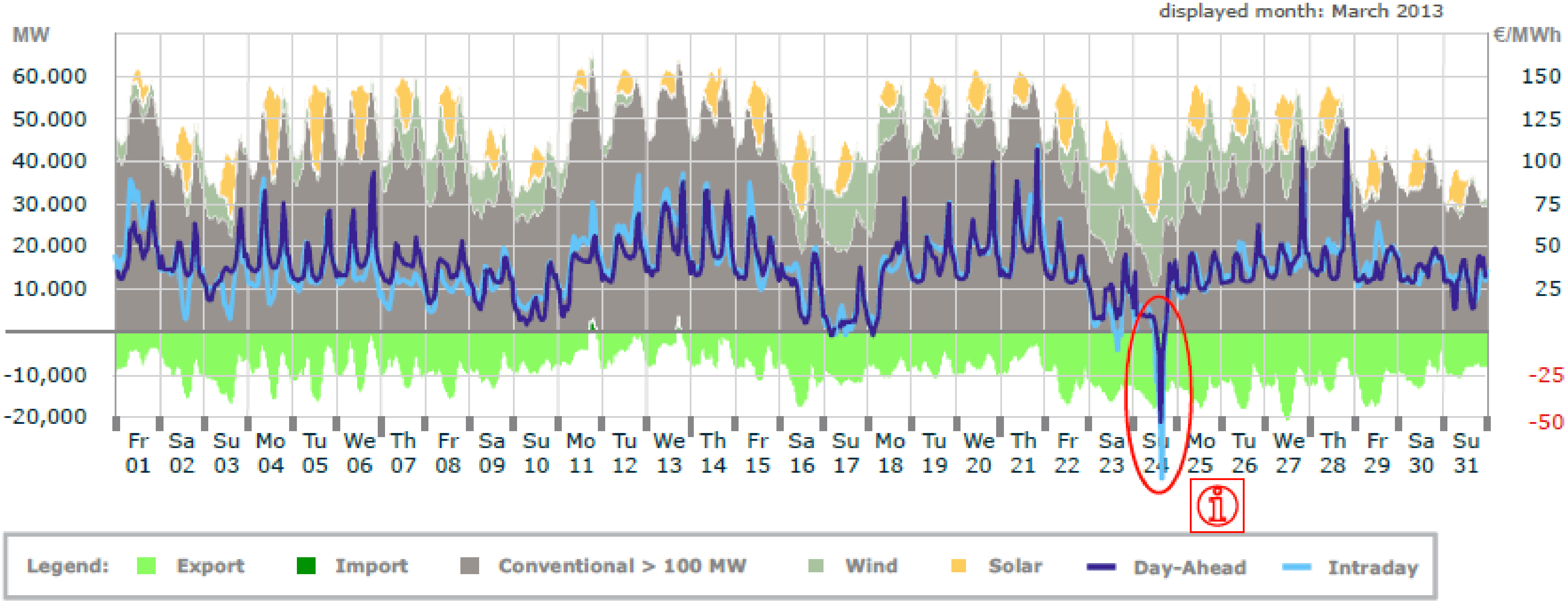
Research questions:

→ Can pipeline transportation cost be reduced with a combination of gas and electrically driven compressor units by
  - switching between these units
  - increasing pipeline pressure at times with available capacity and very low power prices?

→ Are there other economic and ecologic benefits associated with this concept?

→ Will the gas supply still be reliable with pipelines partially operated by electric motors?

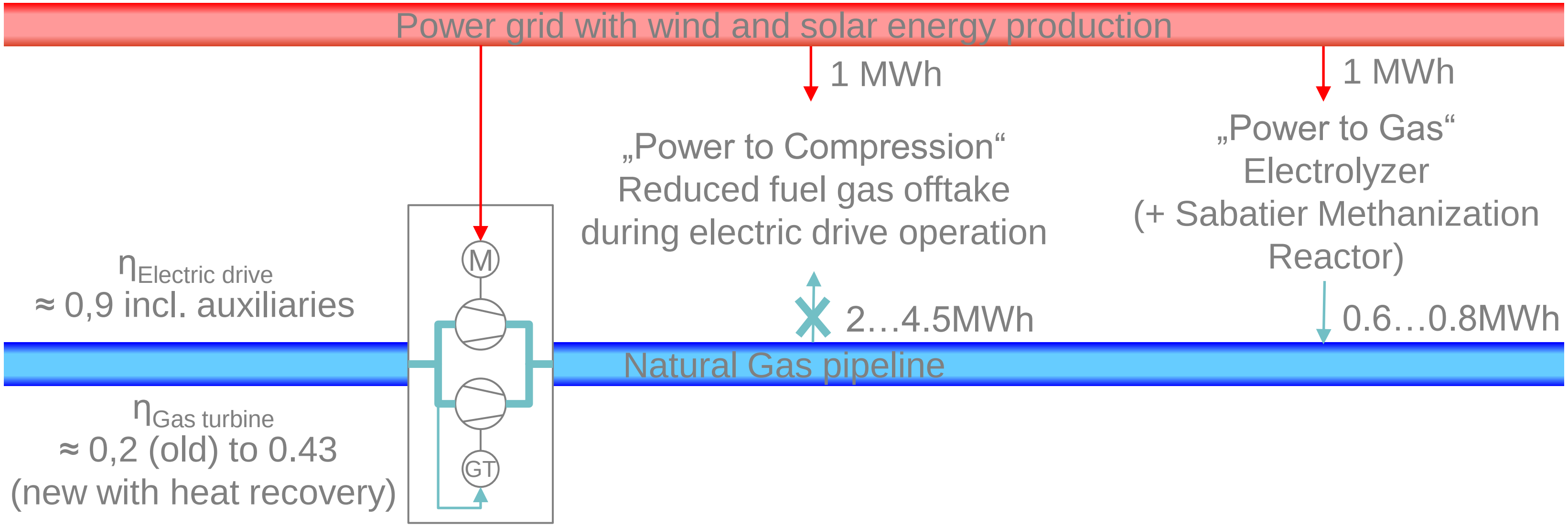
The hourly power price fluctuates with demand, and availability of renewable electricity, indicating power storage demand



€ / MWh	Period Mean	Period Min	Period Max	Trading / GWh
Day-Ahead	**38.97**	**- 50.00**	**120.20**	**21 190**
Intraday	**39.72**	**- 83.20**	**110.40**	**980**

Source: Mayer, Burger (Fraunhofer ISE), Data: EEX, Entso-E

Switching from gas turbine to electric motor compressor drives: Functionally equivalent to „Power to Gas" long term energy storage



Comparison with direct/electrolytic „Power to Gas"

- + Considerably higher efficiency
- + Lower investment cost
- + No hydrogen injection issues
- + No CO_2 sourcing/ Methane emission issues for Sabatier „methanization" option

- – Limited potential:
  - Only possible at compressor locations
  - Only possible at times with compression demand

The mathematical model for nonstationary optimization

- Gas network represented as directed graph $\mathbb{G} = (\mathbb{V}, \mathbb{A})$
- Set of variables $y(t) = [(p(t))_{\mathbb{V}}, (q(t))_{\mathbb{A}}, (s(t))_{\mathbb{V}\cup\mathbb{A}}, (u(t))_{\mathbb{A}_{cs}}]$
- Abstract problem

$$\begin{aligned} \min_{y} \quad & \int_{t=0}^{T} \left[\sum_{a \in \mathbb{A}_{cs}} c(t) P_a(t) \right] dt \\ \text{s.t.} \quad & \mathrm{PDE}(y(t)) = 0 \quad \text{for all pipes} \\ & c_{\mathcal{E}}(y(t)) = 0 \\ & c_{\mathcal{I}}(y(t)) \geq 0 \end{aligned}$$

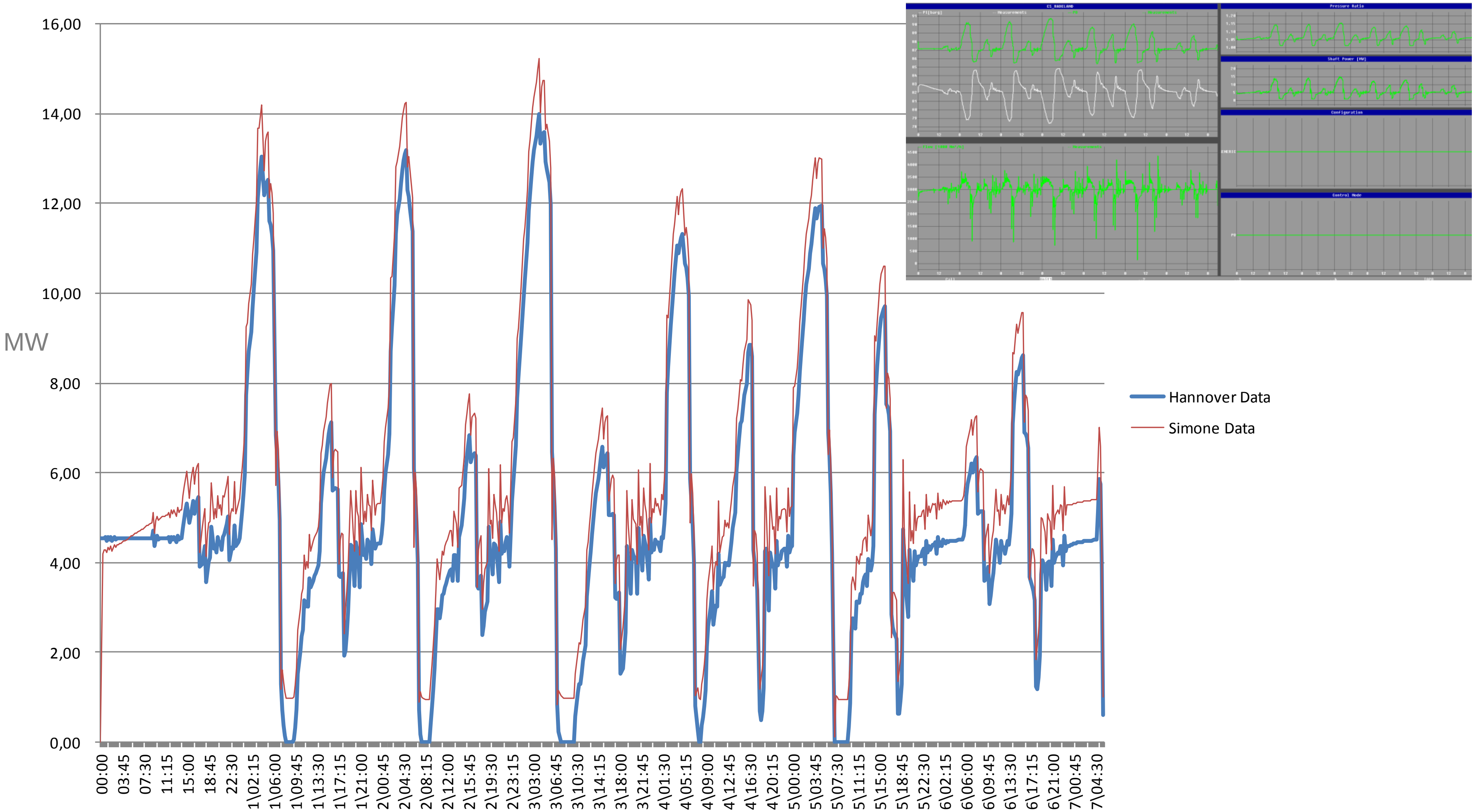
→ Mathematical problem too complex to solve

Acceptable simplifications:

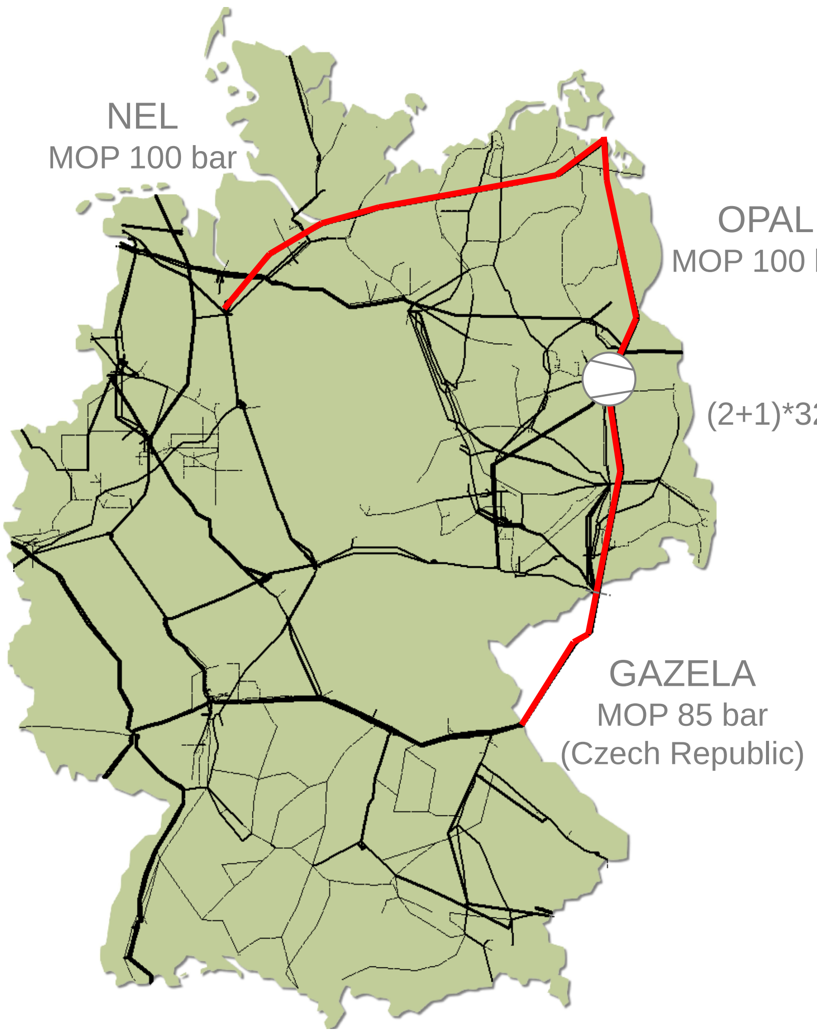
- Discretization of Euler equations with Finite Differences box scheme
- Compressor stations: Piecewise constant control

→ Nonlinear optimization problem with smooth objective and constraints that can be handled with solver Ipopt 3.11 (Wächter, Biegler 2006)

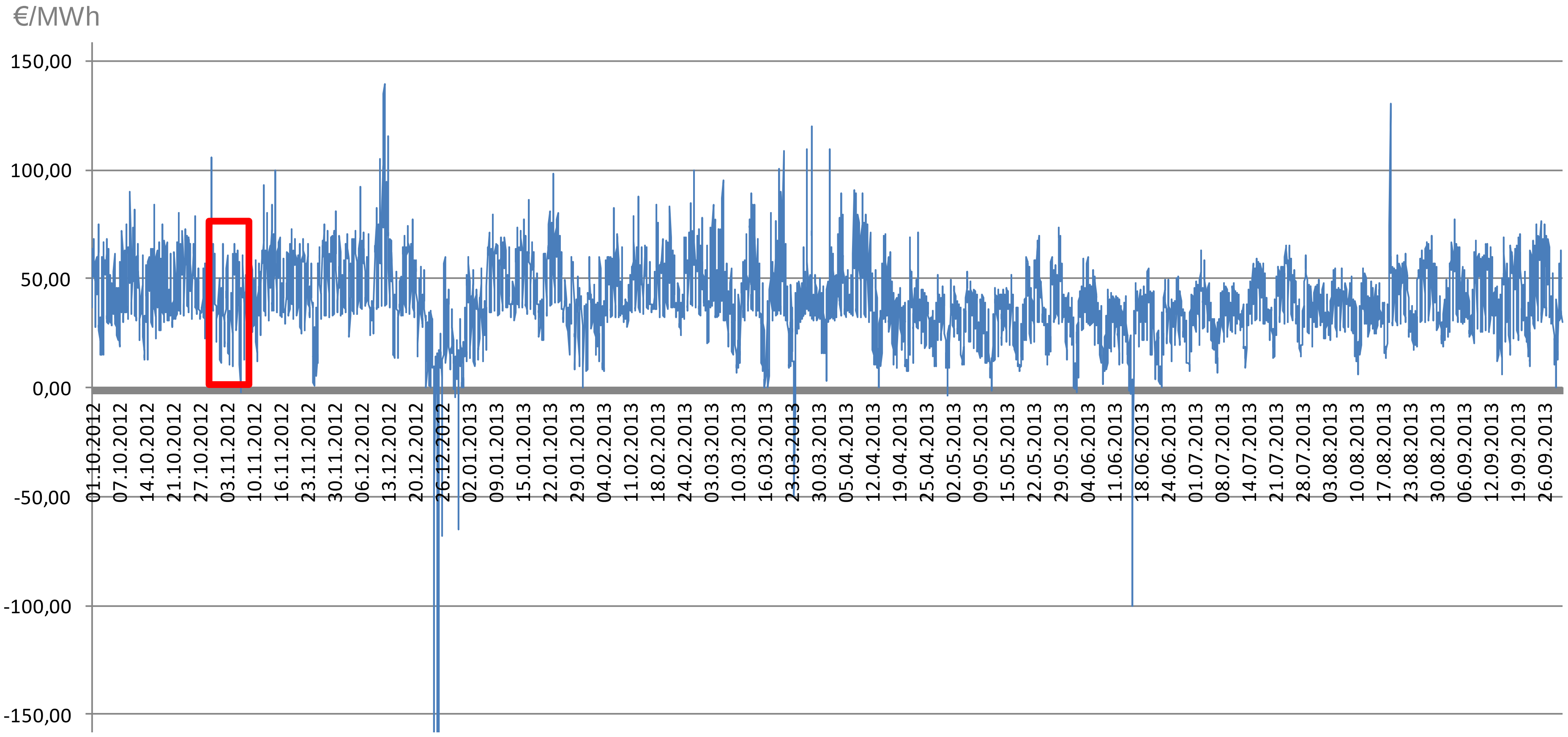
Plausibility check, and comparison of optimization results with SIMONE simulation software



Case study: OPAL/GAZELA, and NEL onshore pipeline extensions of the Baltic Sea pipeline „Nord Stream“



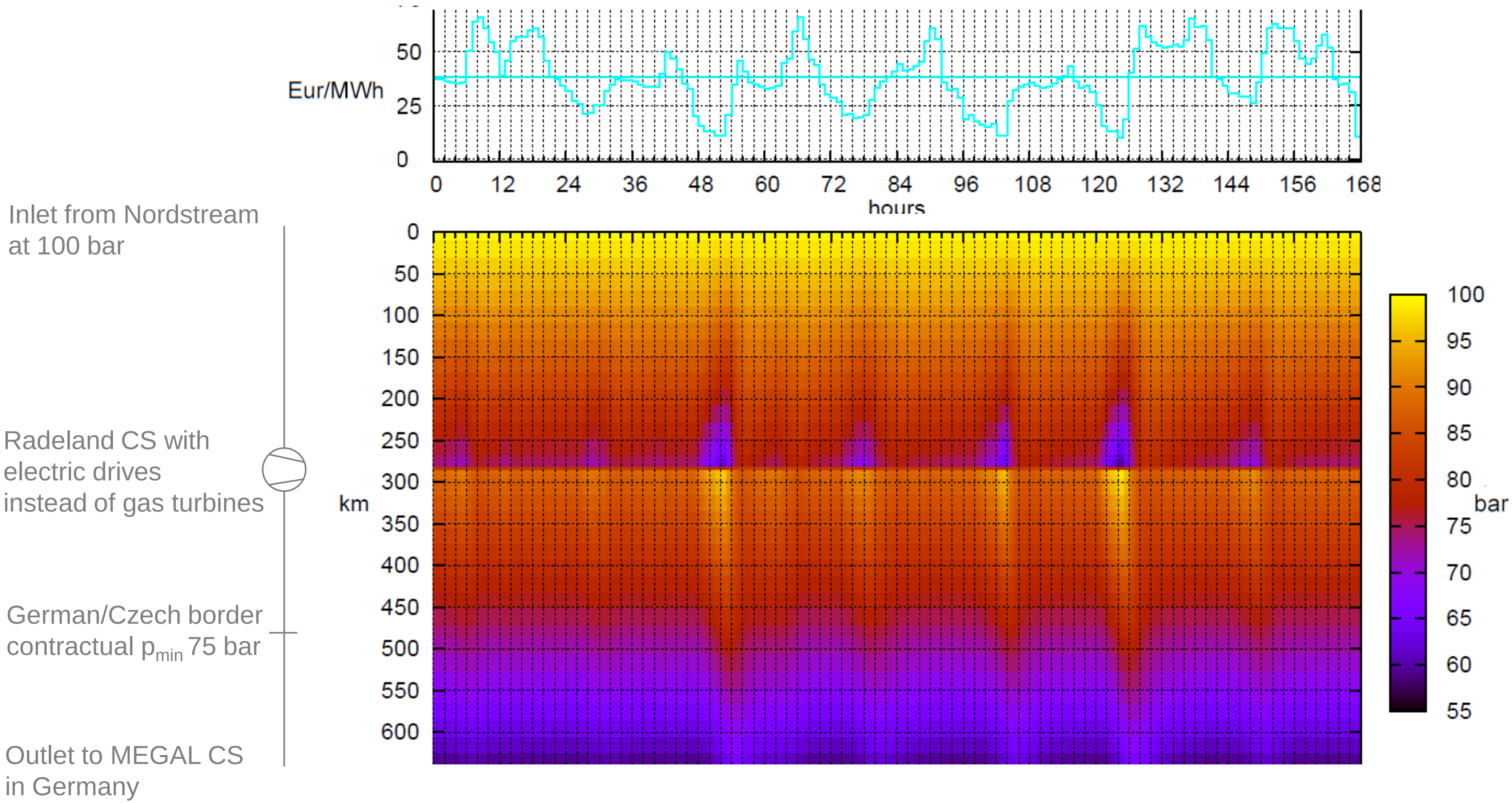
Case study input data: German hourly day-ahead power market price during the gas year 2012/2013



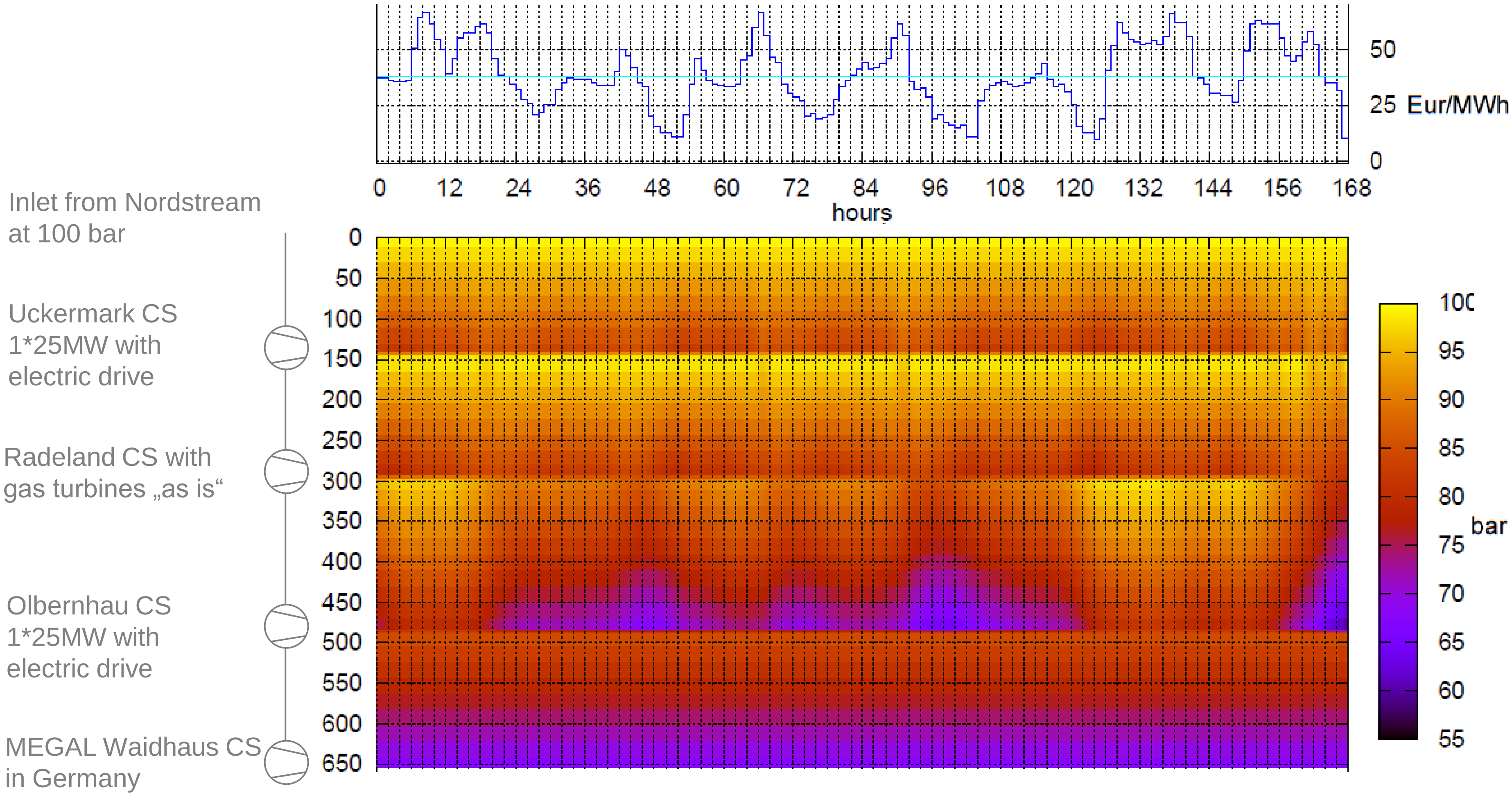
Representative week for subsequent graphical display of case study results

Source: EEX

OPAL/GAZELA pressure profile with hypothetical electric drives in Radeland



OPAL/GAZELA pressure profile for addition of two booster compressor units with electric drives



Case study results and findings summary

Basic case study OPAL (compressor drive replacement in Radeland)

- Extensive use of available linepack for cost optimization
- Cost savings can not justify the necessary investment for electric drives
- Higher compressor energy demand at Radeland compressor station, but energy savings at MEGAL inlet compressor station

Extended case study (MEGAL CS considerated)

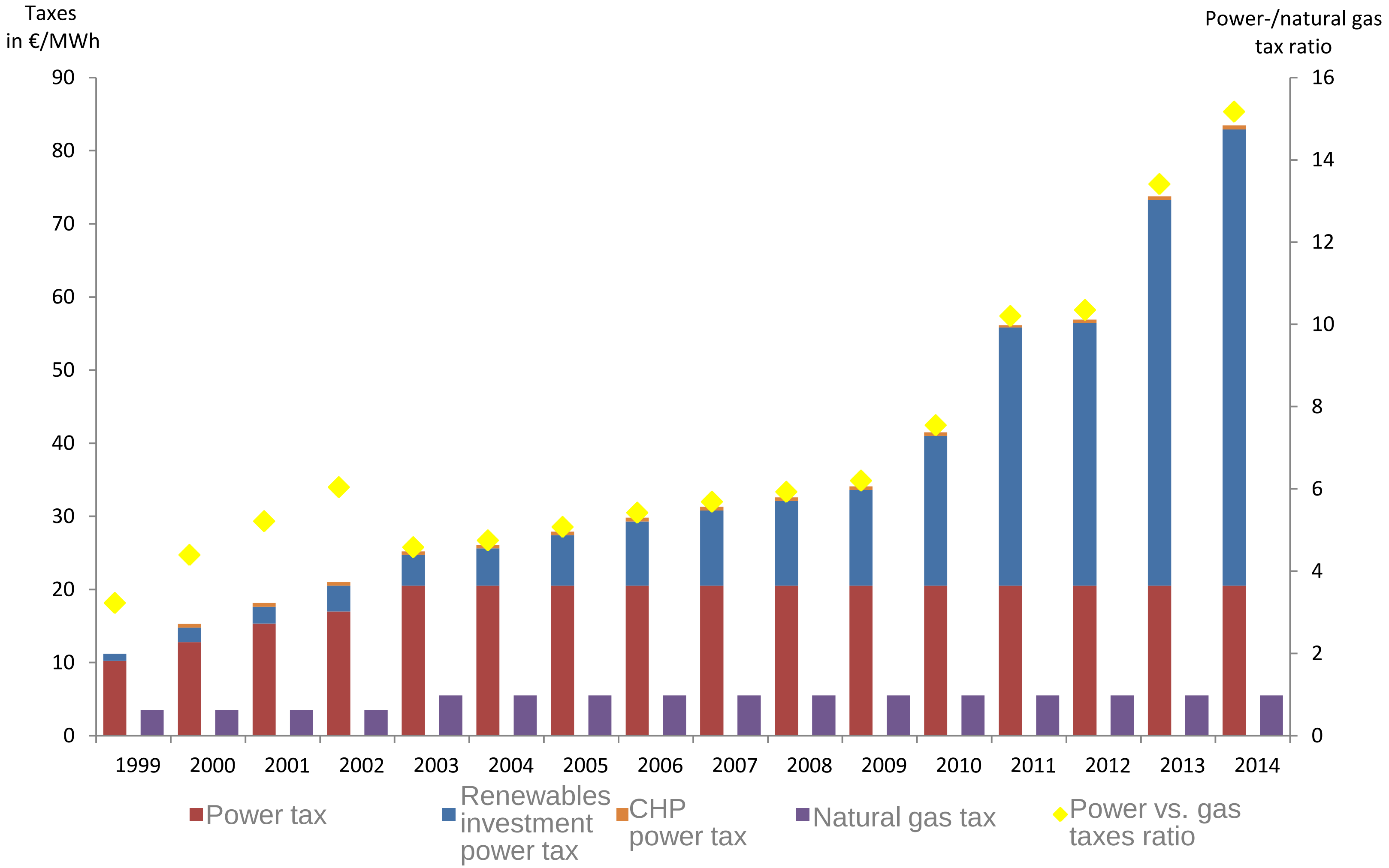
- Considerable cost savings by increased average pressure, and additional linepack flexibility, may justify addition of one or two booster units with electric drives
- Additional savings by increasing the GAZELA MOP, if possible
- Cost savings compensation scheme between OPAL, GAZELA, and MEGAL pipeline companies necessary

Case study NEL capacity extension
(hybrid gas/electric CS with German gas/power grid fees and taxes considered)

- Almost no operation of electric drive unit even at very low, or negative power prices

→ Joint effort of the pipeline companies with regulatory and legislative bodies necessary to achieve lowest gas transport cost solution

Taxes of power and natural gas in Germany (main components)



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Conclusions and Outlook

→ Significant cost reductions possible with electric compressor units @ energy market prices, but national legal issues have to be considered

→ Additional cost reductions by using available linepack for Demand Side Management („price-induced pack & draft“)

→ Positive effects on adjacent gas transport infrastructure possible

→ Electric compressor drives‘ power consumption may reduce power system bottlenecks

→ Reliability can be maintained with gas driven compressor units during power outages

→ Optimum compressor layout must be determined on project-to-project basis

→ Reduction of „Power to Gas“ investment, and efficiency losses possible

Outlook

- Refining the mathematical model (compressor maps, switching costs, …)
- Joint optimization of storage, and pipeline compressors in complex grid structures
- Optimizing the legal details (taxes, regulation) for maximum economic efficiency
- Integrate power market signals into day-to-day dispatching operations
- Investigation of current international pipeline projects
  - Trans Adriatic Pipeline from turkish-greek border to Italy
  - South Stream onshore
  - …?

Thank you for your attention.

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Paper will be available via www.igrc2014.com after the conference

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