Rechenzentrum für Versorgungsnetze
Wehr GmbH

UNIVERSITÄT PADERBORN

A SP model and a DSS for strategic and operational gas purchase portfolio planning

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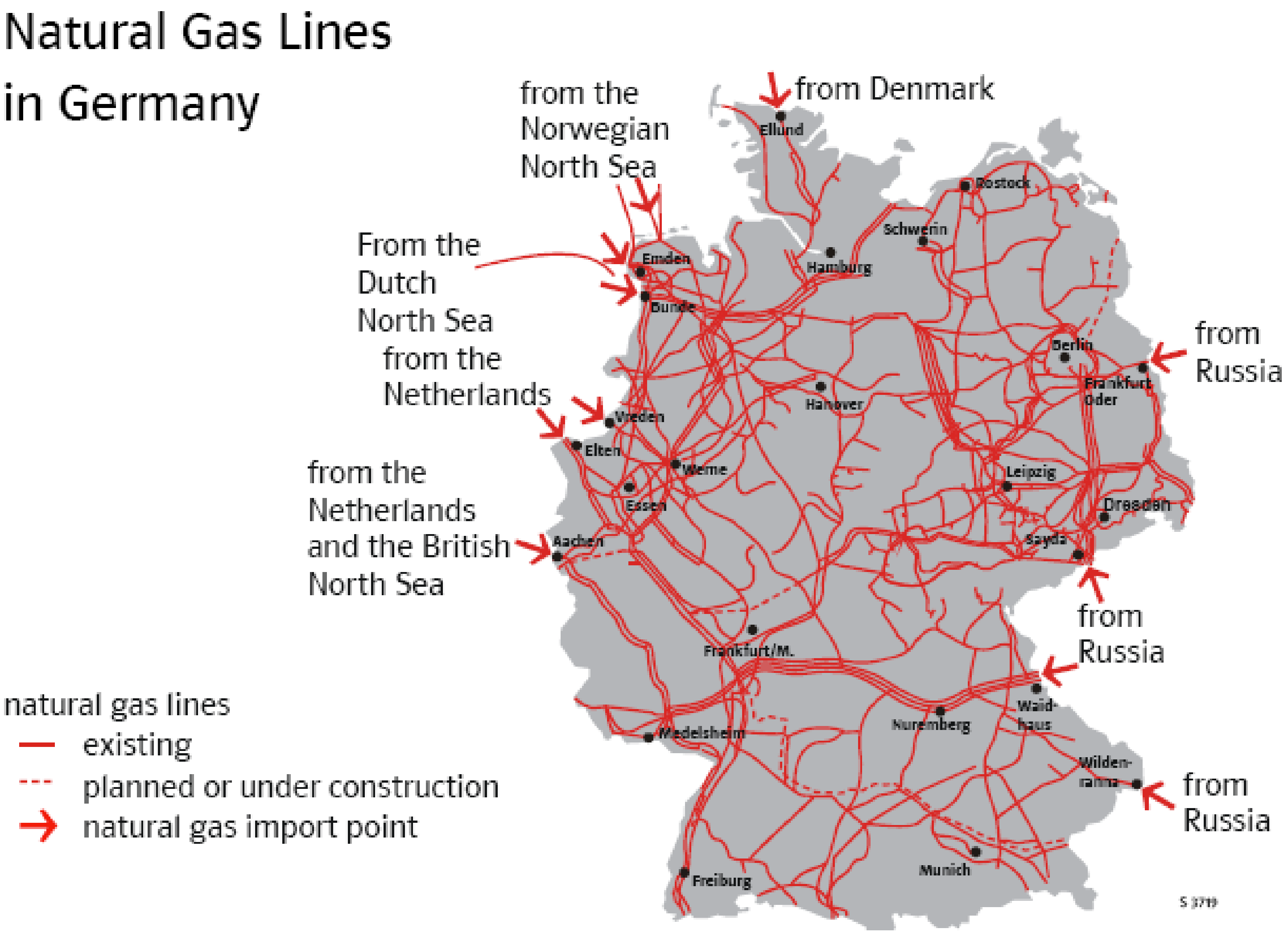
Achim Koberstein koberstein@dsor.de
Dirk König d.koenig@rzvn.de
Leena Suhl suhl@upb.de

Agenda

1. The gas retail problem
2. Modelling
   1. A deterministic model
   2. A two-stage stochastic model
3. The SAPHIR System
4. Some computational experiences
5. Conclusions and outlook

German gas transportation network



Utilities in the German natural gas market

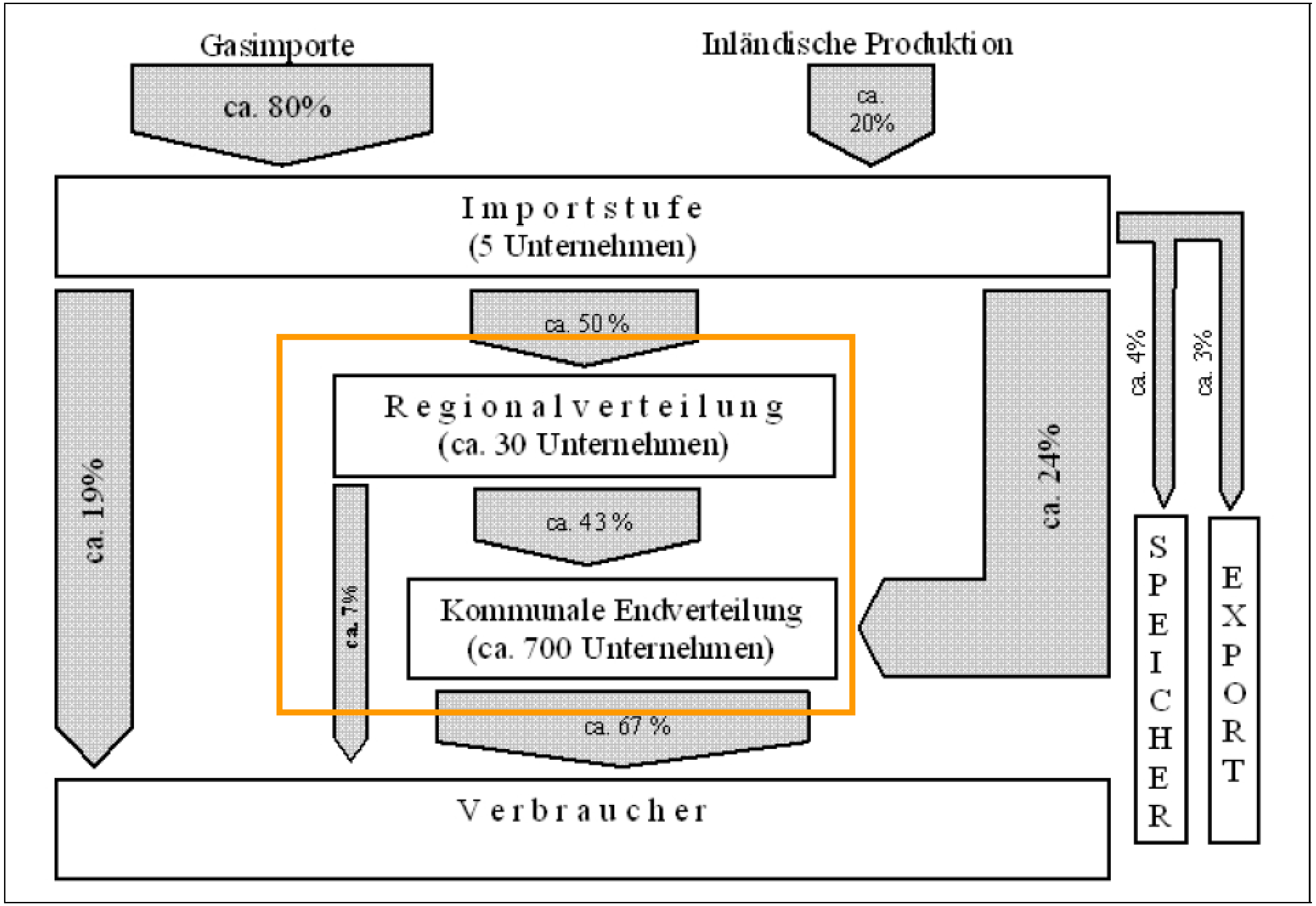
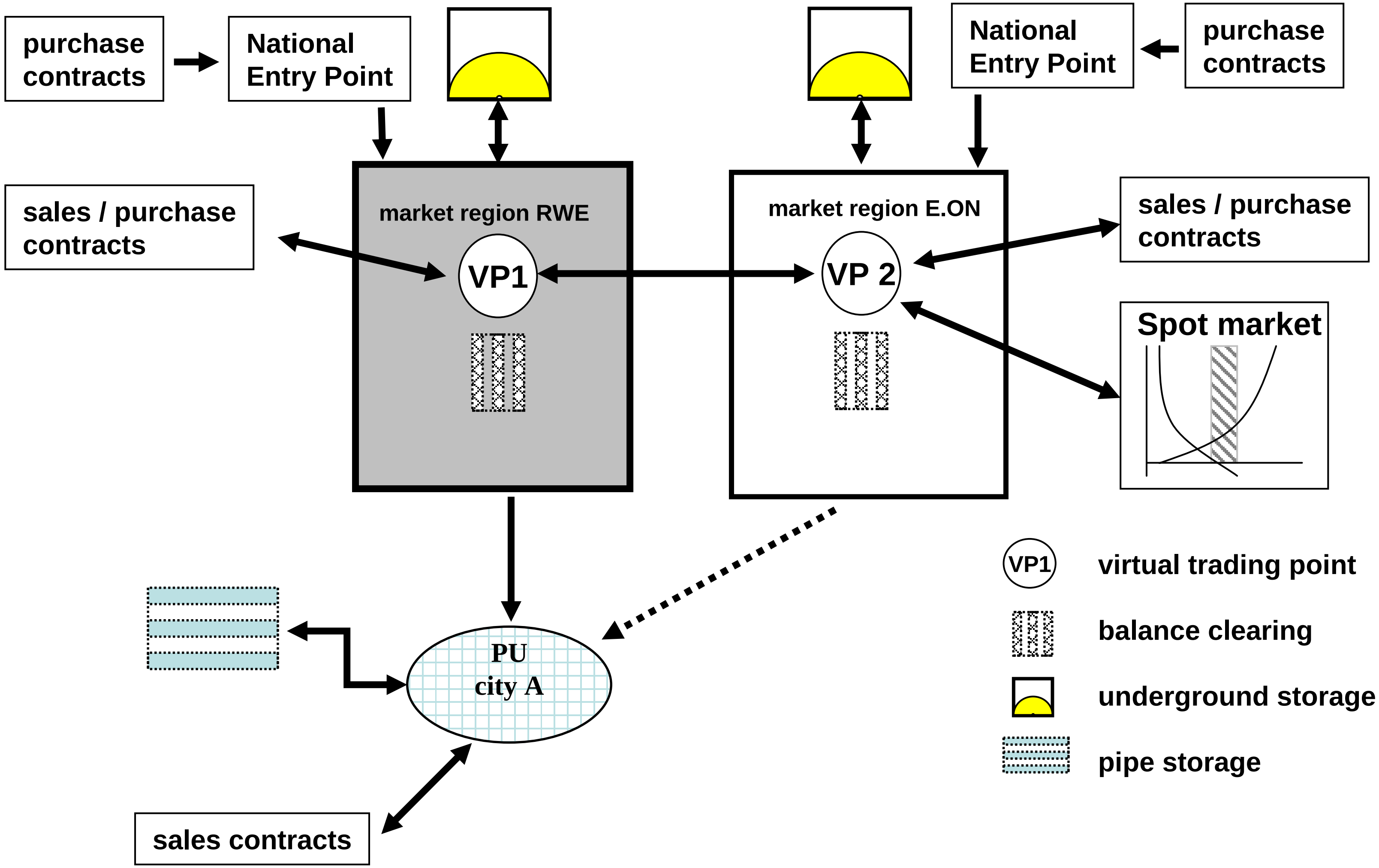


Abbildung 2.1: Versorgungsstufen im deutschen Erdgastransportnetz [Hellwig 2003]

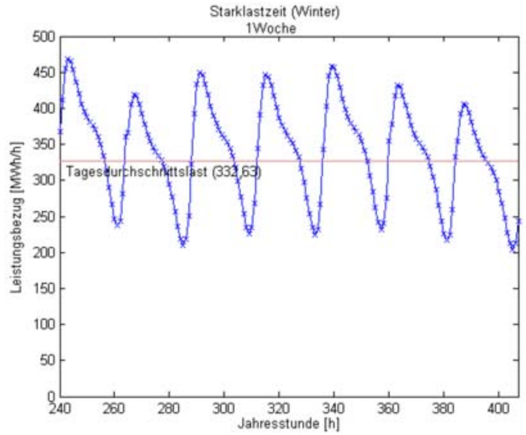
German market model for gas trading



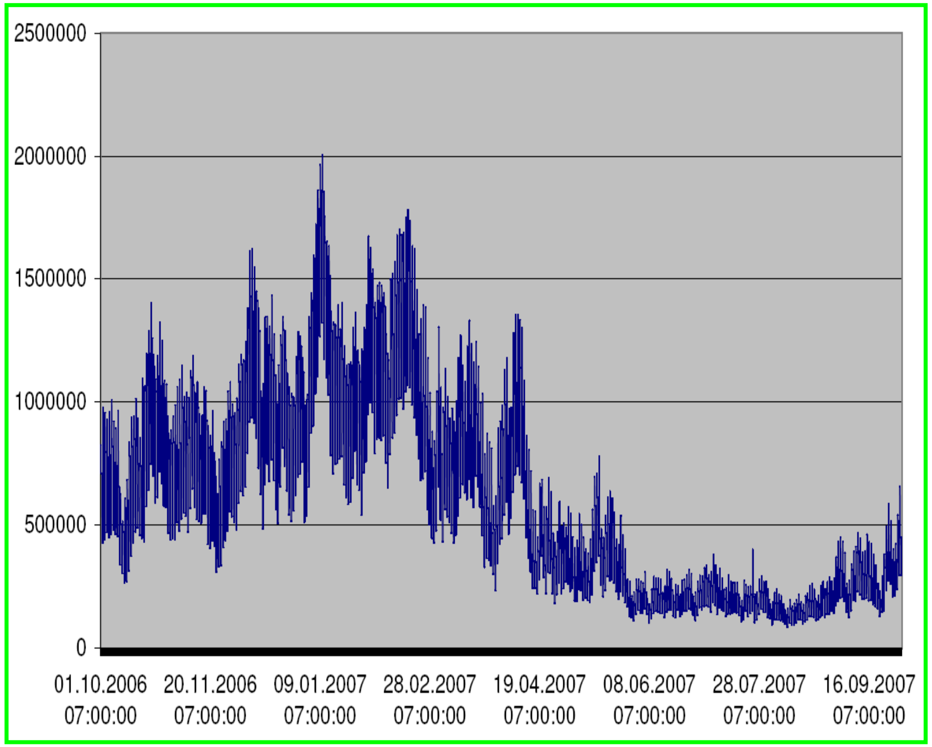
Sales contracts

Typically uninteruptable long term contracts guarantee to cover future demand.

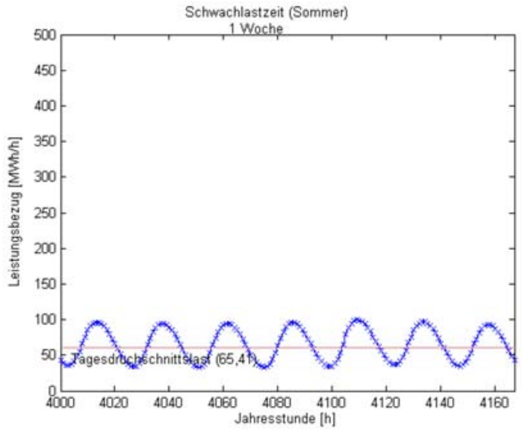
Gas load one week in winter



Gas load for one year (starting in October)



Gas load one week in summer

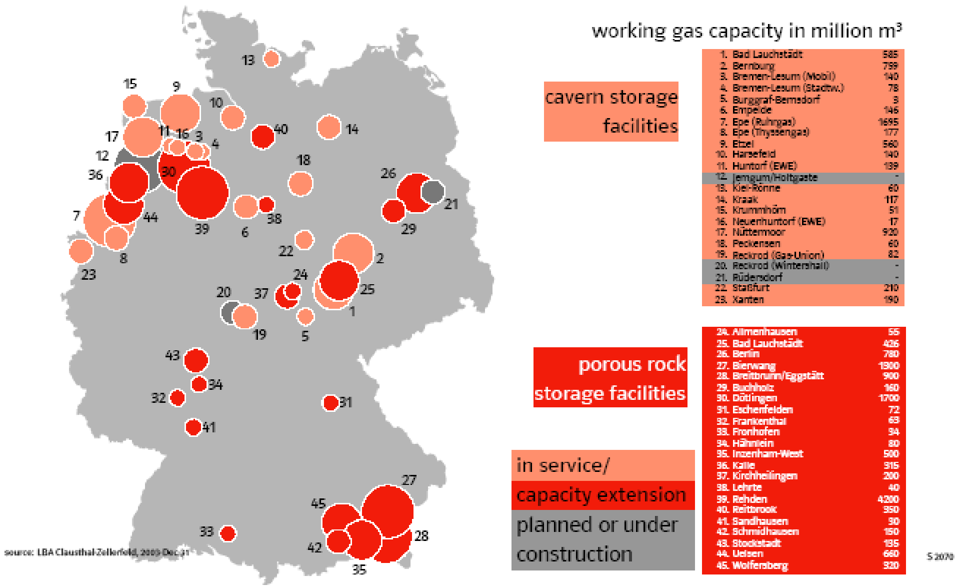


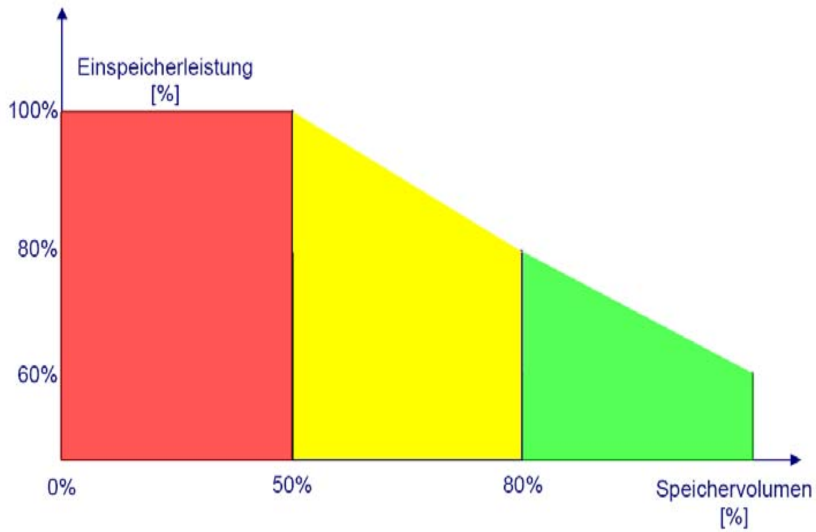
Purchase contracts

- Yearly / monthly baseload contracts
  - Take-or-pay contracts
  - Fixed amount of gas have to be ordered at the beginning of the gas year
  - Prices refer the amount of energy, typically cheap
- Open contracts
  - Amount of energy and power level can vary in a prefixed intervall
  - Prices refer to the amount of energy AND the maximal power level
  - Typically much more expensive than baseload contracts
- Spot market
  - Gas is mainly traded in daily baseload contracts
  - Prices are fixed a day ahead
  - Prices depend largely on temperatur

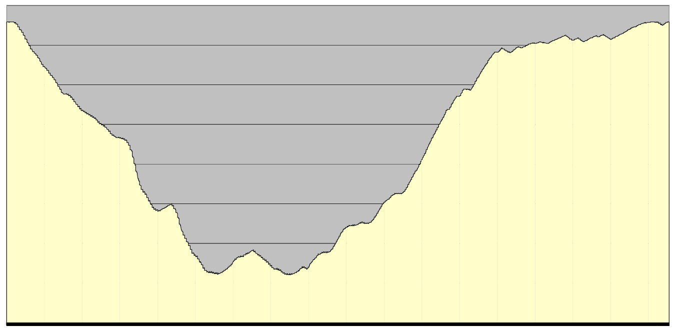
Cavern storages

Natural Gas Storage Facilities in Germany in 2003





Fill level of a cavern storage over one gas year



Compression costs	Fixed costs	Injection costs	Extraction costs

Down times between injection and extraction mode switch.

The gas retail problem

- Strategic problem
  - Point of decision: before beginning of new gas year
  - Planning horizon: one gas year (12 month)
  - Strategic decisions:
    - Baseload purchase portfolio
    - Order limits for used open contracts
    - Ordered storage capacity
- Operational problem
  - Point of decision: every day with rolling planning horizon
  - Planning horizon: 3-4 days, anticipation of rest of gas year
  - Operational decisions:
    - Purchase from open contracts and spot market
    - Transportation
    - Storage injection and extraction quantities
    - Storage down-times have to be taken into account

A multiperiod network flow formulation

(First version was developed by König, Wodianka and Dada in 2004.)

Nodes: market regions, national entry points, storages

Decision Variables:

- Power purchased from purchase contracts and spot market
- Power transported on each arc
- Energy injected into and extracted from storages
- Technical variables to determine maximal power levels

Parameters

- Purchase, storage, transportation prices
- Transportation and storage capacities
- Purchase limits, etc.

A basic deterministic model

$$\max \sum_{t\in T}\sum_{i\in N}\sum_{c\in SC_i^N} EPRICE_c^{SC}\cdot\Delta_t^T\cdot LOAD_{i,t} \quad (1)$$

Revenues

$$-\sum_{b\in BC}\sum_{m\in M_b^{BC}} EPRICE_{b,m}^{BC}\cdot\Delta_m^M\cdot p_{b,m}^{BC} \quad (2)$$

- purchase costs BC

$$-\sum_{o\in OC}\left(\sum_{t\in T_o^{OC}} EPRICE_{o,t}^{OC}\cdot\Delta_t^T\cdot p_{o,t}^{OC} + PPRICE_o^{OC}\cdot pmax_o^{OC}\right) \quad (3)$$

- purchase costs OC

$$-\sum_{(i,j)\in L}\left(CENTRY_{i,j}\cdot pmax_{i,j}^L + CEXIT_{i,j}\cdot pmin_{i,j}^L\right) \quad (4)$$

- transportation costs OC

subject to (5)

$$\sum_{\{b\in BC_i^N:month_t\in M_b^{BC}\}} p_{b,month_t}^{BC} + \sum_{\{o\in SC_i^N:t\in T_o^{OC}\}} p_{o,t}^{OC} - \sum_{\{j:(i,j)\in L\}} p_{i,j,t}^L + \sum_{\{j:(j,i)\in L\}} p_{i,j,t}^L = LOAD_{i,t} \qquad \forall i\in N, t\in T \quad (6)$$

Node balance

$$p_{o,t}^{OC}\le pmax_o^{OC} \qquad \forall o\in OC, t\in T_o^{OC} \quad (7)$$

$$p_{i,j,t}^L\le pmax_{i,j}^L \qquad \forall (i,j)\in L, t\in T \quad (8)$$

$$p_{i,j,t}^L\ge pmin_{i,j}^L \qquad \forall (i,j)\in L, t\in T \quad (9)$$

Determine maximal power levels

$$EMIN_{b,m}^{BC}\le\Delta_m^M\cdot p_{b,m}^{BC}\le EMAX_{b,m}^{BC} \qquad \forall b\in BC, m\in M_b^{BC} \quad (10)$$

$$EMIN_o^{OC}\le\sum_{t\in T_o^{OC}}\Delta_t^T\cdot p_{o,t}^{OC}\le EMAX_o^{OC} \qquad \forall o\in OC \quad (11)$$

$$PMIN_{b,m}^{BC}\le p_{b,m}^{BC}\le PMAX_{b,m}^{BC} \qquad \forall b\in BC, m\in M_b^{BC} \quad (12)$$

$$PMIN_{o,t}^{OC}\le p_{o,t}^{OC}\le PMAX_{o,t}^{OC} \qquad \forall o\in OC, t\in T_o^{OC} \quad (13)$$

Power and energy limits

\+ storages and spot market

Sources for binary variables

- Storage fixed costs
  - Typically very few storages in the model
  - Can be handled by creating different problem instances
- Fill-level dependend injection and extraction power limits
  - storage power limits can be approximated due to typical seasonal fill-levels
- Storage down-times
  - have to be considered only in operational planning

⇒ Strategic problem can be handled as an LP!

A two-stage stochastic model

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1st stage

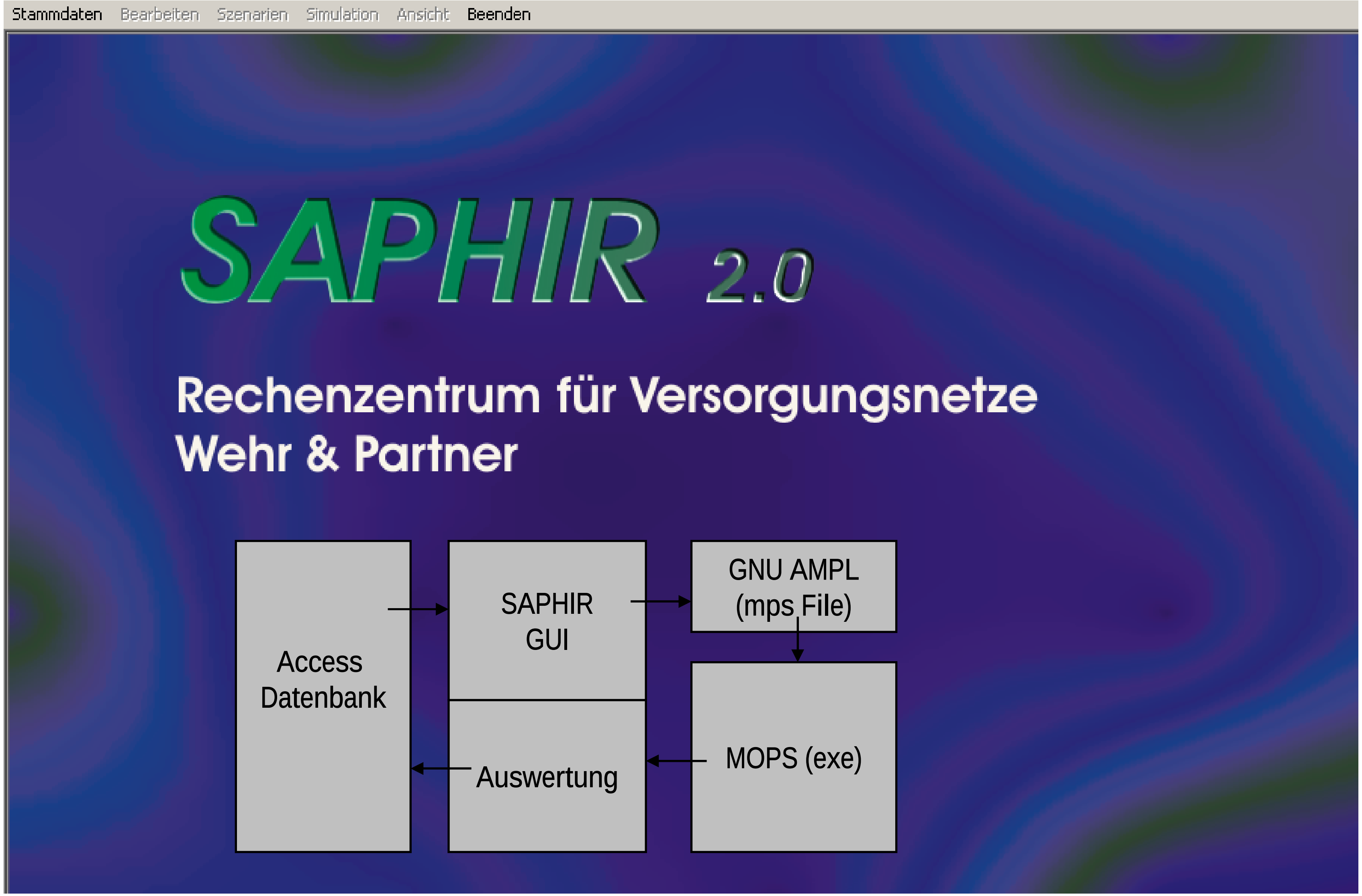
Baseload portfolio
Limits for open constracts
Dimensioning of storage capacity

Realisation of gas load and spot prices

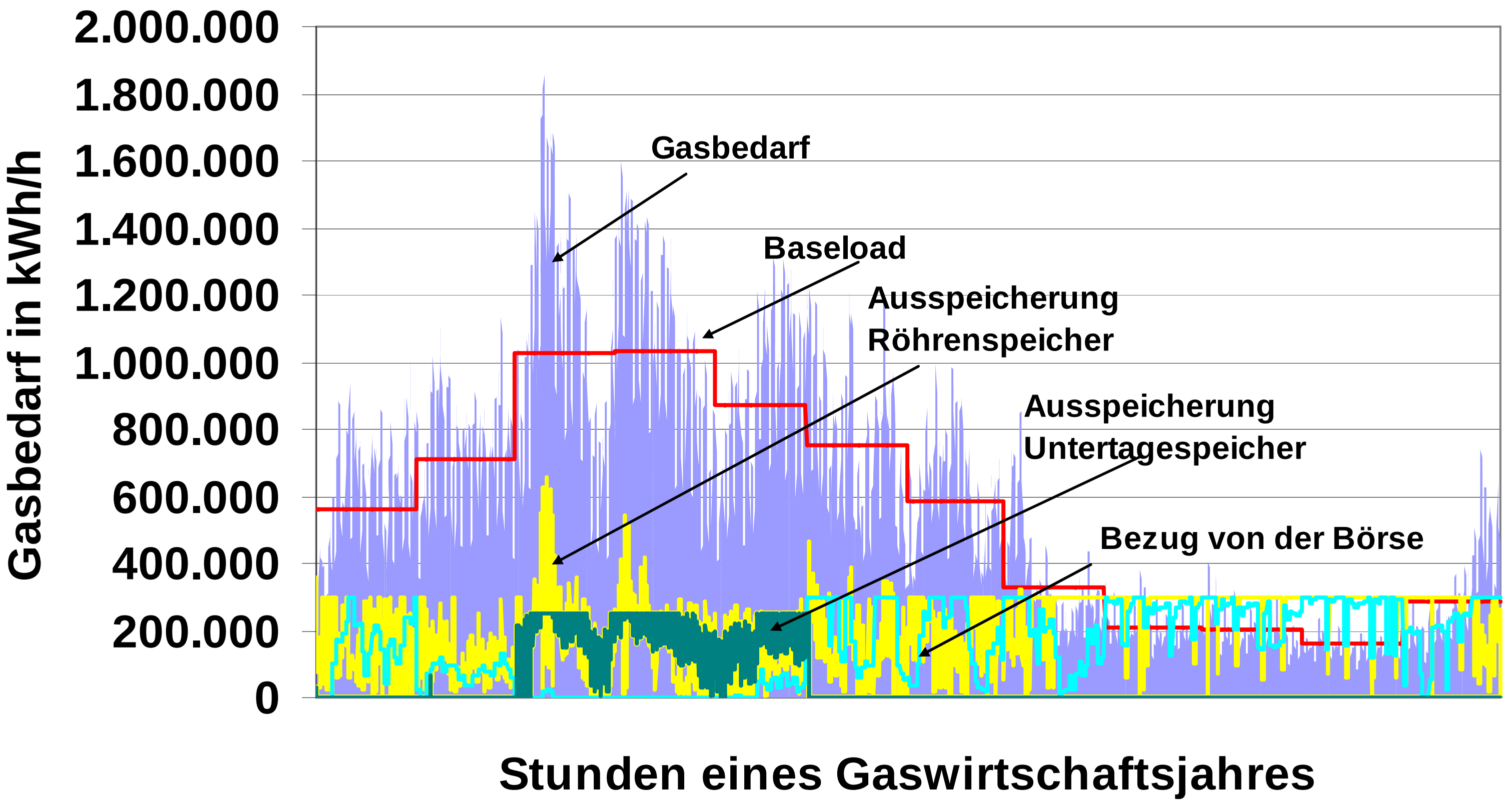
2nd stage

Gas transportation
Purchase via open contracts and spot market
Injection into and extraction from storages

Decision support system



SAPHIR output: purchase portfolio for one year



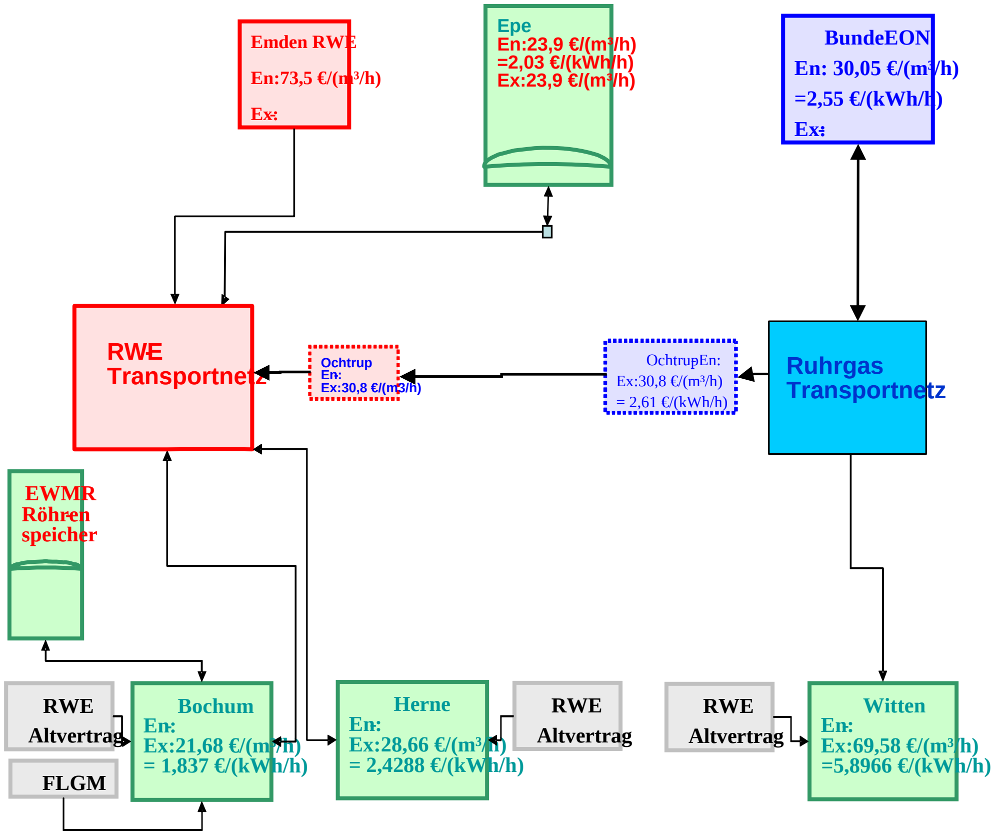
SAPHIR is beeing deployed at a large German public utility.
Cost savings of 4% - 8% compared to traditional purchase strategy.

Test instance (from a large German public utility):

- 11 nodes, 10 arcs
- 2 monthly base load purchase contracts, 3 open purchase contracts
- 3 sales contracts
- Spot market
- 3 storages

Time aggregation:

- Hourly: 8760 time periods
- Daily: 1095 time periods
- Weekly: 159 time periods



Computational experience: deterministic model

Time aggregation	#time periods	#vars	#rows	#nonzrs	Sol. Time [sec]
weekly	159	5572	13579	33926	1
daily	1095	32716	90331	227678	13
hourly	8760	255001	718861	1814333	398

Solved with MOPS 9.17 Interior Point Method (without cross-over) on Intel PIV 3,2 GHz, 2GB.

Optimal objective function values:

Hourly:	141451997.5	
Daily:	141105224.3	Error: 0.2 %
Weekly:	136870610.0	Error: 3.2 %

Is it computationally possible to do stochastic?

Computational experience: stochastic model

Solve deterministic equivalent on Intel Core 2 Duo 64 bit, 8GB:

Aggr.	# periods	#scen-arios	#vars	#rows	#nonzrs	MOPS IPM 64 Time [s]	Cplex 11 Barrier 64 [s]
W	159	500	1958061	4341028	11369098	475	4702
D	1095	50	1527438	3774246	9682258	1995	failed
H	8760	6	1468265	3787374	9624410	398	failed

Computational challenges:

- Cross-over, if basic solution is needed
- Numerical difficulties (Cplex)
- Model generation times (several hours for the above instances)
- LP preprocessing has great impact on actual model sizes

Can decomposition methods help to improve on solution times?
This is currently beeing studied…

Conclusion and outlook

- The gas retail problem is highly relevant for large public utilities.
- Strategic problem can be formulated as an LP and a 2-stage SLP.
- Stochastic model is solvable computationally for daily and weekly time aggregation only.

- Up to 8% of cost savings could be realized using DSS SAPHIR.
- SAPHIR has been made commercially available and will be constantly improved.

- Current and future research is focussing on:
  - Implementation of strategic model in stochastic modelling language SAMPL and SPInE (in cooperation with Prof. G. Mitra, Brunel University)
  - Incorporating risk measures CVaR, ICC into strategic problem

Thank you for your attention!