Multi-Market Optimal Bidding for a Power Producer

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Outline

- Optimal bidding
- Uncertainty characterization
- Problem formulation
- Case study

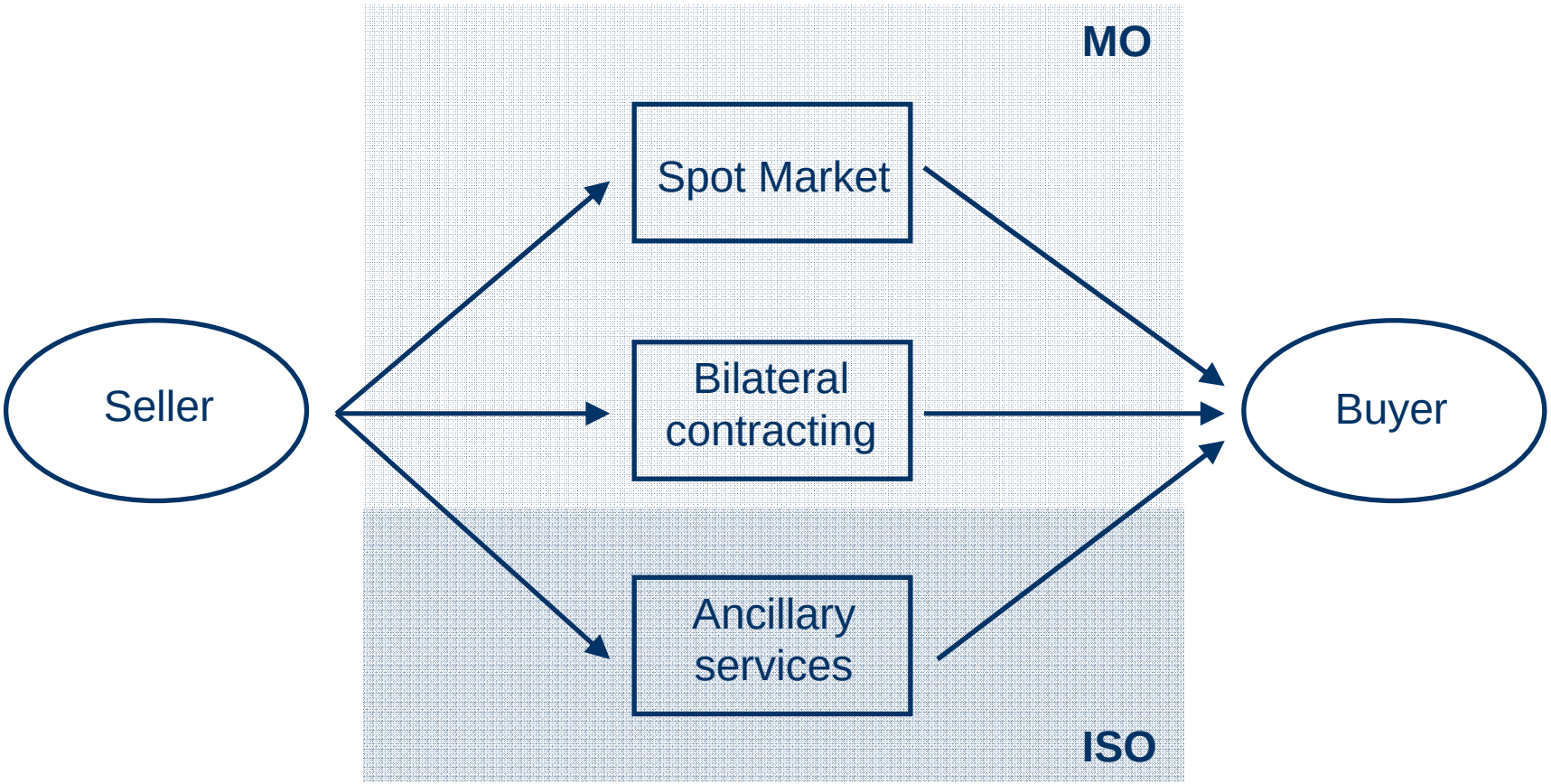
Optimal bidding
Objective

- FIND OUT Optimal bidding curves for the day-ahead market

TAKING INTO ACCOUNT:

- AGC market
- Balancing market

Electricity Markets
Background



Optimal bidding Approach

Three stage stochastic programming

- Day-ahead market
- AGC market
- Balancing market

Optimal bidding Approach

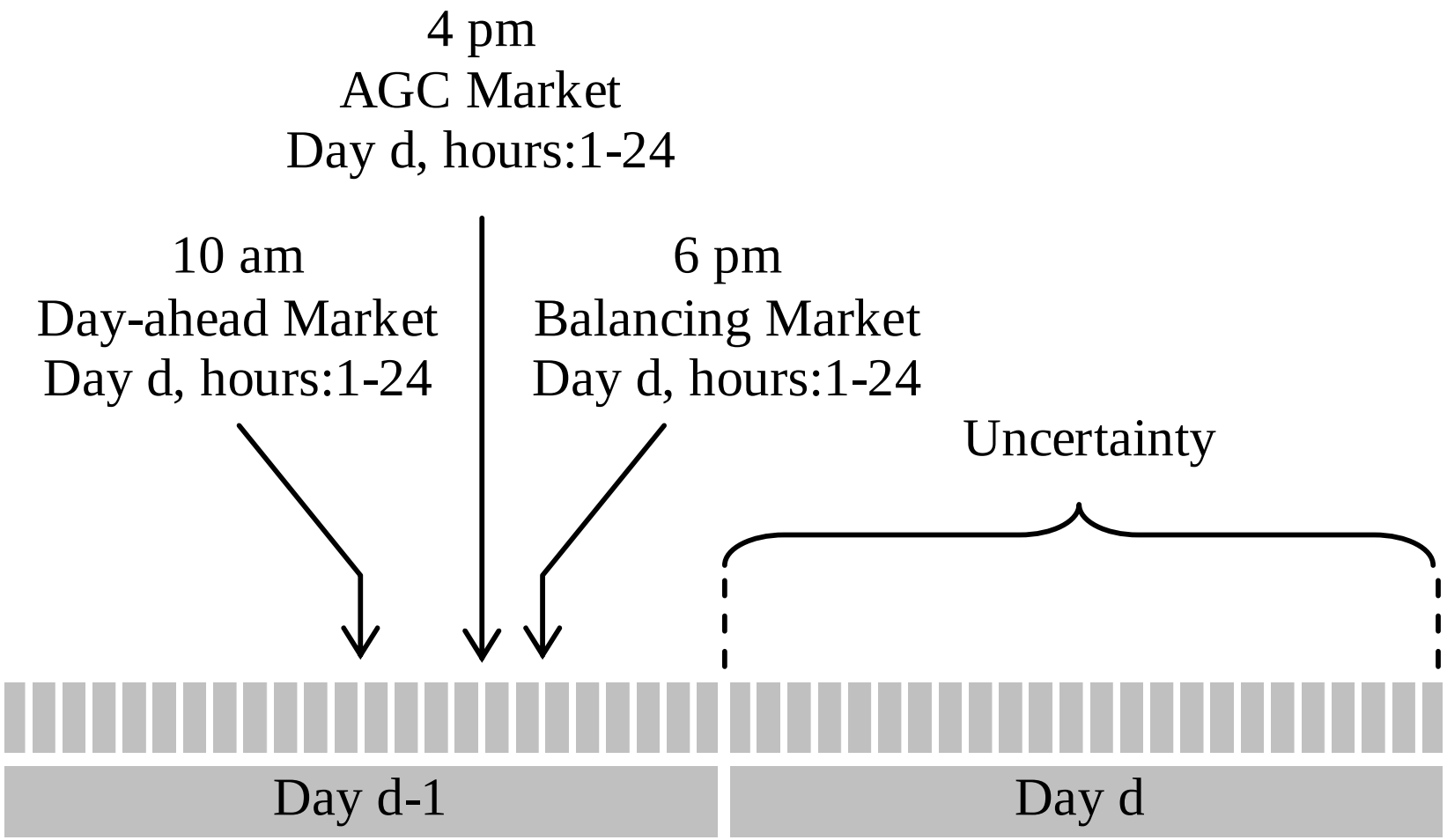
No market power:

- Day-ahead market
- AGC market

Market power:

- Balancing market

Optimal bidding
Decision framework

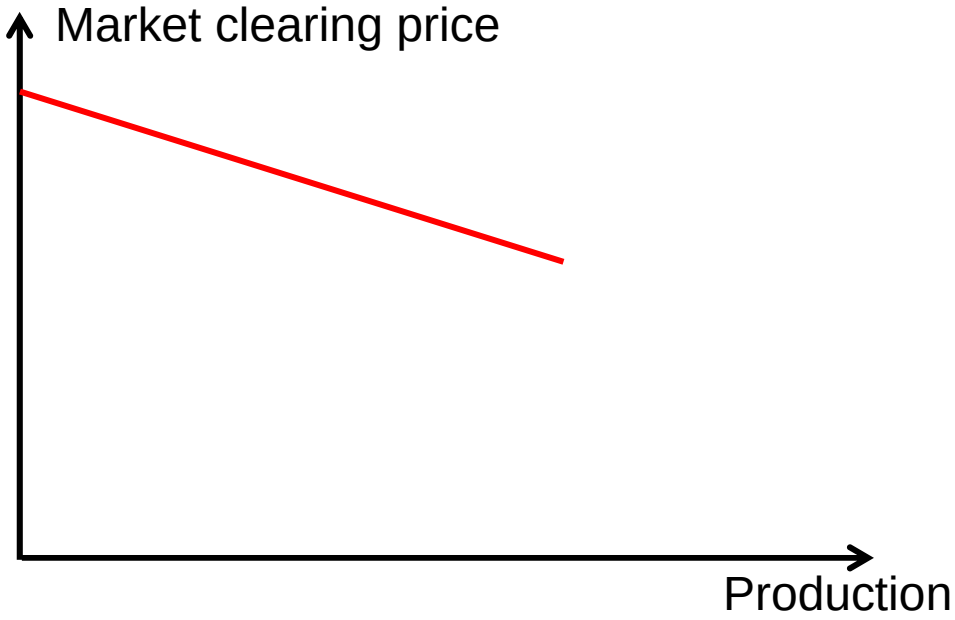


Uncertainty characterization
Random variables

- Day-ahead prices (24)
- AGC prices (24)
- Balancing market
  - Intercepts (24)
  - Slopes (24)

Uncertainty characterization
Random variables

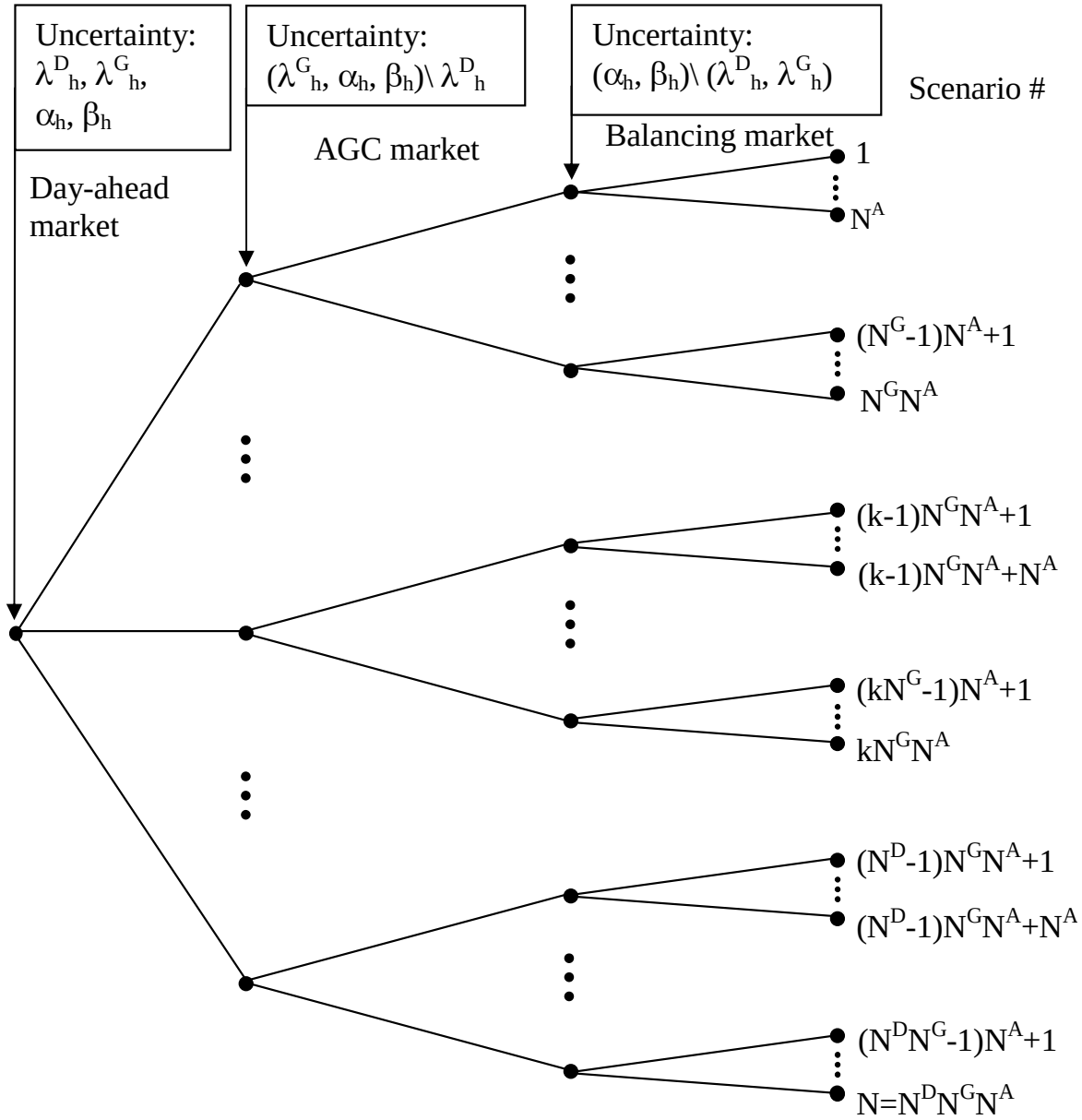
Balancing market (intercepts plus slopes)



Uncertainty characterization
Random variables

Variable	Weekdays
λ_h^D	ARIMA(1,0,1)(2,0,1)$_{24}$
λ_h^G	ARIMA(5,0,1)(1,0,0)$_{24}$
$\alpha_h - \lambda_h^D$	ARIMA(1,0,2)(1,0,1)$_{24}$
β_h	ARIMA(2,0,1)(1,0,1)$_{24}$

Uncertainty characterization. Scenario tree

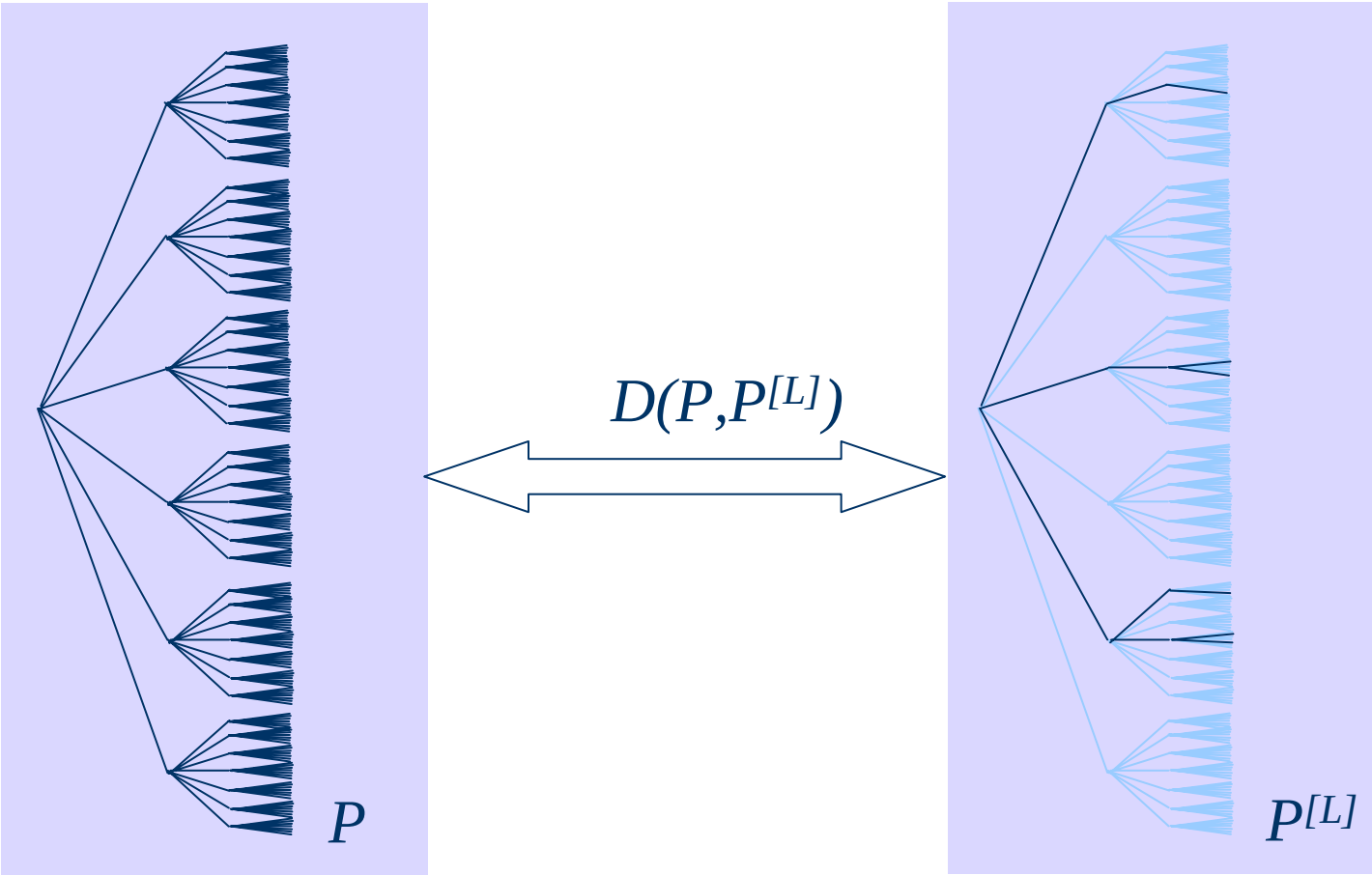


Uncertainty characterization
Scenario reduction

How to attain tractability?

Scenario reduction!

Uncertainty characterization
Scenario reduction



Strategy

- No optimal decisions
- Optimal offer curves

- Decisions dependent on prices (on scenarios !)

PROBLEM FORMULATION
Day-ahead market

$$\text{Maximize}_{q^D_{jhk},\, t^D_{hk}}$$

Expected profit in the day ahead market plus expected profits in subsequent markets:

$$E_K\{\sum_h (t^D_{hk}\lambda^D_{hk} - \sum_j C_j q^D_{jhk}) + \Psi^G_k(q^D_{jhk}, t^D_{hk})\}$$

PROBLEM FORMULATION
Day-ahead market

Subject to:

Production limits (energy) per unit, hour and scenario:

$$q^{D}_{jhk} \leq P^{max}_{j} \qquad \forall j, \forall h, \forall k$$

$$q^{D}_{jhk} \geq P^{min}_{j} \qquad \forall j, \forall h, \forall k$$

Energy production (all units) per hour & scenario:

$$t^{D}_{hk} = \sum_{j} q^{D}_{jhk} \qquad \forall h, \forall k$$

PROBLEM FORMULATION
Day-ahead market

Offer curves must be increasing over k (price scenarios):

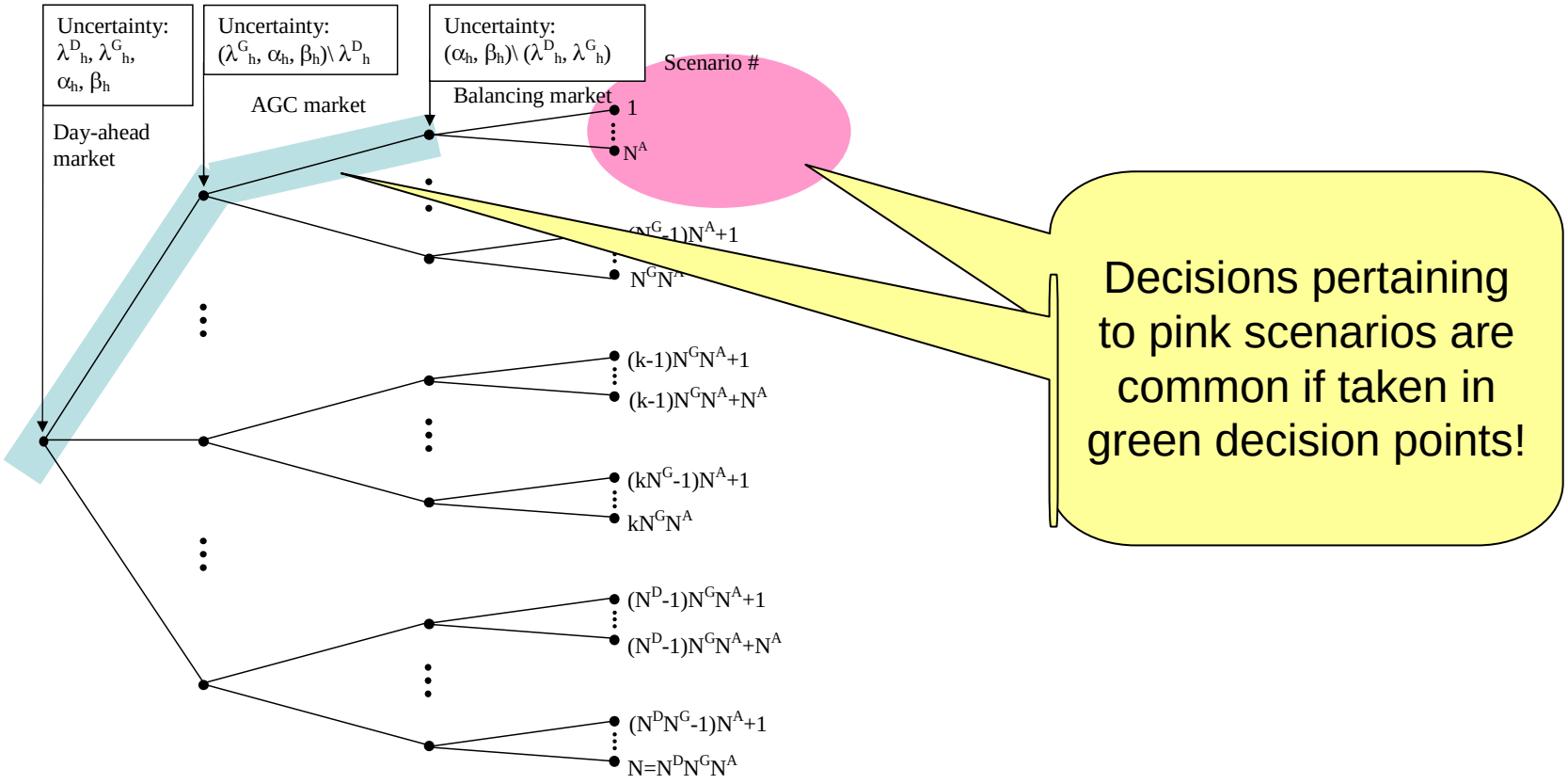
$$q^{D}_{jhk} - q^{D}_{jh\tilde{k}} \leq 0 \qquad \forall j, \forall h, \forall k, \tilde{k} : O(\lambda^{D}_{hk}) + 1 = O(\lambda^{D}_{h\tilde{k}})$$

No anticipativity over k (price scenarios):

$$q^{D}_{jhk} = q^{D}_{jh\tilde{k}} \qquad \forall j, \forall k, \tilde{k} : (\lambda^{D}_{hk} = \lambda^{D}_{h\tilde{k}} \ \forall h)$$

PROBLEM FORMULATION
Day-ahead market

No anticipativity over k (price scenarios):



PROBLEM FORMULATION
AGC market

$$\text{Maximize}_{q^G_{jhk}, t^G_{hk}, w_{jhk}}$$

Expected profit in AGC market plus expected profit in balancing market:

$$E_{K \setminus \lambda^D_{hk}} \{ \sum_h t^G_{hk} \lambda^G_{hk} + \Psi^A_k (q^D_{jhk}, t^D_{hk}, q^G_{jhk}, t^G_{hk}, w_{jhk}) \}$$

PROBLEM FORMULATION
AGC market

Subject to:

AGC contribution iff binary variables equal 1 (per unit, hour and scenario):

$$q^{G}_{jhk} \leq w_{jhk} P^{AGC}_{j} \quad \forall j, \forall h, \forall k$$

Total power dedicated to AGC (per hour and scenario):

$$t^{G}_{hk} = \sum_{j} q^{G}_{jhk} \qquad \forall h, \forall k$$

PROBLEM FORMULATION
AGC market

No antivipativity over k (price scenario):

$$q^{G}_{jhk} = q^{G}_{jh\tilde{k}} \qquad \forall j, \forall k, \tilde{k} : ((\lambda^{D}_{hk}, \lambda^{G}_{hk}) = (\lambda^{D}_{h\tilde{k}}, \lambda^{G}_{h\tilde{k}}) \ \forall h)$$

Binary variable declaration:

$$w_{jhk} \in \{0,1\} \qquad \forall j, \forall h, \forall k$$

PROBLEM FORMULATION
Balancing market

$$\underset{p_{jhk},q^A_{jhk},t^A_{hk}}{\text{Maximize}}$$

Expected profit in balancing market:

$$E_{K\setminus(\lambda^D_{hk},\lambda^G_{hk})}\{\sum_h(t^A_{hk}\underbrace{(\alpha_{hk}+\beta_{hk}t^A_{hk})}_{\lambda^D_{hk}(\cdot)}-\sum_j C_j q^A_{jhk})\}$$

PROBLEM FORMULATION
Balancing market

Subject to:

Power capacity limits (per unit, hour and scenario):

$$p_{jhk} \leq P_j^{max} \qquad p_{jhk} \geq P_j^{min} \qquad \forall j,h,k$$

Energy capacity limits (per unit, hour and scenario):

$$q_{jhk}^{D} + q_{jhk}^{A} + \tfrac{1}{2} q_{jhk}^{G} \leq P_j^{max} \qquad \forall j,h,k$$

$$q_{jhk}^{D} + q_{jhk}^{A} - \tfrac{1}{2} q_{jhk}^{G} \geq P_j^{min} \qquad \forall j,h,k$$

PROBLEM FORMULATION
Balancing market

Energy and power relationship (linear change), per unit, hour and scenario:

$$q^{D}_{jhk} + q^{A}_{jhk} = \tfrac{1}{2}(p_{j(h-1)k} + p_{jhk}) \qquad \forall j,h,k$$

If ramping no AGC and vice versa (per unit, hour and scenario):

$$p_{jhk} - p_{j(h-1)k} \le (1 - w_{jhk}) R^{up}_{j} \qquad \forall j,h,k$$

$$p_{j(h-1)k} - p_{jhk} \le (1 - w_{jhk}) R^{dw}_{j} \qquad \forall j,h,k$$

PROBLEM FORMULATION
Balancing market

Total energy in balancing market (all unit) (per hour and scenario):

$$t_{hk}^{A} = \sum_{j} q_{jhk}^{A} \qquad \forall h,k$$

Problem formulation
Program with recourse

$$\text{Maximize}_{q^D_{jhk},t^D_{hk},q^G_{jhk},t^G_{hk},w_{jhk},p_{jhk},q^A_{jhk},t^A_{hk}}$$

$$\sum_k \Big[\sum_h (t^D_{hk}\lambda^D_{hk} - \sum_j C_j q^D_{jhk})$$ (*Day-ahead market profit*)

$$+ \sum_h t^G_{hk}\lambda^G_{hk}$$ (*AGC market profit*)

$$+ \sum_h (t^A_{hk}(\alpha_{hk} + \beta_{hk} t^A_{hk}) - \sum_j C_j q^A_{jhk}) \Big] \pi_k$$ (*Balancing market profit*)

subject to

Day-ahead market constrains

AGC market constrains

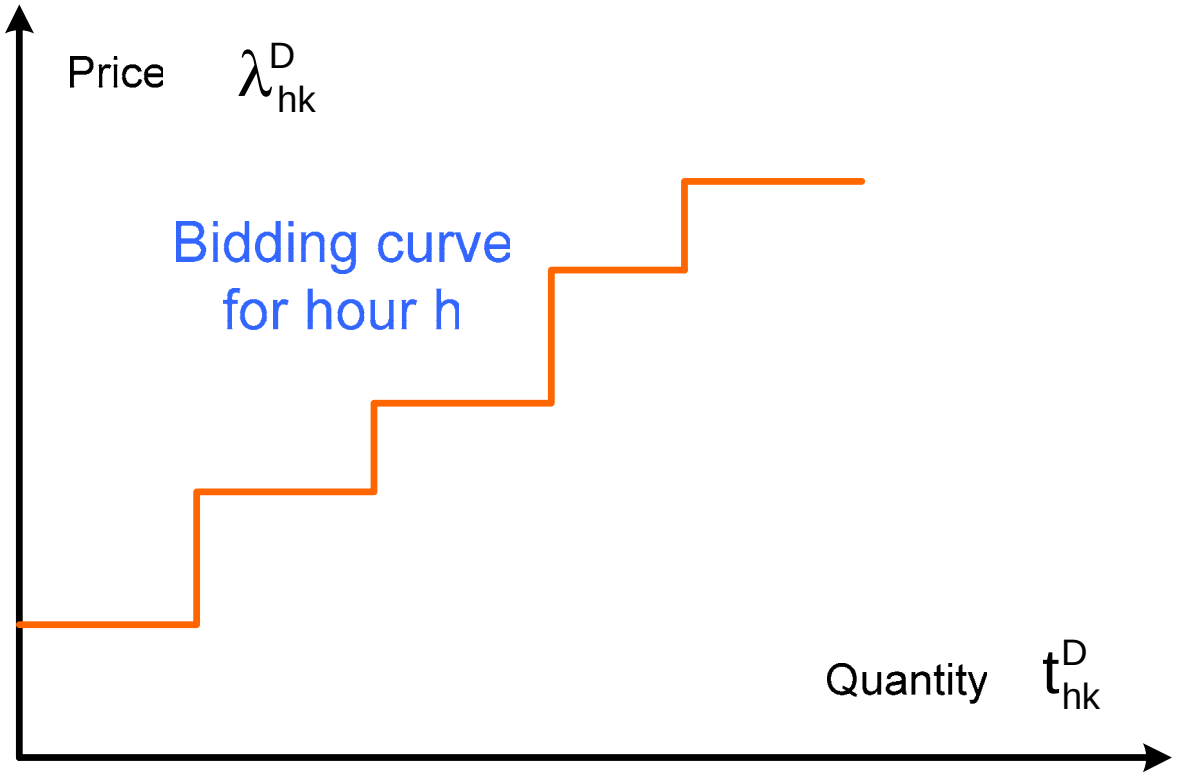
Balancing market constrains

Solution technique

Solution:

- CPLEX
- Coordinate descent: each unit optimized with others at fixed values. Iteration!

Solution: Bidding curves



Solution quality

Quality:

- VSS: Value of the Stochastic Solution
- RP: Average value over scenarios of the day ahead profit evaluated with the *stochastic solution*
- EEV: Average value over scenarios of the day ahead profit evaluated with the *deterministic solution* (random variables substituted by their respective expected values)
- VSS = RP - EEV

Solution quality

Comparison among different approaches

Profit for actual prices:

- EEM: Multi-market stochastic solution
- DEM: Multi-market deterministic solution
- DEU: Single-market deterministic solution

Case Study

- Case 1: May 3-7, 2004 (Monday-Friday)
  - Low temperature
  - Low demand
  - Low prices
- Case 2: June 7-11, 2004 (Monday-Friday)
  - High temperatures
  - High demand
  - Low hydro production
  - High prices

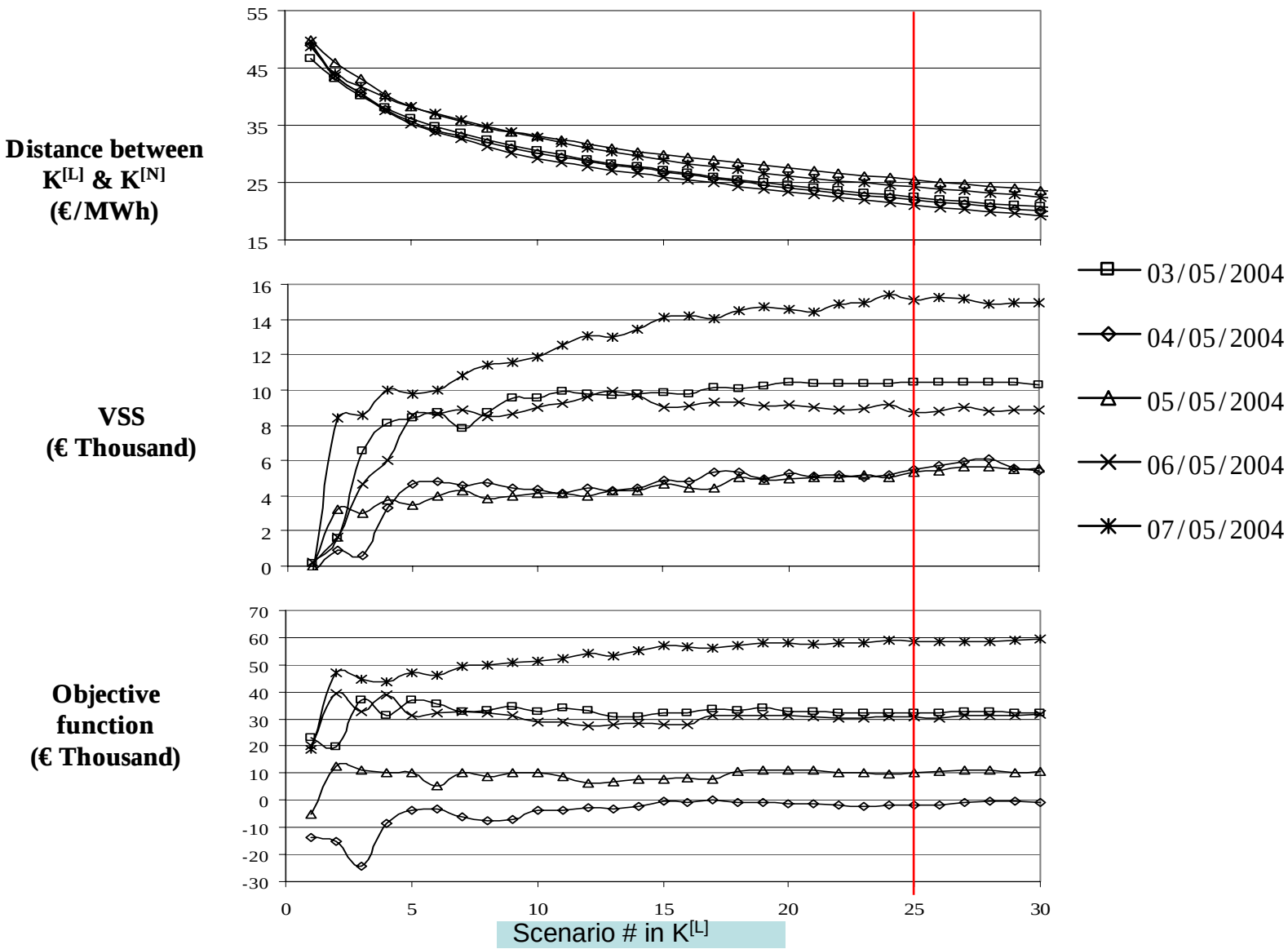
Case Study1: Production Company

	C_j^F	C_j	P_j^{max}	P_j^{min}	P_j^{AGC}	R_j^{up}	R_j^{dw}	P_{j0}
	€/h	**€/MWh**	**MW**	**MW**	**MW**	**MW/h**	**MW/h**	**MW**
Coal 1	**126.0**	**19.81**	**140**	**75**	**20**	**65**	**65**	**130**
Coal 2	**708.8**	**23.40**	**350**	**150**	**30**	**200**	**200**	**335**
CCGT 1	**1097.2**	**25.17**	**380**	**160**	**50**	**220**	**220**	**185**
CCGT 2	**992.8**	**25.51**	**390**	**180**	**50**	**210**	**210**	**205**
Coal 3	575.0	29.37	500	250	40	250	250	270
Fuel 1	1800	33.91	300	200	20	100	100	220
Fuel 2	91.5	37.91	50	25	0	25	25	25

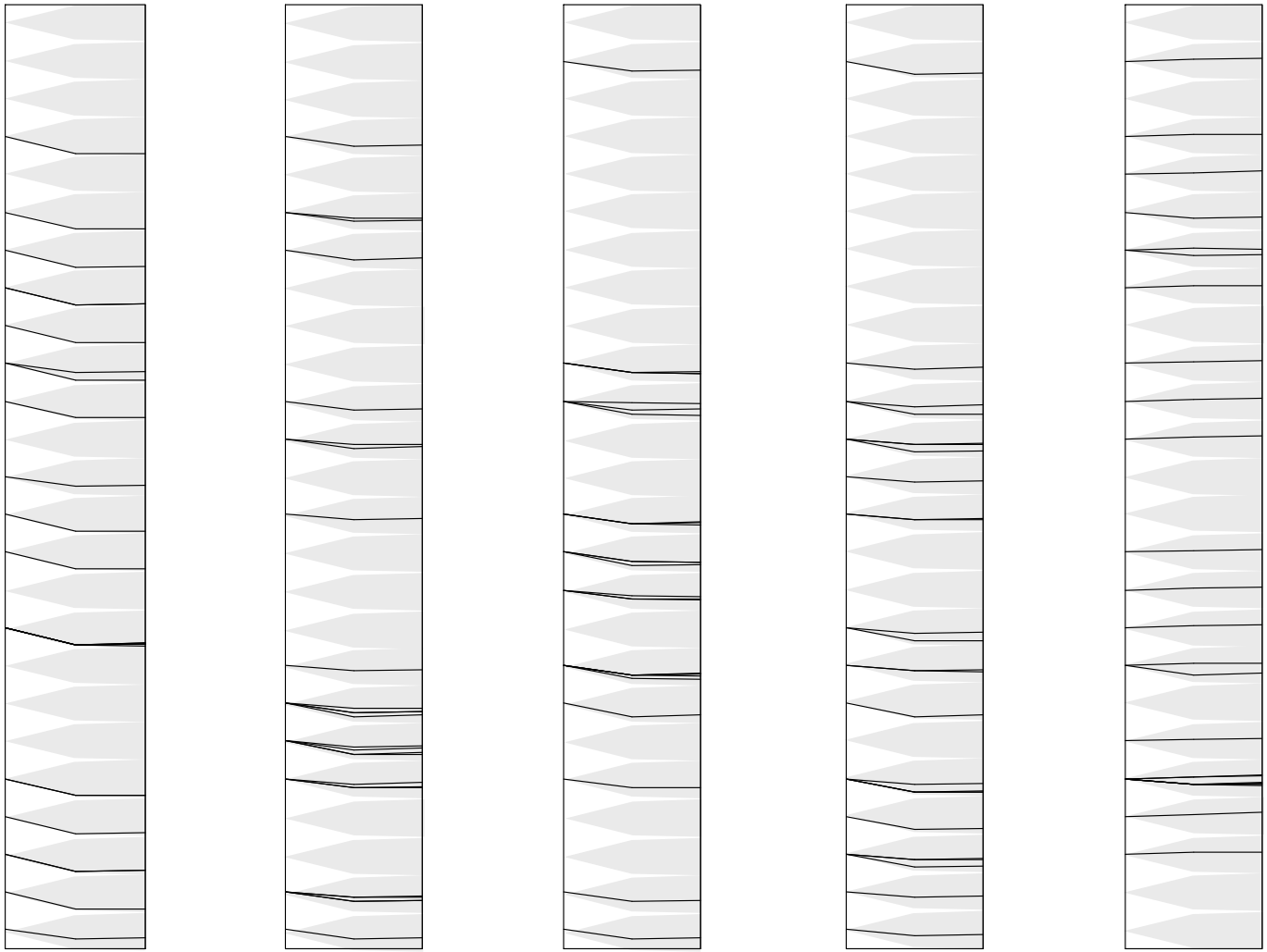
Case Study1. Uncertainty

Variable	Model
λ_h^D	$ARIMA(1,0,1)(2,0,1)_{24}$
λ_h^G	$ARIMA(5,0,1)(1,0,1)_{24}$
α_h	$ARIMA(1,0,2)(1,0,1)_{24}$
β_h	$ARIMA(2,0,1)(1,0,1)_{24}$

Case 1. Scenario Reduction



Case 1. Scenario Reduction



Case 1: Solution

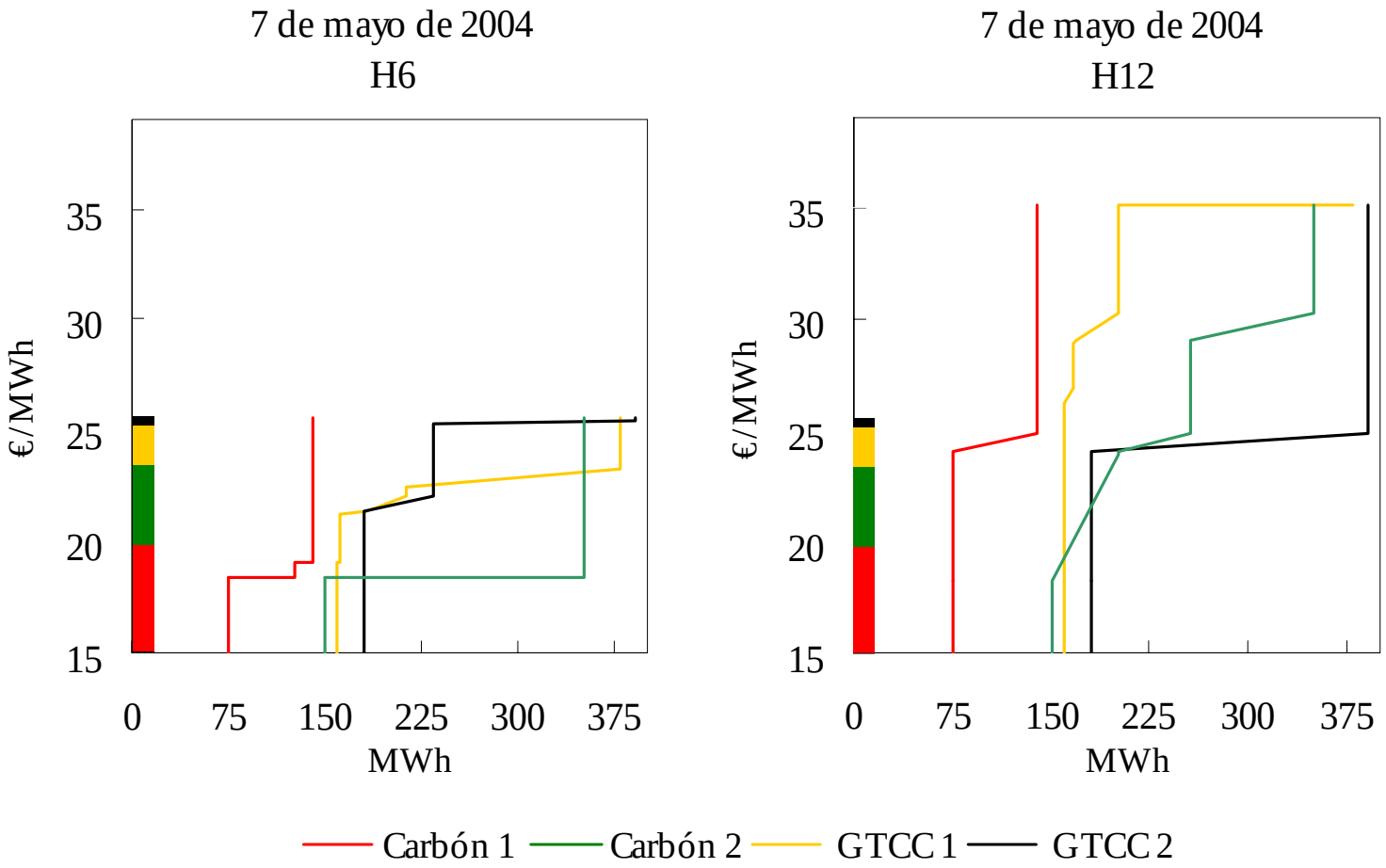
Coordinate Descent

	03-05-04	04-05-04	05-05-04	06-05-04	07-05-04
Iteration #	4	3	3	3	2
Result (€)	32654	-1878	10496	30690	58672
Error (€)	12	12	46	1	33
Error (%)	0.0	0.7	0.4	0.0	0.1
CPU time (s)	411	310	310	313	210

Direct Solution (CPLEX)

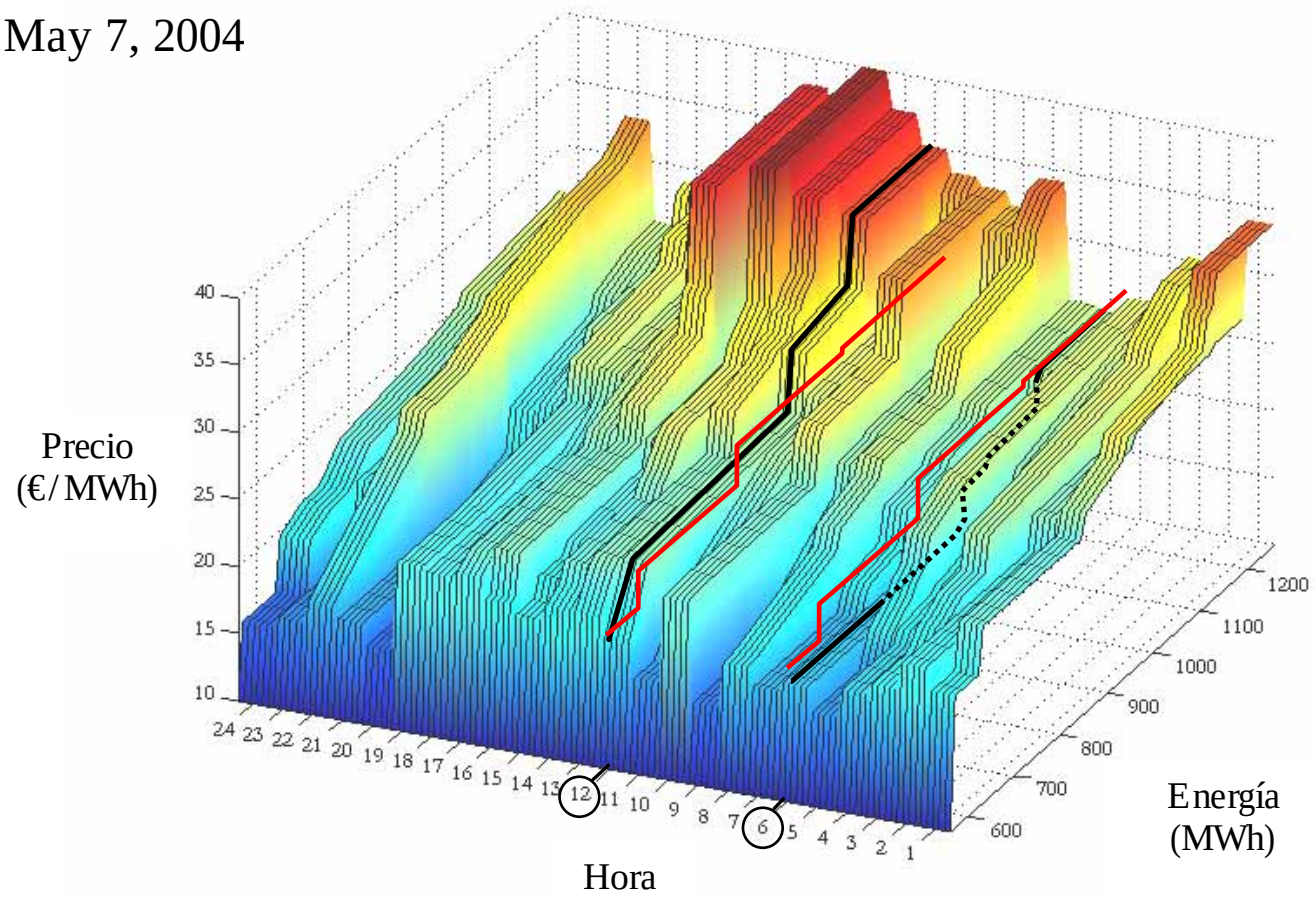
	03-05-04	04-05-04	05-05-04	06-05-04	07-05-04
Result (€)	32670	-1620	10662	30734	58737
Error (€)	535	619	532	687	673
Error (%)	1.6	38.2	5.0	2.2	1.1
CPU time (s)	411	310	310	313	210

Case1: Individual offers



Case1: Portfolio offers

May 7, 2004



Case 1: Solution Quality

VSS

Day	**03-05-04**	**04-05-04**	**05-05-04**	**06-05-04**	**07-05-04**	**Total**
RP (€)	32670	-1620	10662	30734	58737	131184
EEV (€)	27980	-6522	6904	25379	54252	107993
VSS (€)	**4690**	**4902**	**3758**	**5355**	**4486**	**23191**
VSS/RP (%)	**14**	**303**	**35**	**17**	**8**	**18**

Case 1: Solution Quality

Comparison among different approaches

Day	03-05-04	04-05-04	05-05-04	06-05-04	07-05-04	Total
EEM (€)	6307	-924	35564	44658	83325	168929
DEM (€)	4126	-3889	30952	38932	80192	150312
DEU (€)	1873	-3764	32259	41953	79609	151929

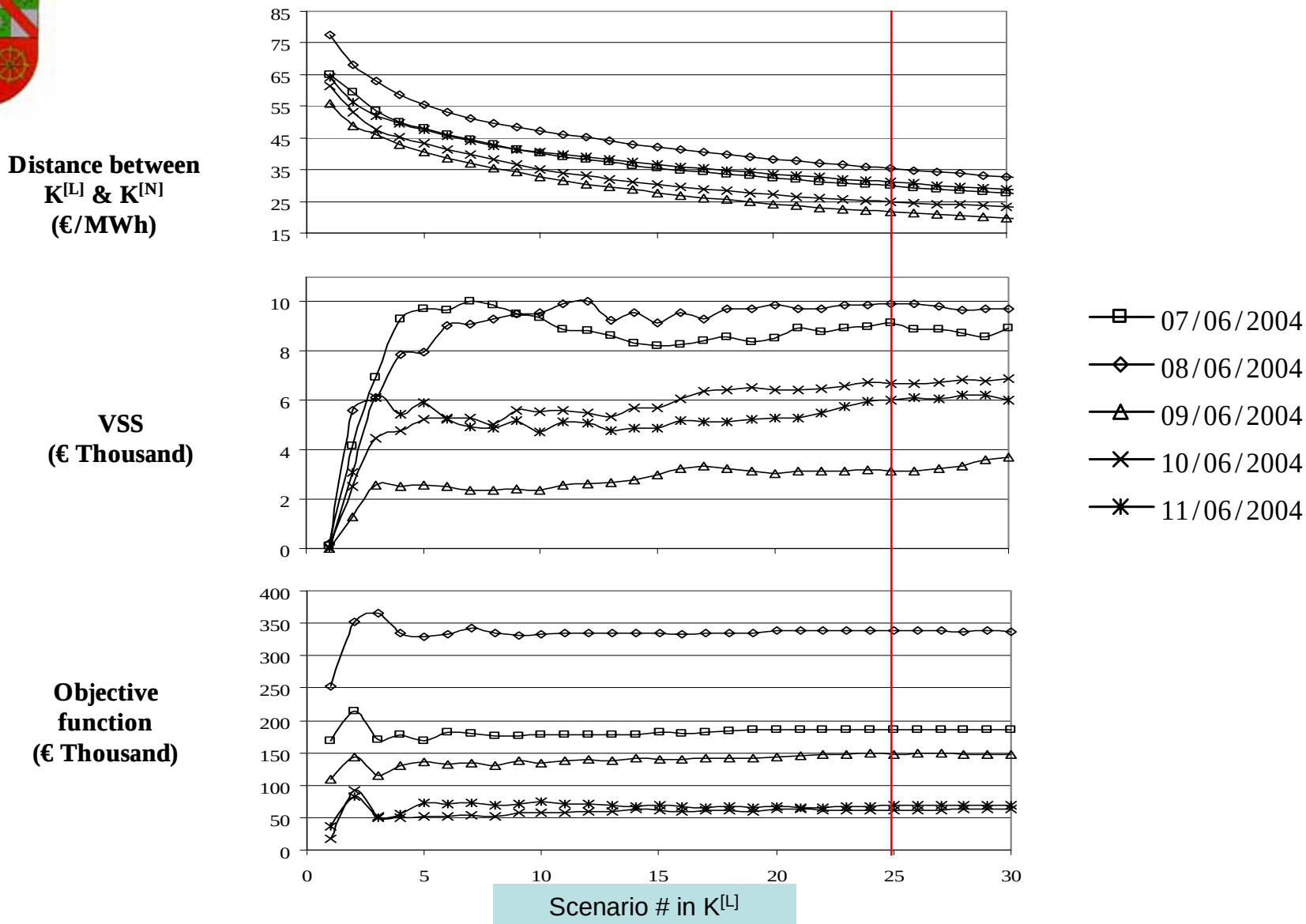
Case Study 2: Production Company

	C_j^F	C_j	P_j^{max}	P_j^{min}	P_j^{AGC}	R_j^{up}	R_j^{dw}	P_{j0}
	€/h	€/MWh	MW	MW	MW	MW/h	MW/h	MW
Coal 1	126.0	19.81	140	75	20	65	65	130
Coal 2	708.8	23.40	350	150	30	200	200	335
CCGT 1	1097.2	25.17	380	160	50	220	220	185
CCGT 2	992.8	25.51	390	180	50	210	210	205
Coal 3	575.0	29.37	500	250	40	250	250	270
Oil 1	1800	33.91	300	200	20	100	100	220
Oil 2	91.5	37.91	50	25	0	25	25	25

Case 2: Uncertainty

Variable	Model
λ_h^D	$ARIMA(1,0,1)(2,0,1)_{24}$
λ_h^G	$ARIMA(5,0,1)(1,0,1)_{24}$
α_h	$ARIMA(1,0,2)(1,0,1)_{24}$
β_h	$ARIMA(2,0,1)(1,0,1)_{24}$

Case 2: Scenario Reduction



Case 2: Scenario Reduction

Case 2: Solution

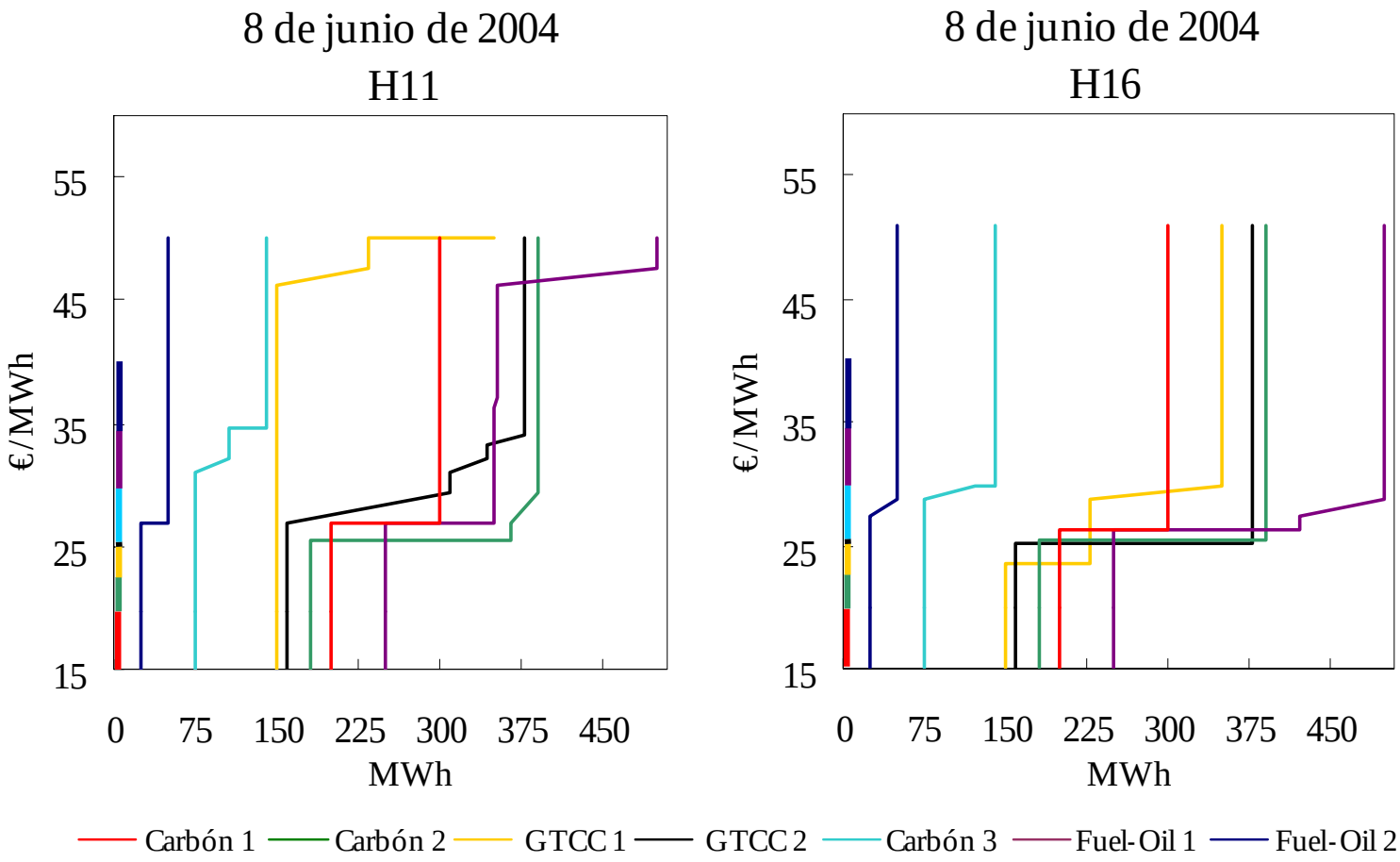
Coordinate Descent

	07-06-04	08-06-04	09-06-04	10-06-04	11-06-04
Iterations #	2	2	2	2	2
Result (€)	185525	338411	148240	61268	68445
Error (€)	31	54	94	36	46
Error (%)	0.02	0.02	0.06	0.06	0.07
CPU time (s)	315	315	316	319	319

Direct Solution (CPLEX)

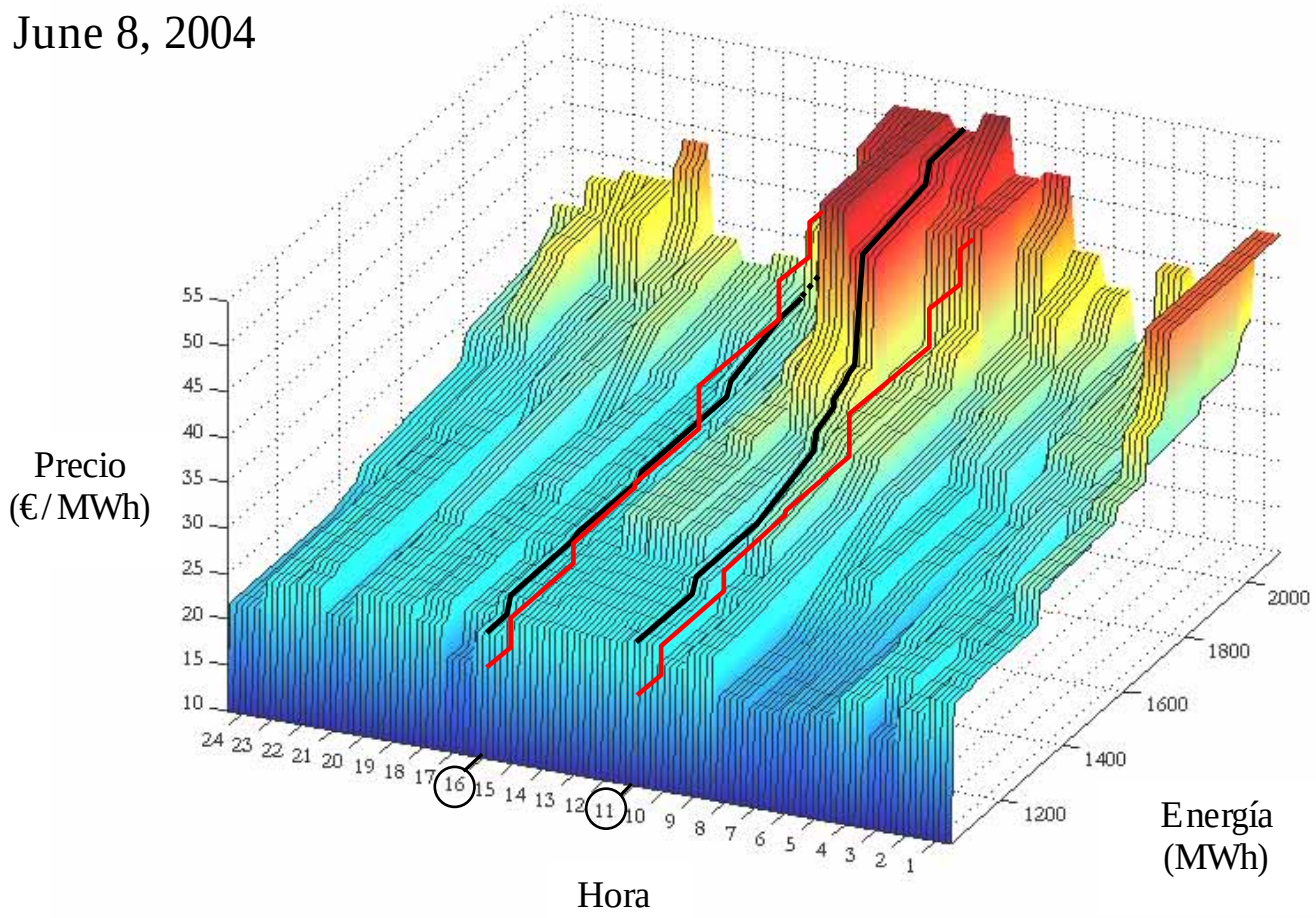
	07-06-04	08-06-04	09-06-04	10-06-04	11-06-04
Result (€)	185473	338274	148269	61205	68380
Error (€)	815	849	625	886	784
Error (%)	0.44	0.25	0.42	1.45	1.15
CPU time (s)	315	315	316	319	319

Case 2: Individual Offers



Case 2: Portfolio Offers

June 8, 2004



Case 2: Solution Quality

VSS

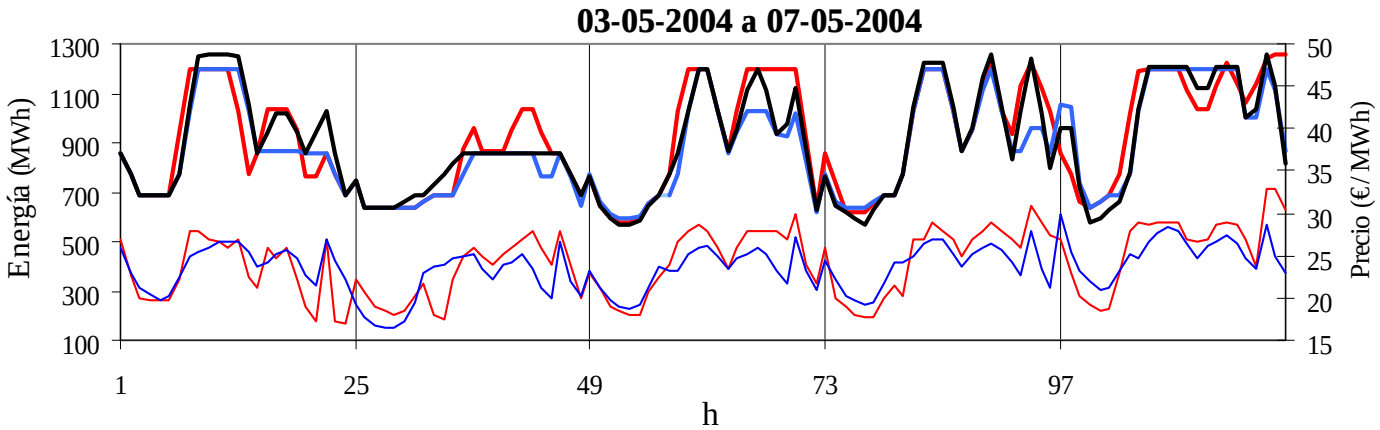
Day	**07-06-04**	**08-06-04**	**09-06-04**	**10-06-04**	**11-06-04**	**Total**
RP (€)	185473	338274	148269	61205	68380	801601
EEV (€)	180671	335105	145278	55890	64340	781284
VSS (€)	**4802**	**3169**	**2991**	**5315**	**4039**	**20317**
VSS/RP (%)	**3**	**1**	**2**	**9**	**6**	**3**

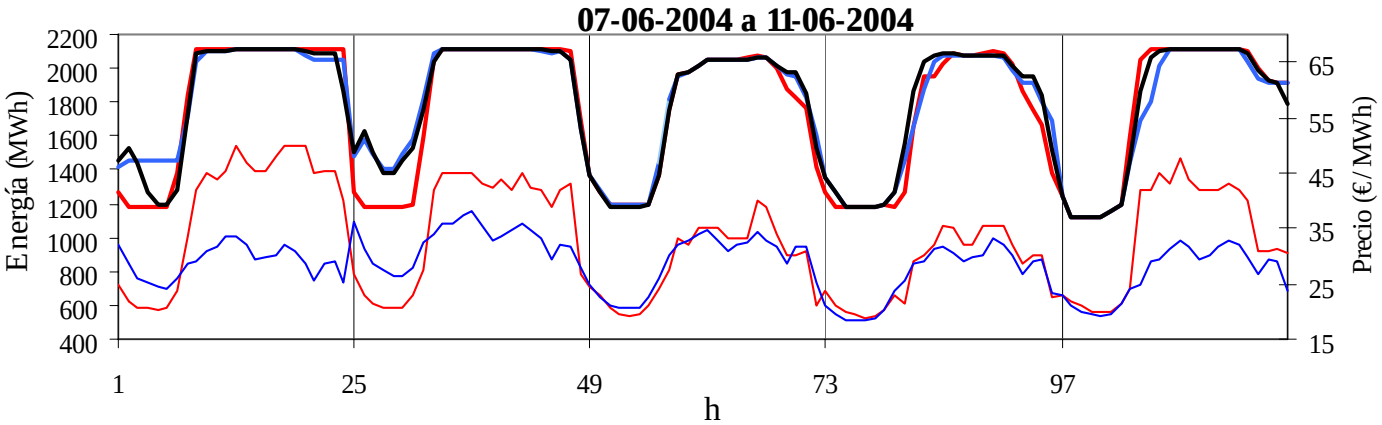
Case 2: Solution Quality

Comparison among different approaches

Day	07-06-04	08-06-04	09-06-04	10-06-04	11-06-04	Total
EEM (€)	618845	473392	148247	97228	387314	1725026
DEM (€)	605769	466852	151551	98983	385438	1708592
DEU (€)	607922	467459	151834	97670	388928	1713814

Case Study Summary





EEM — DEM — DEU — Precio real — Precio esperado

End

GSEE: http://www.uclm.es/area/gsee/