Producer Self-Scheduling

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&

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Producer self-scheduling

Maximize	Profits
Subject to	Operation constraints

Producer self-scheduling

Price-taker

- A price-taker has no capability of altering the market-clearing price
- The profit maximization self-scheduling problem decomposes by generator

Producer self-scheduling

Price-taker

$$\underset{P_{Gt}}{\text{Maximize}} \quad \sum_{t=1}^{24} \lambda_t \, P_{Gt} - C_t\left(P_{Gt}\right)$$

$$\text{Subject to} \quad P_{Gt} \in \Delta_G \qquad \forall t$$

Price-taker

Production cost:	2 € /MWh
Maximum capacity:	10 MW
Minimum power output:	2 MW
Ramp-up limit:	5 MW/h
Ramp-down limit:	4 MW/h
Initial power output:	2 MW

Market price forecasts:

Hour	1	2	3	4
Price [€ /MWh]	2	4	3	1

Price-taker

$$\underset{P_{G1},P_{G2},P_{G3},P_{G4}}{\text{MAXIMIZE}} \quad 2P_{G1}+4P_{G2}+3P_{G3}+P_{G4}-2(P_{G1}+P_{G2}+P_{G3}+P_{G4})$$

SUBJECT TO

$$2u_1 \le P_{G1} \le 10u_1$$
$$2u_2 \le P_{G2} \le 10u_2$$
$$2u_3 \le P_{G3} \le 10u_3$$
$$2u_4 \le P_{G4} \le 10u_4$$

$$P_{G1}-2 \le 5$$
$$P_{G2}-P_{G1} \le 5$$
$$P_{G3}-P_{G2} \le 5$$
$$P_{G4}-P_{G3} \le 5$$

$$2-P_{G1} \le 4$$
$$P_{G1}-P_{G2} \le 4$$
$$P_{G2}-P_{G3} \le 4$$
$$P_{G3}-P_{G4} \le 4$$

$$u_1,u_2,u_3,u_4 \in \{0,1\}$$

Price-taker

Optimal production and price				
Hour	1	2	3	4
Price [€ /MWh]	2	4	3	1
Production (MW)	5	10	6	2

Price-Taker Example

Price-Taker Example

Pmax (MW)	Pmin (MW)	Rup (MW/h)	Rdown (MW/h)	Rstart (MW/h)	Rshut (MW/h)	V_0	P_0 (MW)
300	10	50	80	20	10	1	50

Fixed cost (€)	Variable cost (€/MWh)
30	6

Hours	1	2	3	4	5	6	7	8	9	10	11	12
Price (€\MWh)	9	8	8	5	4	3	4	6	4	8	4	6

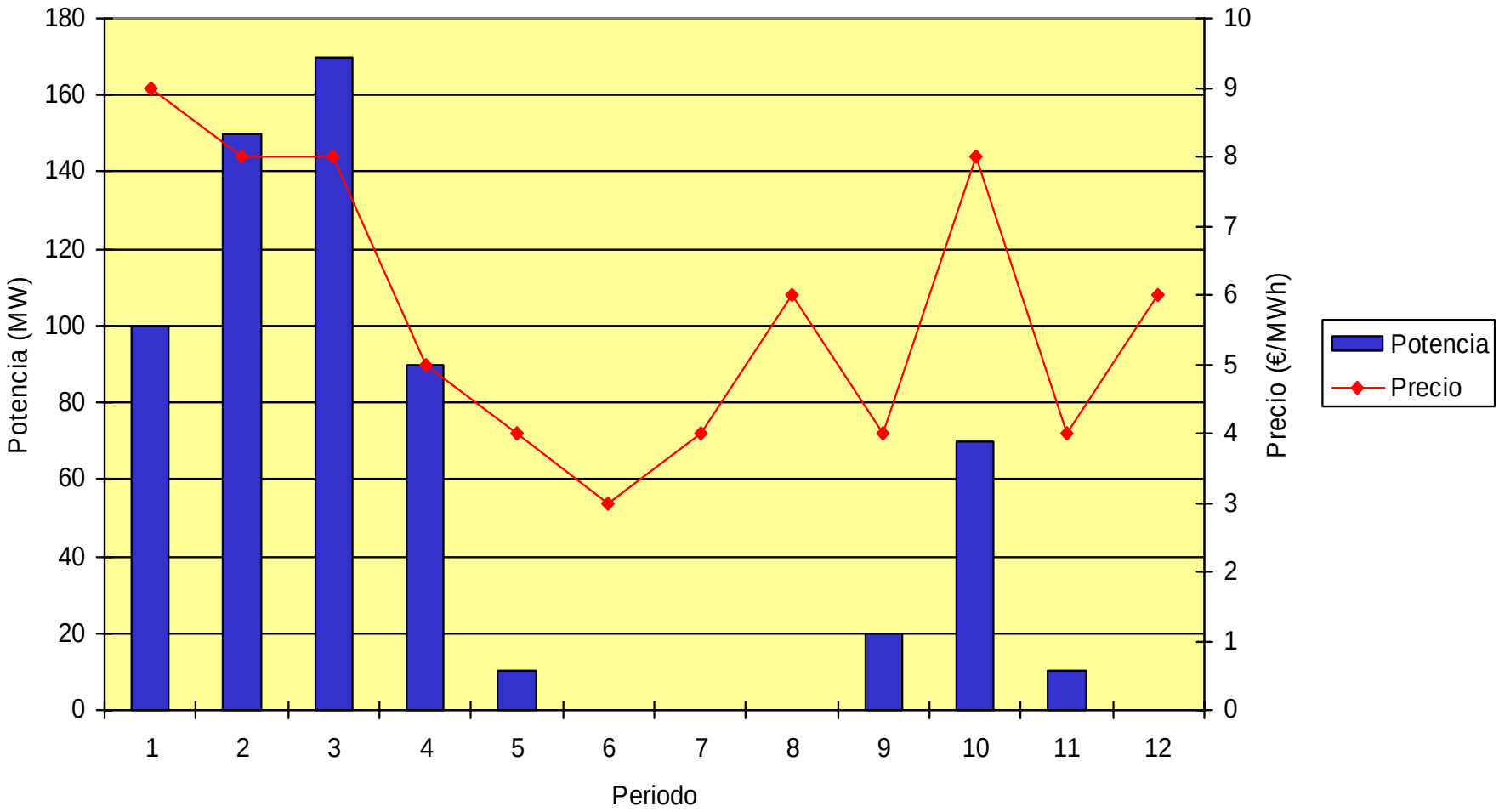
Price-Taker Example

Solution

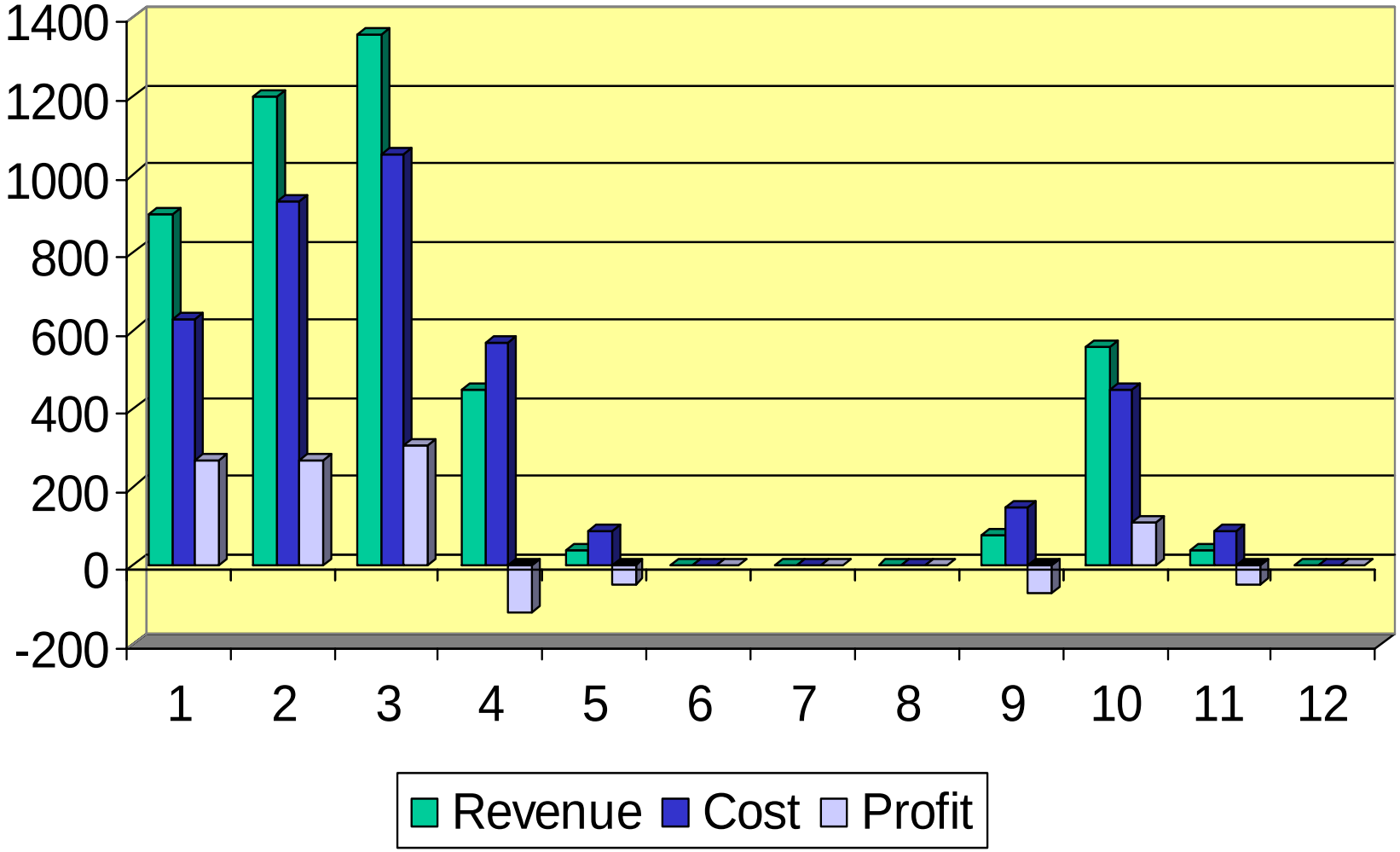
Hour	1	2	3	4	5	6	7	8	9	10	11	12
Power (MW)	100	150	170	90	10	0	0	0	20	70	10	0
Revenue (€)	900	1200	1360	450	40	0	0	0	80	560	40	0
Cost (€)	630	930	1050	570	90	0	0	0	150	450	90	0

Total profit € 670

Price-Taker Example



Price-Taker Example



Hydroelectric price-taker

Hydroelectric price-taker

$$\underset{P_{Ght};V;Q}{\text{MAXIMIZE}} \quad \sum_{t=1}^{24}\left(\lambda_t \sum_{h=1}^{N_H} P_{Ght}\right)$$

$$\text{SUBJECT TO} \quad P_{Ght} = P_{Ght}\left(V_{ht}, Q_{ht}\right) \qquad \forall h, \forall t$$

$$AV + BQ = b$$

Hydroelectric price-taker

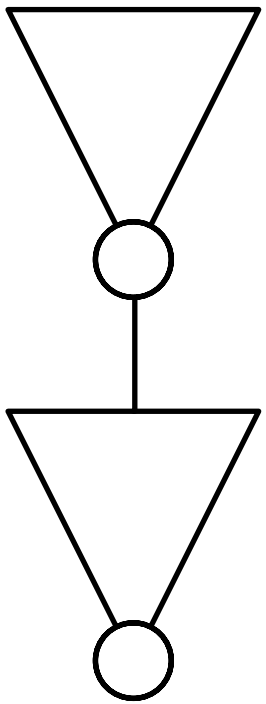
- Revenues
- Power output
- Water conservation law

Hydroelectric Price-Taker

- Spatial coupling: units located along the river
- Temporal coupling: limited amount of water

Hydroelectric price-taker

Example (1)



Hydroelectric price-taker
Example (2)

Upper reservoir:

Initial volume:	2 Hm^3
Maximum volume:	10 Hm^3
Minimum volume:	2 Hm^3
Inflow (constant):	1 Hm^3
Maximum discharge:	4 Hm^3
Conversion factor :	5 MWh/Hm^3

Lower reservoir:

Initial volume:	3 Hm^3
Maximum volume:	10 Hm^3
Minimum volume:	2 Hm^3
Inflow (constant):	2 Hm^3
Maximum discharge:	4 Hm^3
Conversion factor:	8 MWh/Hm^3

Hydroelectric price-taker
Example (3)

Planning horizon: 3 hours

Prices

Hour	1	2	3
Price [€/MWh]	2	4	3

Hydroelectric price-taker. Example (4)

$$\underset{P_{G11},P_{G21},P_{G12},P_{G22},P_{G13},P_{G23}}{\text{MAXIMIZE}} \quad 2(P_{G11}+P_{G21})+4(P_{G12}+P_{G22})+3(P_{G13}+P_{G23})$$

SUBJECT TO

$$P_{G11}=5Q_{11},\quad P_{G12}=5Q_{12},\quad P_{G13}=5Q_{13}$$
$$P_{G21}=8Q_{21},\quad P_{G22}=8Q_{22},\quad P_{G23}=8Q_{23}$$

Volume at the beginning of period 1, reservoir 1

Inflow during period 1, reservoir 1

$$V_{12}=2-Q_{11}+1$$

Discharged volume during period 1, reservoir 1

$$V_{13}=V_{12}-Q_{12}+1$$
$$V_{14}=V_{13}-Q_{13}+1$$

Volume at the beginning of period 2, reservoir 1

$$V_{22}=3-Q_{21}+2+Q_{11}$$
$$V_{23}=V_{22}-Q_{22}+2+Q_{12}$$
$$V_{24}=V_{23}-Q_{23}+2+Q_{13}$$

$$2\le V_{12}\le 10,\quad 2\le V_{13}\le 10,\quad 2\le V_{14}\le 10,$$
$$2\le V_{22}\le 10,\quad 2\le V_{23}\le 10,\quad 2\le V_{24}\le 10,$$

$$0\le Q_{12}\le 4,\quad 0\le Q_{13}\le 4,\quad 0\le Q_{14}\le 4,$$
$$0\le Q_{22}\le 4,\quad 0\le Q_{23}\le 4,\quad 0\le Q_{24}\le 4,$$

Hydroelectric price-taker
Example (5)

Optimal production (MW)			
Hour	1	2	3
Unit 1	0	10	5
Unit 2	16	32	32
Total	16	42	37

Price-Taker
Uncertain prices

Price-Taker. Uncertain prices

- Maximum expected profit

Subject to:

✓ Operating constraints

Price-Taker. Uncertain prices

Expected profit:

$$\text{Profit} = E_{\lambda_1,\lambda_2,\ldots,\lambda_{24}}\left\{\sum_{t=1}^{24}\left[\lambda_t P_t - C_t(P_t)\right]\right\} = \quad \Leftarrow \quad \text{Linear}$$

$$= \sum_{t=1}^{24}\left[E_{\lambda_t}\left\{\lambda_t P_t - C_t(P_t)\right\}\right] =$$

$$= \sum_{t=1}^{24}\left[E_{\lambda_t}\left\{\lambda_t P_t\right\} - C_t(P_t)\right] =$$

$$= \sum_{t=1}^{24}\left[\lambda_t^{avg} P_t - C_t(P_t)\right]$$

Price-Taker. Uncertain prices

Profit volatility (variance)

$$\mathrm{Var}_{\lambda_1,\lambda_2,\ldots,\lambda_{24}}\left\{\sum_{t=1}^{24}\left[\lambda_t P_t - C_t(P_t)\right]\right\} =$$

$$= \mathrm{Var}_{\lambda_1,\lambda_2,\ldots,\lambda_{24}}\left\{\sum_{t=1}^{24}\lambda_t P_t\right\} = \sum_{i=1}^{24}\sum_{j=1}^{24} Q_{ij} P_i P_j$$

Q_{ij} Covariance matrix (24×24)

Price-Taker. Uncertain prices

Covariance matrix estimation

$$Q^{est} = (1-\alpha)\sum_{i=1}^{D}\alpha^{i-1}\left(\Lambda^{true}_{D-i+1} - \Lambda^{est}_{D-i+1}\right)\left(\Lambda^{true}_{D-i+1} - \Lambda^{est}_{D-i+1}\right)^{T}$$

where:

$D =$ number of days

$\Lambda =$ 24 hour price vector (day)

$\alpha = 0.98$ (for example)

Price-Taker. Uncertain prices

- Maximize expected profit

Subject to

✓ Variance (profit) <= Q

✓ Operating constraints

Price-Taker. Uncertain prices

New constraint

$$Var = \sum_{i=1}^{12} \sum_{j=1}^{12} Q_{ij} P_i P_j \leq Q$$

Q is a pre-specified value

Price-Taker. Uncertain prices

Pmax (MW)	Pmin (MW)	Rup (MW/h)	Rdown (MW/h)	Rstart (MW/h)	Rshut (MW/h)	V_0	P_0 (MW)
200	20	90	90	20	20	1	100

Fixed cost (€)	Variable cost (€/MWh)
10	10

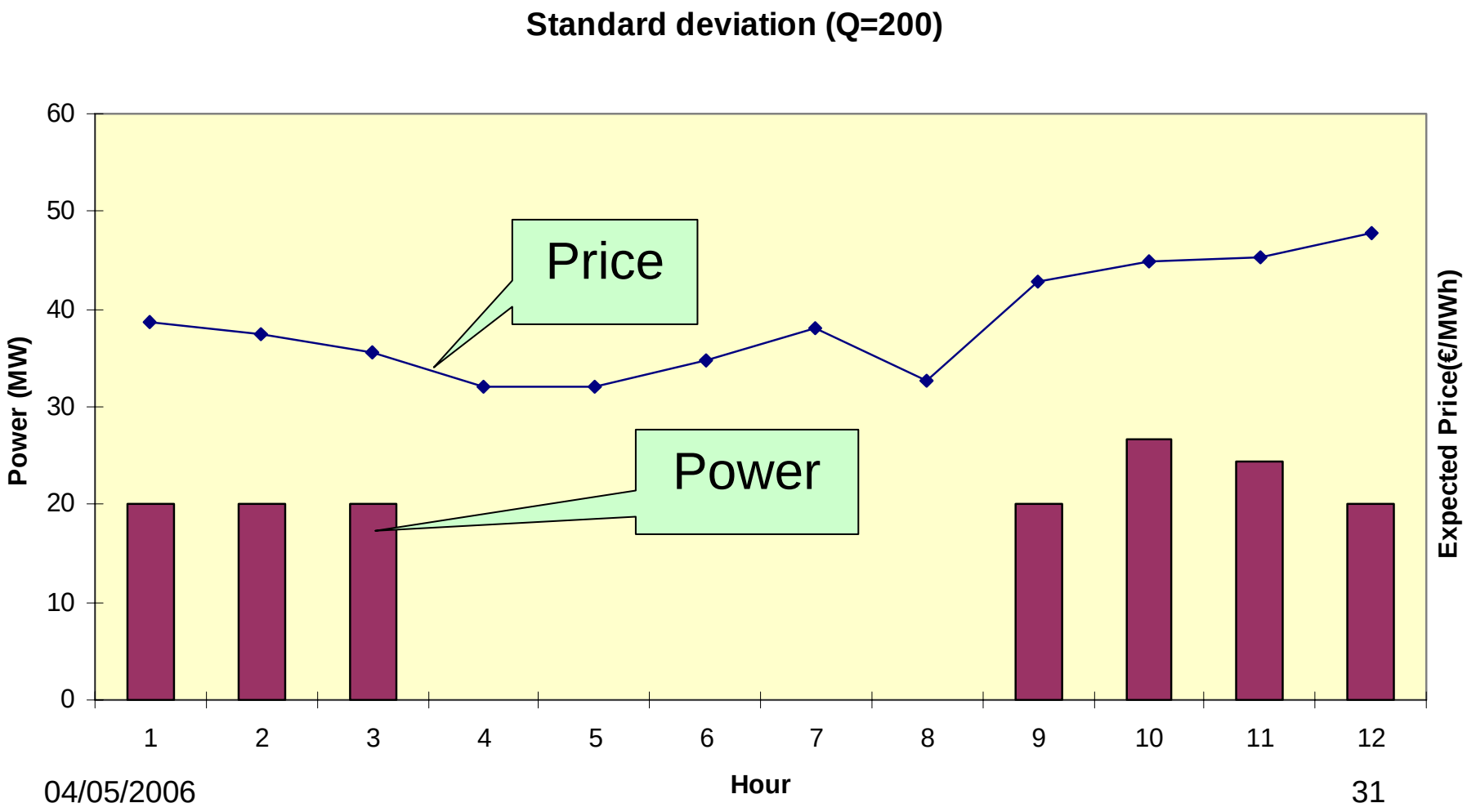
Price-Taker. Uncertain prices

Hours	1	2	3	4	5	6
Expected Price (€/MWh)	38.66	37.37	35.55	31.98	31.98	34.75

Hours	7	8	9	10	11	12
Expected Price (€/MWh)	38.17	32.67	42.83	45	45.37	47.73

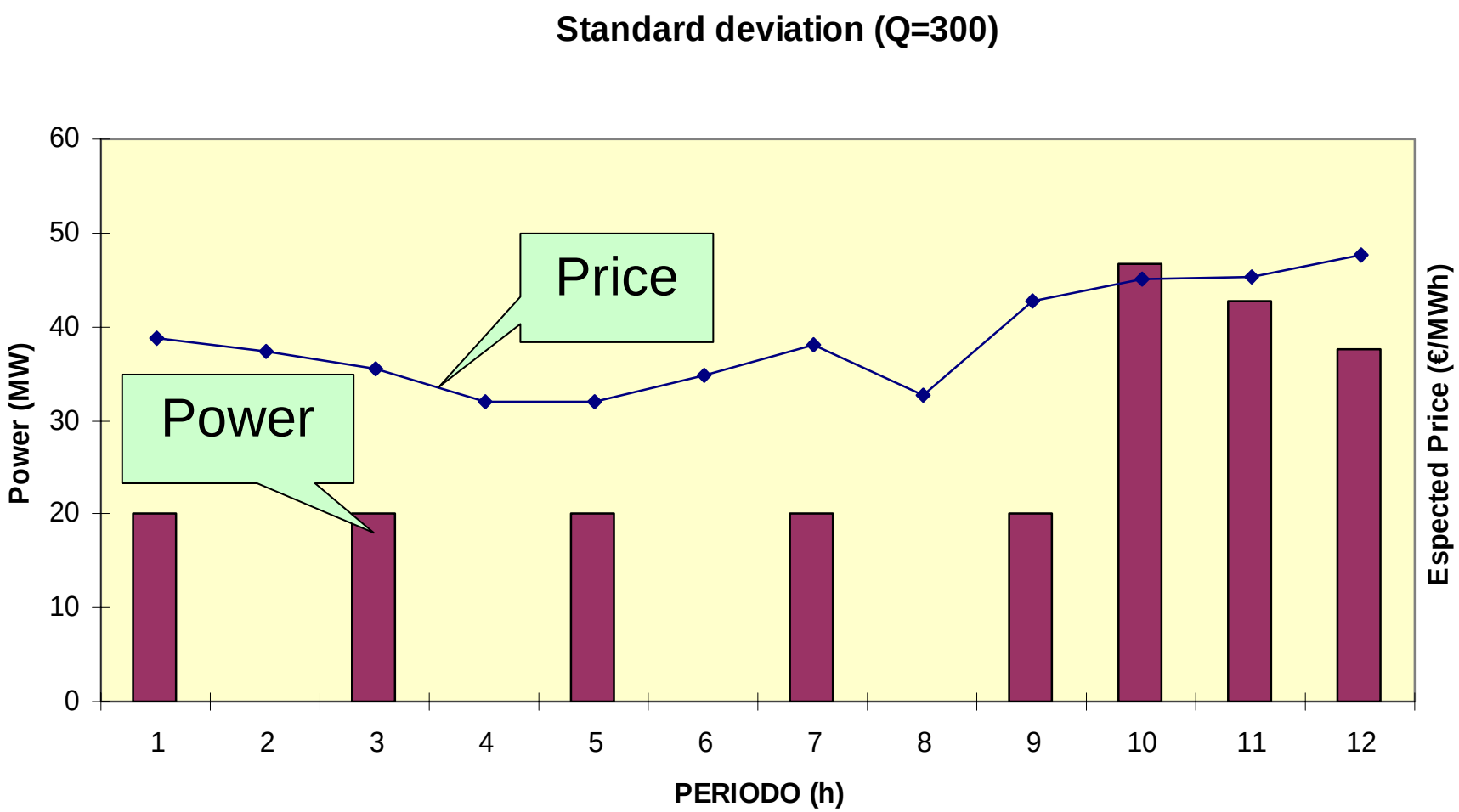
Price-Taker. Uncertain prices

Profit (€): 4771.12



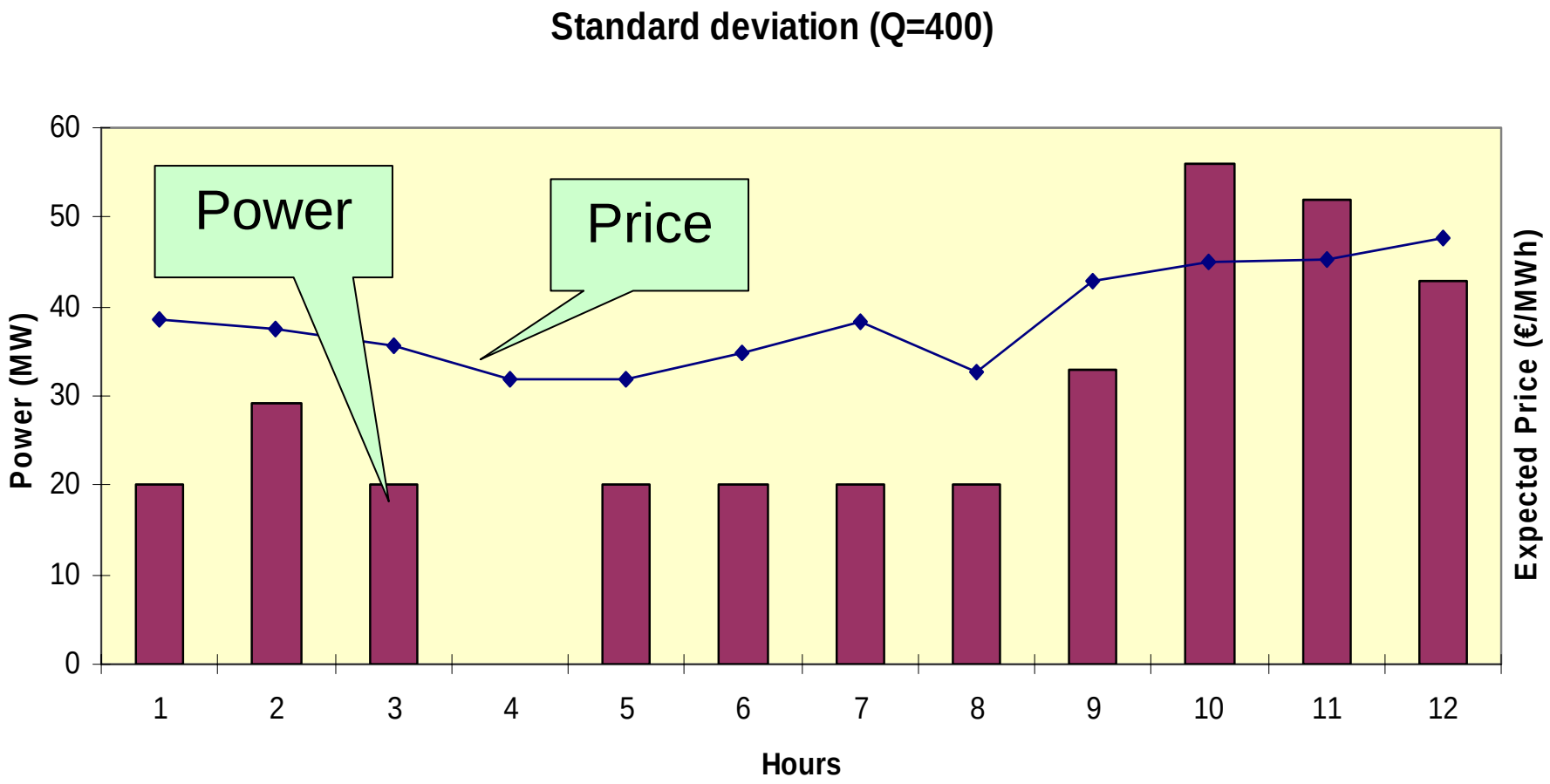
Price-Taker. Uncertain prices

Profit (€): 7225.94



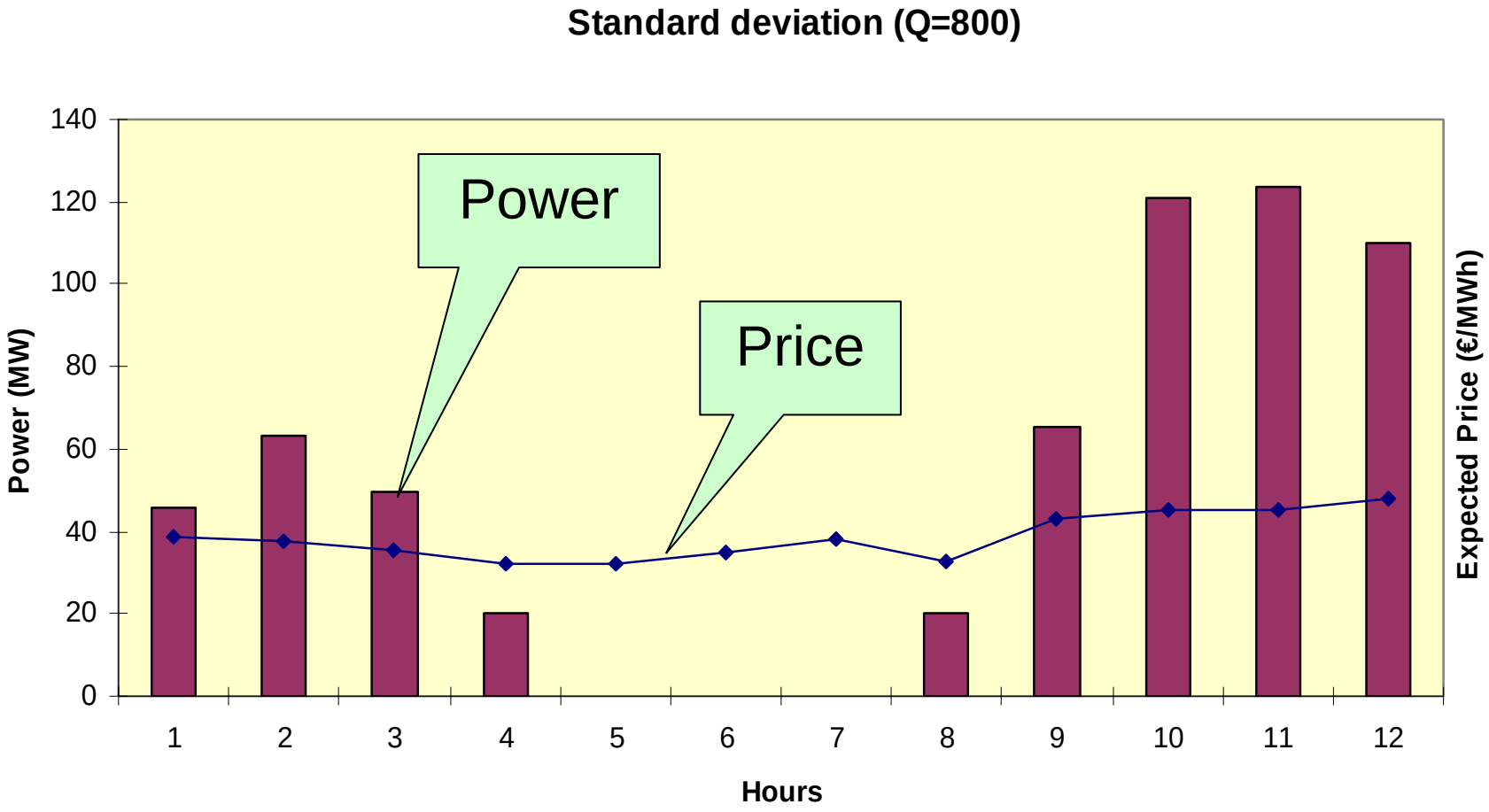
Price-Taker. Uncertain prices

Profit (€): 10208.04



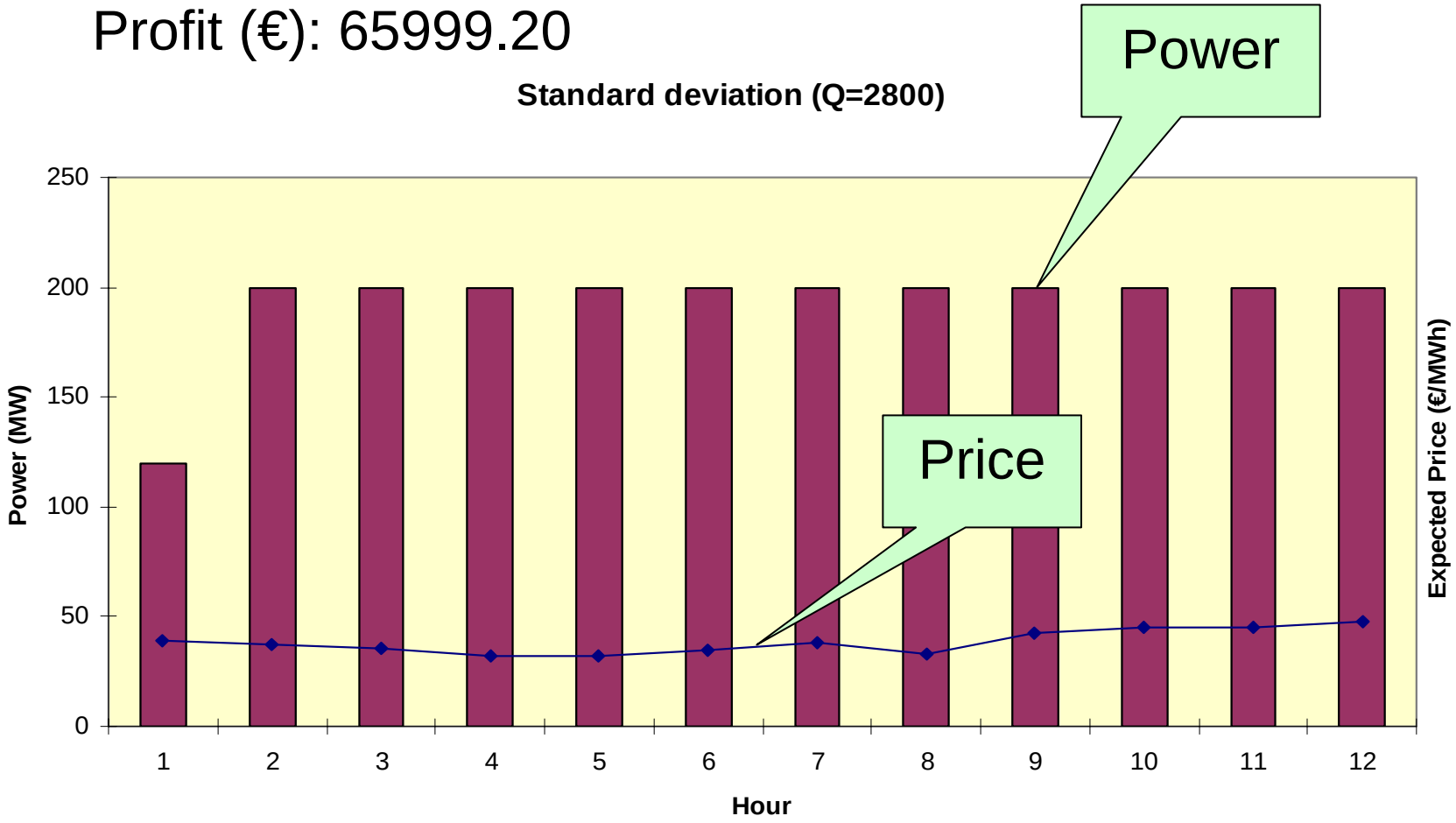
Price-Taker. Uncertain prices

Profit (€): 20022.83



Price-Taker. Uncertain prices

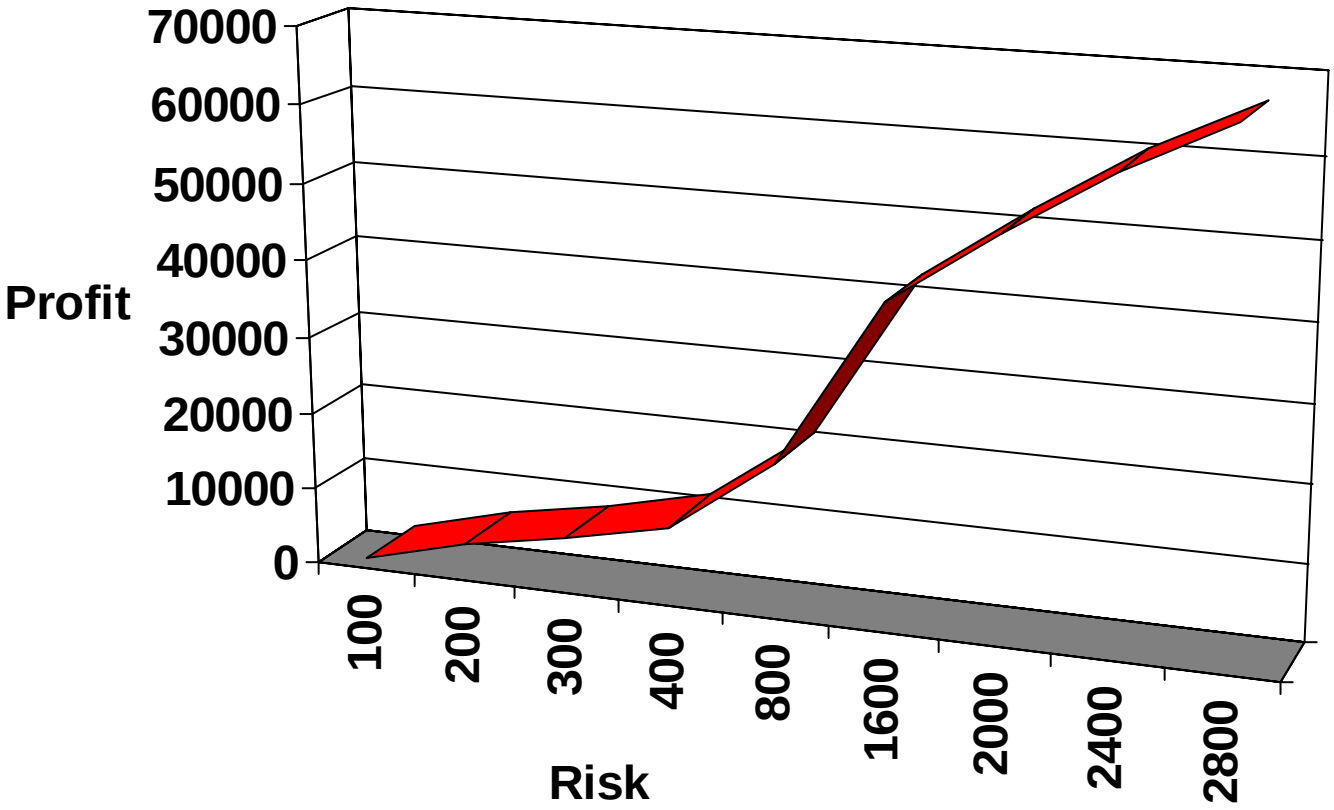
Profit (€): 65999.20



Price-Taker. Uncertain prices

Q (€)	Profit (€)	Energy (MWh)
100	1307	40
200	4771	151
300	7225	226
400	10208	332
800	20022	390
1600	41482	1341
2000	50924	1703
2400	59297	2035
2800	**65999**	**2320**

Price-Taker. Uncertain prices



Price-maker self-scheduling

Price-maker self-scheduling

Maximize	Profits
Subject	Operational constraints

Market-clearing prices are altered by the price-marker seeking its own benefit

Price-maker self-scheduling

Key point!

MAXIMIZE $$\sum_{t=1}^{24}\left[\lambda_t(Q_t)Q_t - \sum_{j=1}^{N_G} C_{jt}(P_{Gjt})\right]$$

SUBJECT TO $$Q_t = \sum_{j=1}^{N_{Gt}} P_{Gjt} \qquad \forall t$$

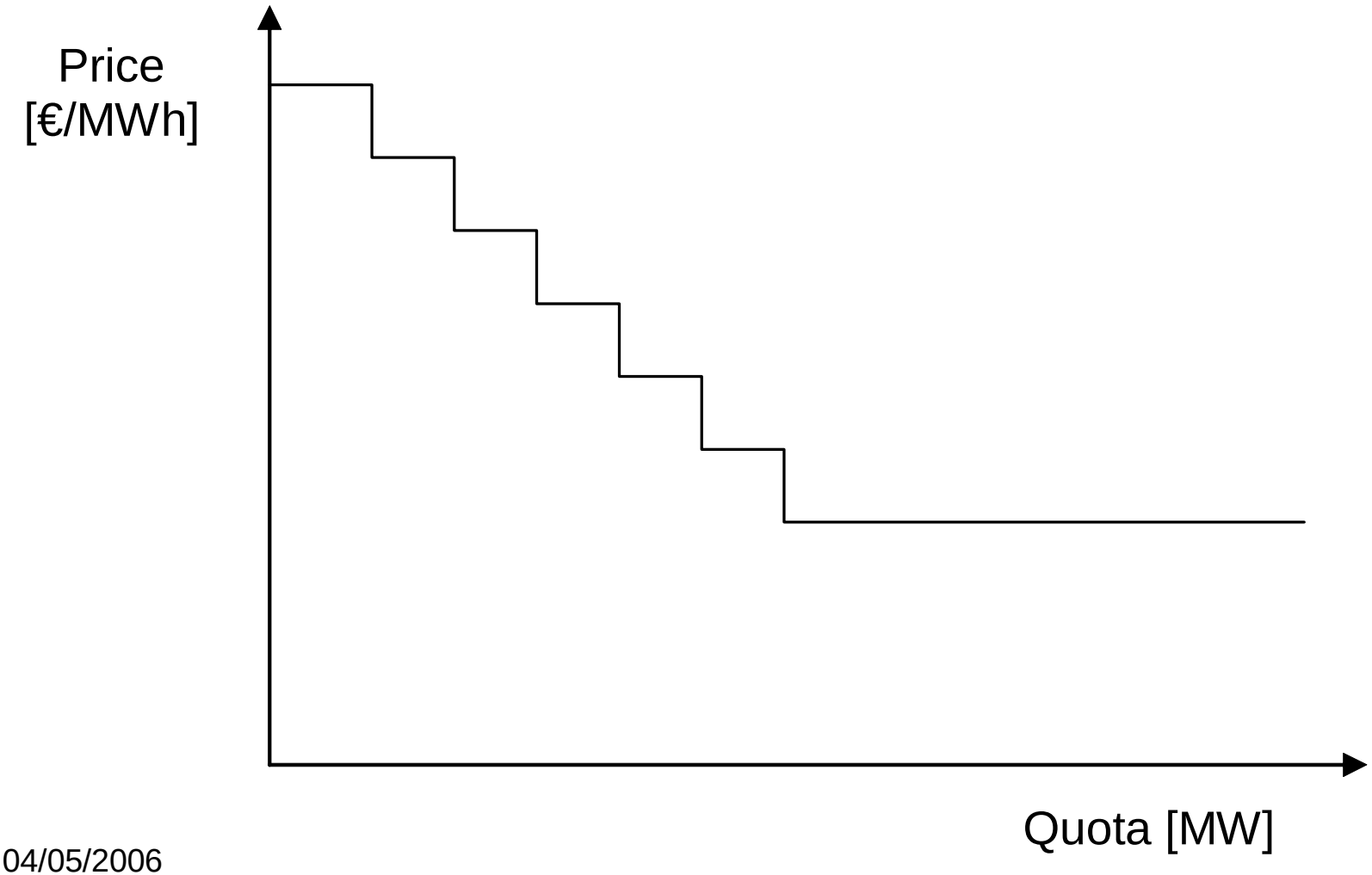
$$P_{Gjt} \in \Delta_{Gj} \qquad \forall j, \forall t$$

Price-maker self-scheduling

- Profits as a function of market-clearing prices
- Quota
- Operating region of generators

Price-maker self-scheduling

Price-quota curve



Price-maker self-scheduling

Price-quota curve

Warning!
I might benefit others more than myself!

Price-maker self-scheduling

Problem:

- Nonlinear
- Discontinuous
- Includes binary variable

Hard to solve!

Price-maker self-scheduling
Example (1)

Price-quota curves:

$$\lambda_1 = 3 - \frac{1}{10} Q_1$$

$$\lambda_2 = 5 - \frac{1}{10} Q_2$$

$$\lambda_3 = 4 - \frac{1}{10} Q_3$$

Time horizon : 3 hours

Price-maker self-scheduling
Example (2)

Price-market producer owns 2 generators

Unit	1	2
Maximum capacity (MW)	10	8
Minimum power output (MW)	0	0
Cost [€ /MWh]	2	2.5

No minimum power output!

Price-maker self-scheduling

Example (3)

MAXIMIZE $$\left(3-\frac{1}{10}Q_1\right)Q_1+\left(5-\frac{1}{10}Q_2\right)Q_2+\left(4-\frac{1}{10}Q_3\right)Q_3$$

$$-2\left(P_{G11}+P_{G12}+P_{G13}\right)-2.5\left(P_{G21}+P_{G22}+P_{G23}\right)$$

SUBJECT TO

$$Q_1=P_{G11}+P_{G21}$$
$$Q_2=P_{G12}+P_{G22}$$
$$Q_3=P_{G13}+P_{G23}$$

$$0\le P_{G11}\le 10,\quad 0\le P_{G12}\le 10,\quad 0\le P_{G13}\le 10$$
$$0\le P_{G21}\le 8,\quad 0\le P_{G22}\le 8,\quad 0\le P_{G23}\le 8$$

Price-maker self-scheduling

Example (4)

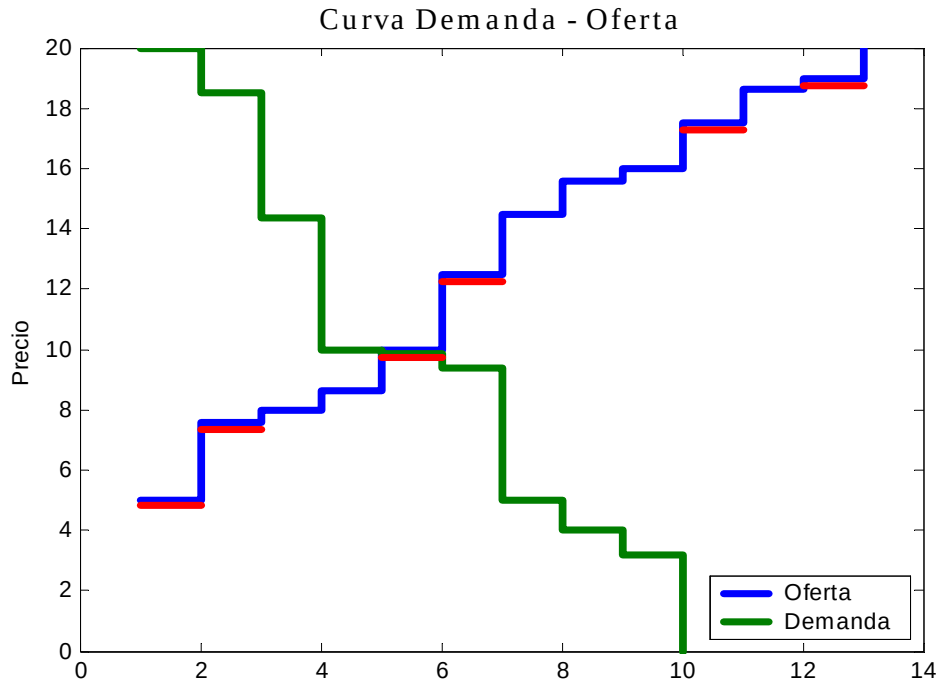
OPTIMAL PRODUCTION (MW)				
HOUR	1	2	3	
UNIT 1	5	10	10	
UNIT 2	0	2.5	0	
QUOTA	5	12.5	10	

PRICES [€ /MWh]				
HOUR	1	2	3	
PRICE	2.5	3.75	3.00	

Price-quota curves
Example

Price-quota curves

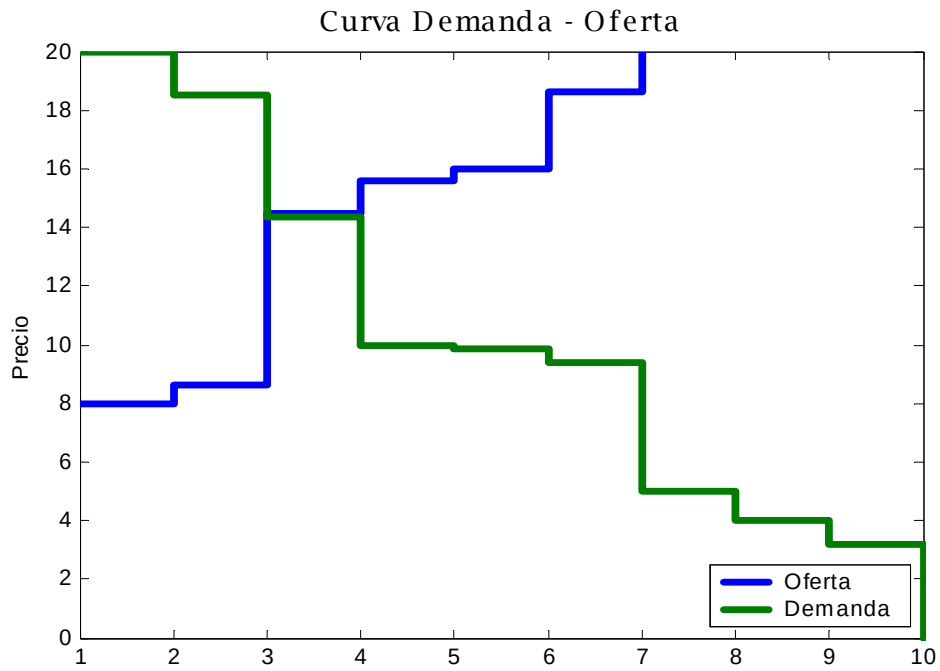
Our bids in red



Price-quota curves

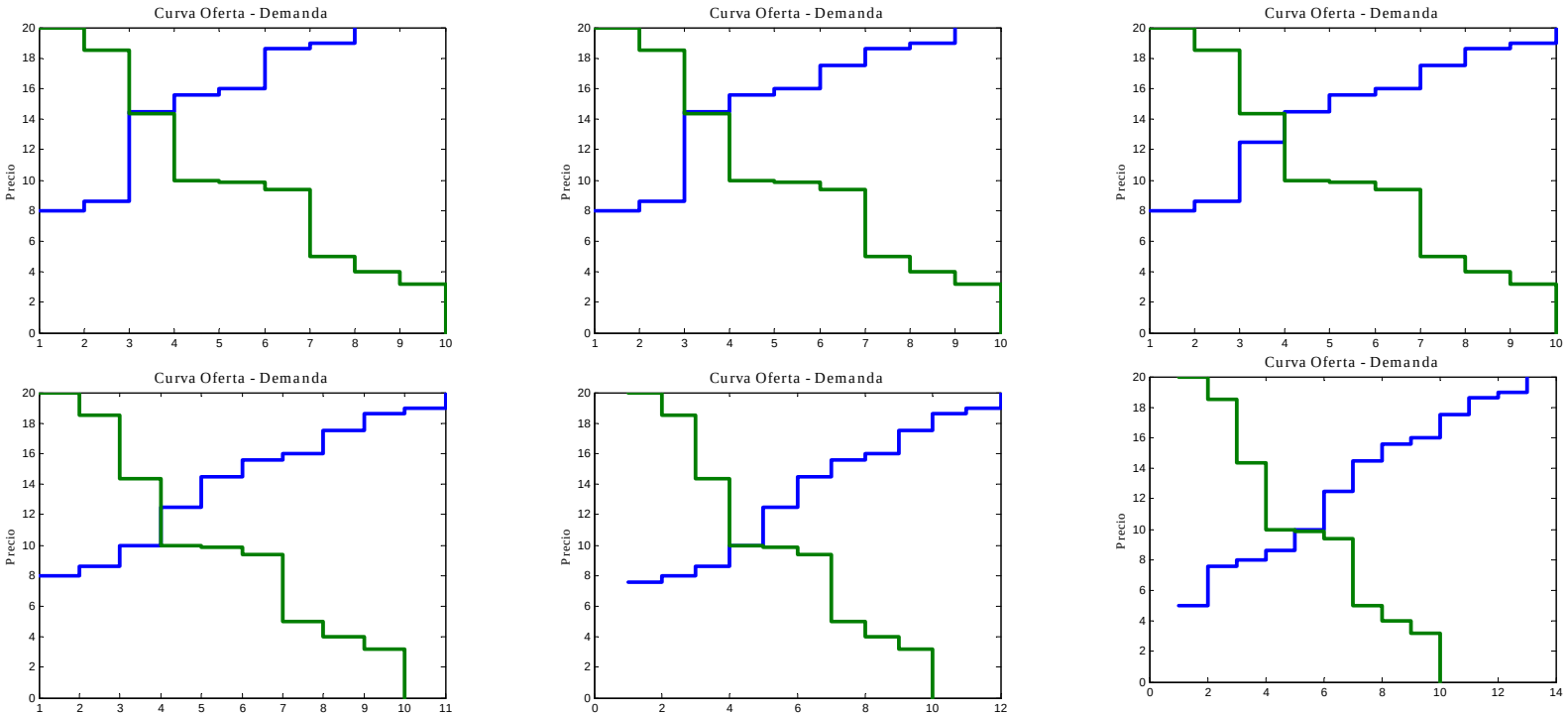
Our bids eliminated

New intersection computed



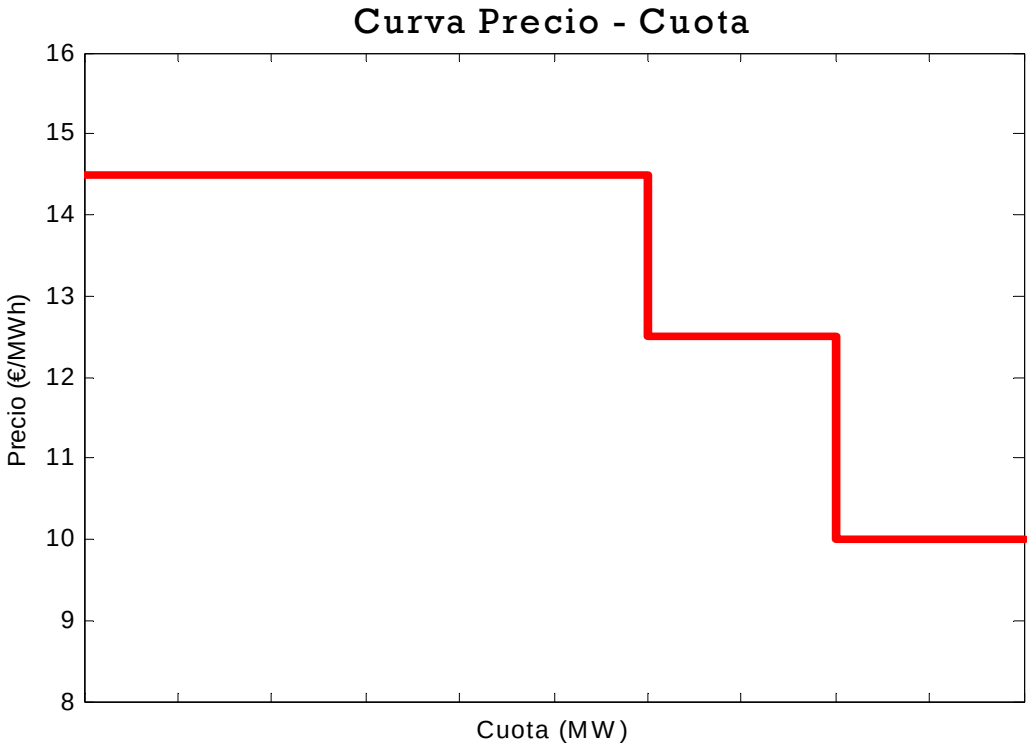
Price-quota curves

Process is repeated including our bids for lower to higher cost



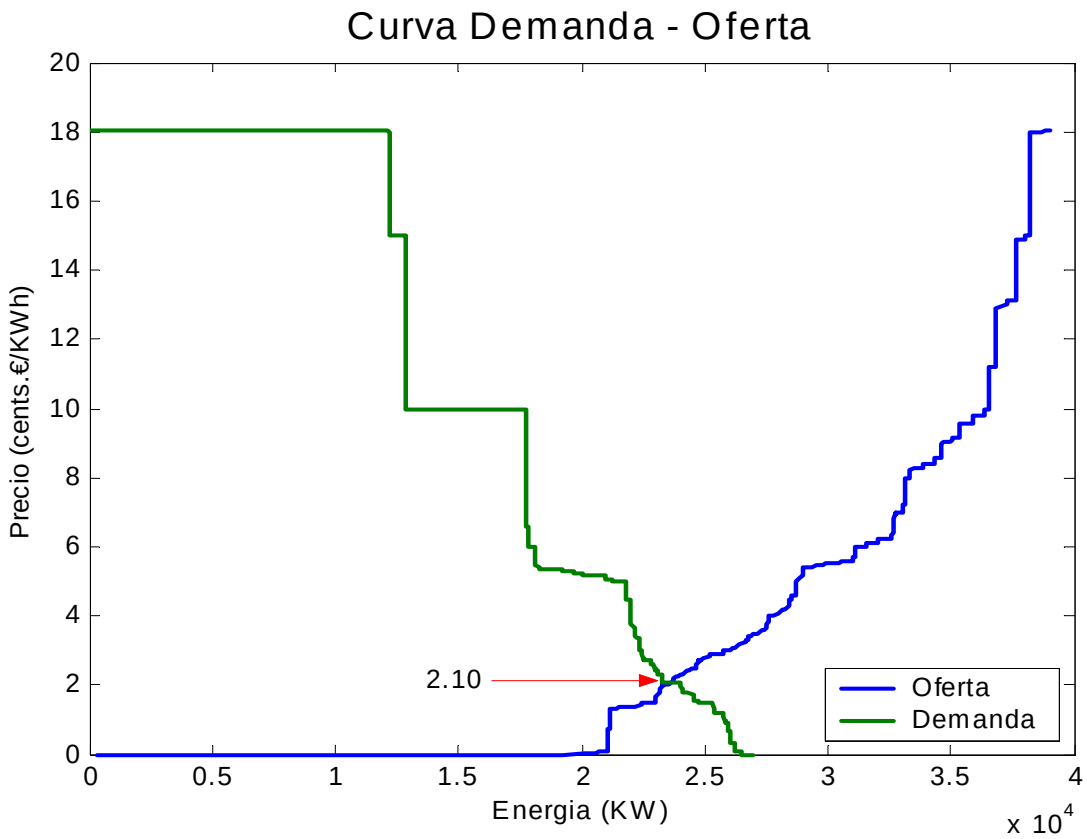
Price-quota curves

Price vs. quota curve



Price-quota curves
(Day 1, Hour 20)

Market clearing



Total bid power:

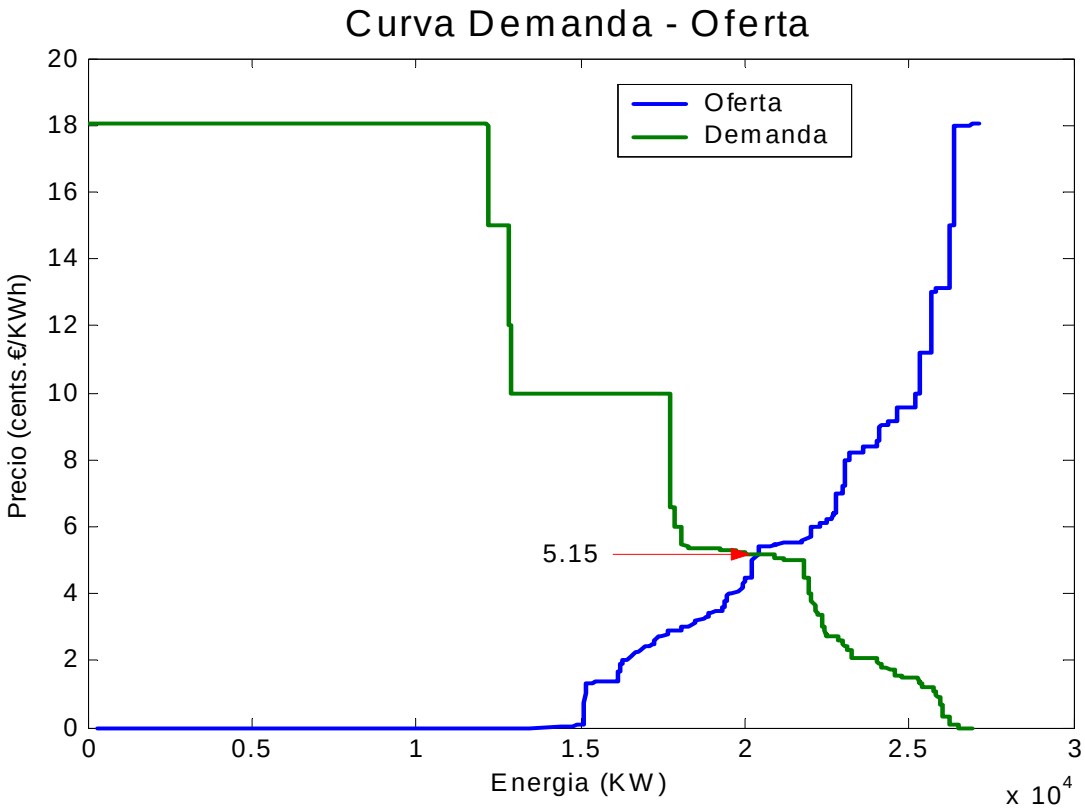
38998.8 kW

Accepted power:

23070.1 kW

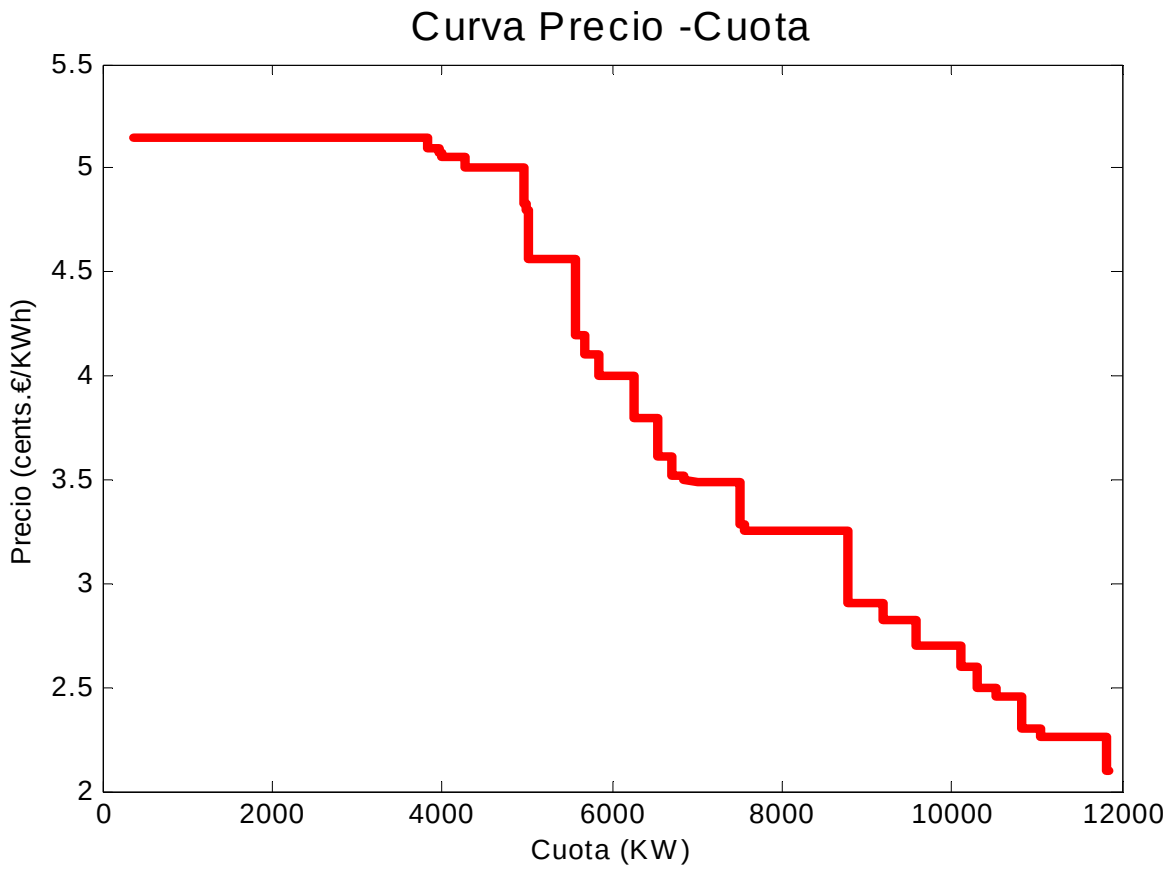
Price-quota curves
(Day 1, Hour 20)

Blocks eliminated up to 11.8 MW; Price 5.15 cents€/kWh



Price-quota curves
(Day 1, Hour 20)

Building price-quota curve



End

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