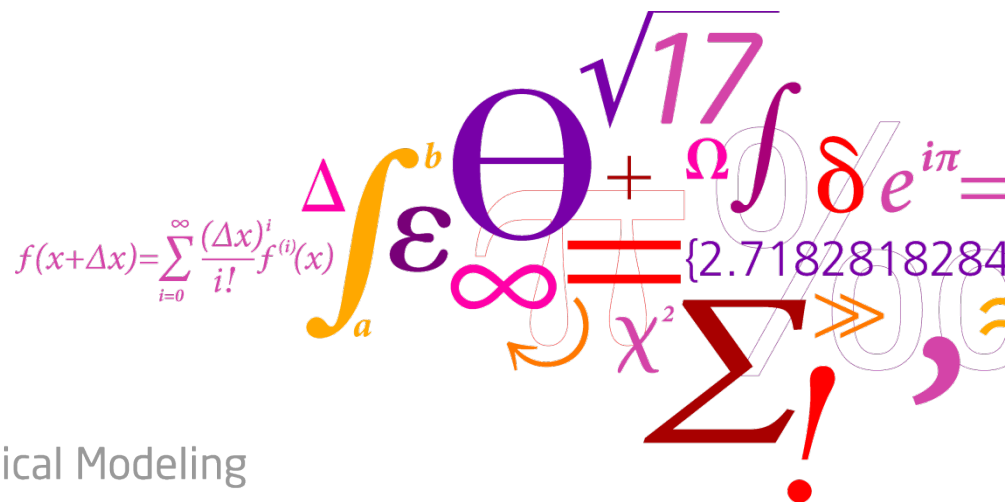


Tools for decision making under uncertainty in electricity markets

Lecture 4: “Power producer self-scheduling”

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Outline

- Thermal producer self-scheduling
 - Motivation
 - Deterministic
 - Stochastic
- Hydroelectric producer self-scheduling
 - Motivation
 - Deterministic
 - Stochastic

Thermal producer

- Power producers have to determine its optimal self-production

Production cost (€/MWh)	20
Maximum capacity (MW)	150
Minimum output (MW)	50

	t1	t2	t3	t4	t5	t6
Price (€/MWh)	25	30	23	21	26	29

Thermal producer

- Self-scheduling

Production cost (€/MWh)	20
Maximum capacity (MW)	150
Minimum output (MW)	50

	t1	t2	t3	t4	t5	t6
Price (€/MWh)	25	30	23	21	26	29
Production (MW)						

Thermal producer

- Self-scheduling

Production cost (€/MWh)	20
Maximum capacity (MW)	150
Minimum output (MW)	50

	t1	t2	t3	t4	t5	t6
Price (€/MWh)	25	30	23	21	26	29
Production (MW)	150	150	150	150	150	150

Thermal producer

- Self-scheduling

Production cost (€/MWh)	20
Maximum capacity (MW)	150
Minimum output (MW)	50

	t1	t2	t3	t4	t5	t6
Price (€/MWh)	25	17	23	10	26	20

Thermal producer

- Self-scheduling

Production cost (€/MWh)	20
Maximum capacity (MW)	150
Minimum output (MW)	50

	t1	t2	t3	t4	t5	t6
Price (€/MWh)	25	17	23	10	26	20
Production (MW)						

Thermal producer

- Self-scheduling

Production cost (€/MWh)	20
Maximum capacity (MW)	150
Minimum output (MW)	50

	t1	t2	t3	t4	t5	t6
Price (€/MWh)	25	17	23	10	26	20
Production (MW)	150	50	150	50	150	150

Optimization problem?

Thermal producer

- Optimization problem

$$\textit{Maximize} \quad \sum_{t=1}^T \left(\lambda_t P_t^G - C_t P_t^G \right)$$

$$\textit{S.T.} \quad P^{\min} \leq P_t^G \leq P^{\max} \quad \forall t$$

Thermal producer

- Self-scheduling

Production cost (€/MWh)	20
Maximum capacity (MW)	150
Minimum output (MW)	50

	t1	t2	t3	t4	t5	t6
Price (€/MWh)	25	17	23	10	26	20
Production (MW)	150	50	150	50	150	150

What about ramps limits?

Thermal producer

- Self-scheduling

Production cost (€/MWh)	20
Maximum capacity / Minimum output (MW)	150/50
Up ramp limit / Down ramp limit	50/50

	t1	t2	t3	t4	t5	t6
Price (€/MWh)	25	17	23	10	26	20
Prod 1 (MW)						

Thermal producer

- Self-scheduling

Production cost (€/MWh)	20
Maximum capacity / Minimum output (MW)	150/50
Up ramp limit / Down ramp limit	50/50

	t1	t2	t3	t4	t5	t6
Price (€/MWh)	25	17	23	10	26	20
Prod 1 (MW)	150	100	150	100	150	150

Thermal producer

- Self-scheduling

Production cost (€/MWh)	20
Maximum capacity / Minimum output (MW)	150/50
Up ramp limit / Down ramp limit	50/50

	t1	t2	t3	t4	t5	t6
Price (€/MWh)	25	17	23	10	26	20
Prod 1 (MW)	150	100	150	100	150	150
Prod 2 (MW)						

Thermal producer

- Self-scheduling

Production cost (€/MWh)	20
Maximum capacity / Minimum output (MW)	150/50
Up ramp limit / Down ramp limit	50/50

	t1	t2	t3	t4	t5	t6
Price (€/MWh)	25	17	23	10	26	20
Prod 1 (MW)	150	100	150	100	150	150
Prod 2 (MW)	100	50	100	50	100	100

Thermal producer

- Self-scheduling

Production cost (€/MWh)	20
Maximum capacity / Minimum output (MW)	150/50
Up ramp limit / Down ramp limit	50/50

	t1	t2	t3	t4	t5	t6	Profit
Price (€/MWh)	25	17	23	10	26	20	
Prod 1 (MW)	150	100	150	100	150	150	800
Prod 2 (MW)	100	50	100	50	100	100	750

Thermal producer

- Optimization problem

$$\begin{aligned} & \textit{Maximize} && \sum_{t=1}^T \left(\lambda_t P_t^G - C_t P_t^G \right) \\ & \textit{S.T.} && P^{\min} \leq P_t^G \leq P^{\max} \quad \forall t \end{aligned}$$

Thermal producer

- Optimization problem

$$\text{Maximize} \quad \sum_{t=1}^T \left(\lambda_t P_t^G - C_t P_t^G \right)$$

$$S.T. \quad P^{\min} \leq P_t^G \leq P^{\max} \quad \forall t$$

$$P_t^G \leq P_{t-1}^G + RU \quad \forall t$$

$$P_t^G \geq P_{t-1}^G - RD \quad \forall t$$

Thermal producer

- Self-scheduling

Production cost (€/MWh)	20
Maximum capacity / Minimum output (MW)	150/50
Up ramp limit / Down ramp limit	50/50

	t1	t2	t3	t4	t5	t6	Profit
Price (€/MWh)	25	17	23	10	26	20	
Prod 1 (MW)	150	100	150	100	150	150	800
Prod 2 (MW)	100	50	100	50	100	100	750
Prod 3 (MW)	150	100	100	50	100	50	850

Thermal producer

- Other technical constraints
 - Minimum up time
 - Minimum down time
 - Start-up cost
 - ...
- Modeled with binary variables.

Thermal producer

- Optimization problem (stochastic)

$$\text{Maximize} \quad \sum_{t=1}^T \left(\lambda_t P_t^G - C_t P_t^G \right)$$

$$S.T. \quad P^{\min} \leq P_t^G \leq P^{\max} \quad \forall t$$

$$P_t^G \leq P_{t-1}^G + RU \quad \forall t$$

$$P_t^G \geq P_{t-1}^G - RD \quad \forall t$$

Thermal producer

- Optimization problem (stochastic)

$$\text{Maximize} \quad \sum_{w=1}^W \sum_{t=1}^T \pi_w \left(\lambda_{tw} P_t^G - C_t P_t^G \right)$$

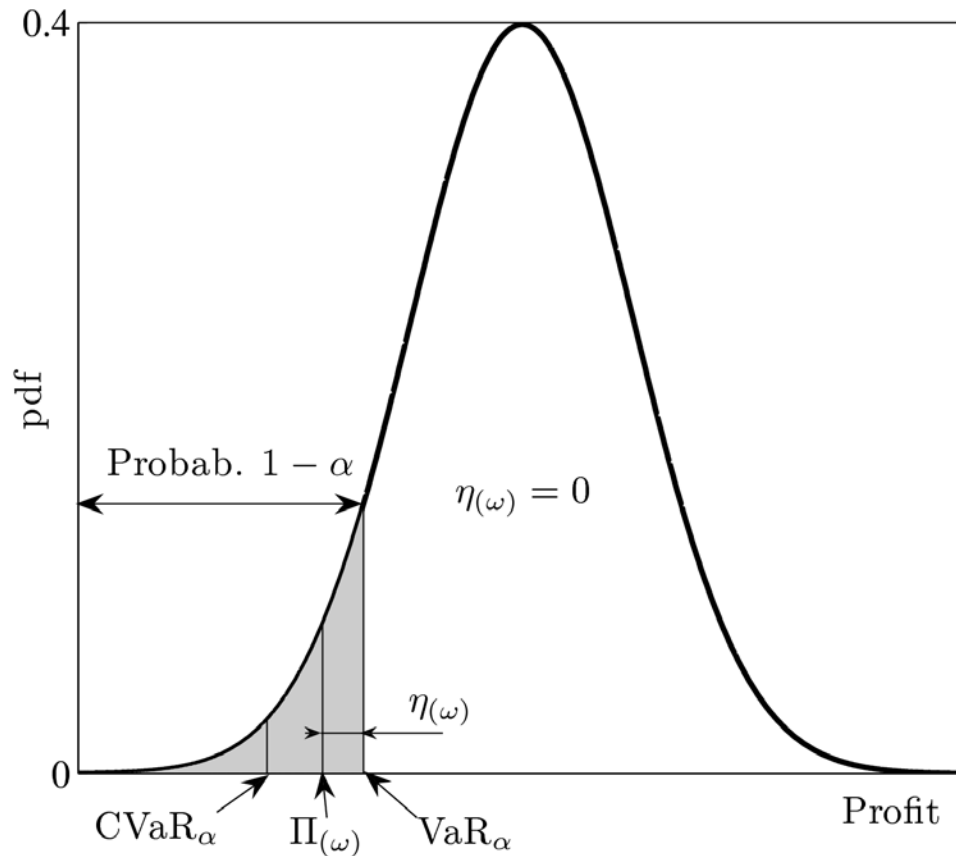
$$S.T. \quad P^{\min} \leq P_t^G \leq P^{\max} \quad \forall t$$

$$P_t^G \leq P_{t-1}^G + RU \quad \forall t$$

$$P_t^G \geq P_{t-1}^G - RD \quad \forall t$$

Thermal producer

- Conditional Value-at-Risk



$$\begin{aligned} \text{Maximize} \quad & CVaR_\alpha = \xi - \frac{1}{1-\alpha} \sum_{w=1}^W \pi_w \eta_w \\ \text{S.T.} \quad & \eta_w \geq -\Pi_w + \xi \quad \forall w \\ & \eta_w \geq 0 \quad \forall w \end{aligned}$$

Thermal producer

- Optimization problem (stochastic)

$$\text{Maximize } CVaR_{\alpha} = \xi - \frac{1}{1-\alpha} \sum_{w=1}^W \pi_w \eta_w$$

$$S.T. \quad \Pi_w = \sum_{t=1}^T (\lambda_{tw} P_t^G - C_t P_t^G) \quad \forall w$$

$$P^{\min} \leq P_t^G \leq P^{\max} \quad \forall t$$

$$P_t^G \leq P_{t-1}^G + RU \quad \forall t$$

$$P_t^G \geq P_{t-1}^G - RD \quad \forall t$$

$$\eta_w \geq -\Pi_w + \xi \quad \forall w$$

$$\eta_w \geq 0 \quad \forall w$$

Thermal producer

- Self-scheduling (stochastic)

Production cost (€/MWh)	20
Maximum capacity / Minimum output (MW)	150/50
Up ramp limit / Down ramp limit	50/50

	t1	t2	t3	t4	t5	t6	Prob
Scenario 1	25	15	26	16	27	17	0.3
Scenario 2	22	22	22	22	22	22	0.4
Scenario 3	15	25	14	24	13	23	0.3

Thermal producer

- Self-scheduling (stochastic)

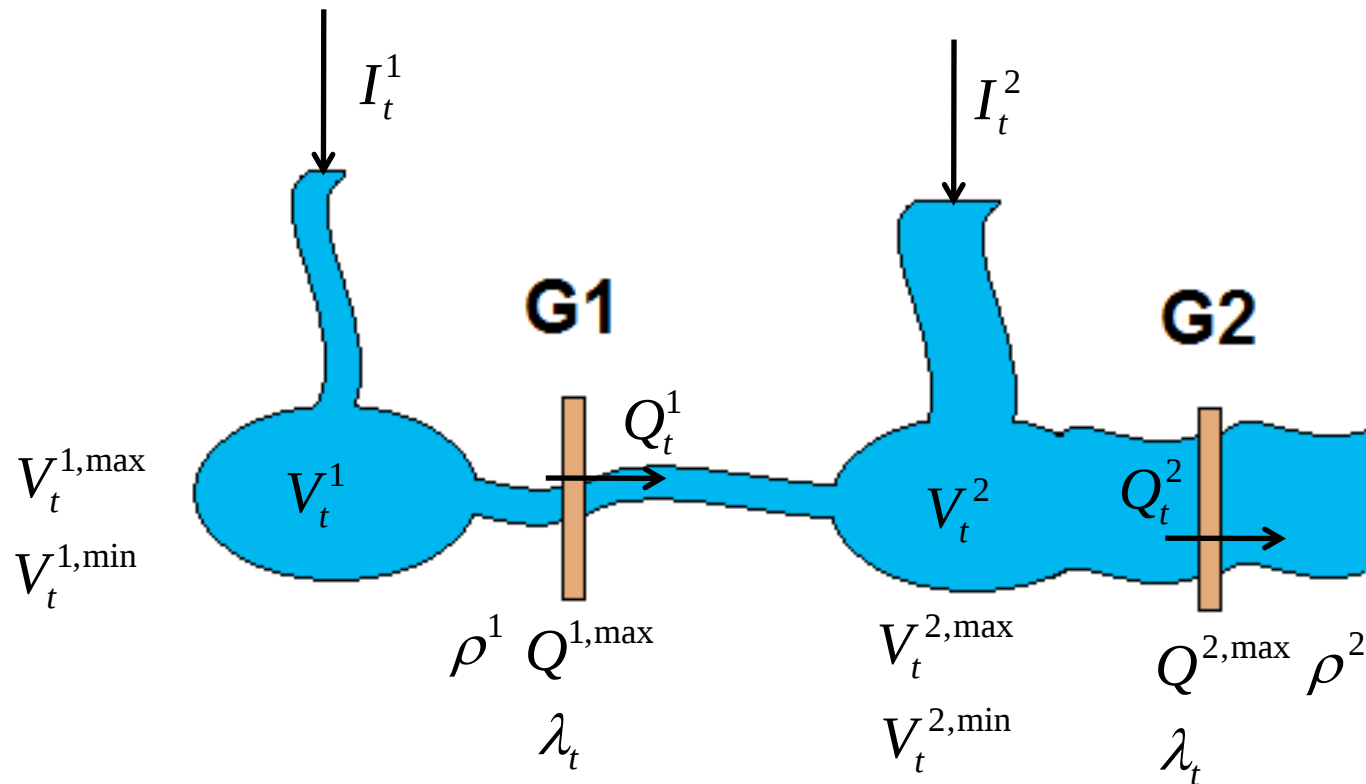
	t1	t2	t3	t4	t5	t6	Profit		Exp.
$\alpha = 0$	150	150	150	150	150	150	w1	900	720
							w2	1800	
							w3	-900	
$\alpha = 0.9$	50	100	50	50	50	67	w1	0	294
							w2	733	
							w3	0	

Outline

- Thermal producer self-scheduling
 - Motivation
 - Deterministic
 - Stochastic
- Hydroelectric producer self-scheduling
 - Motivation
 - Deterministic
 - Stochastic

Hydroelectric producer

- Self-scheduling of hydroproducer



Hydroelectric producer

- Self-scheduling of hydroproducer

$$\text{Maximize} \quad \sum_{t=1}^T \sum_{g=1}^G \lambda_t P_{t,g}^G$$

$$S.T. \quad P_{t,g}^G = \rho_g Q_{t,g} \quad \forall t, g$$

$$0 \leq Q_{t,g} \leq Q_g^{\max} \quad \forall t, g$$

$$V_g^{\min} \leq V_{t,g} \leq V_g^{\max} \quad \forall t, g$$

$$V_{t,1} = V_{t-1,1} - Q_{t,1} + I_t^1 \quad \forall t$$

$$V_{t,2} = V_{t-1,2} - Q_{t,2} + Q_{t-1,1} + I_t^2 \quad \forall t$$

Hydroelectric producer

- Self-scheduling of hydroproducer

	Upper reservoir (G1)	Lower reservoir (G2)
Initial volume (Hm^3)	2	3
Maximum volume (Hm^3)	10	10
Minimum volume (Hm^3)	2	2
Inflow (constant) (Hm^3/h)	1	2
Maximum discharge (Hm^3/h)	4	4
Conversion factor (MWh/Hm^3)	5	8

Hydroelectric producer

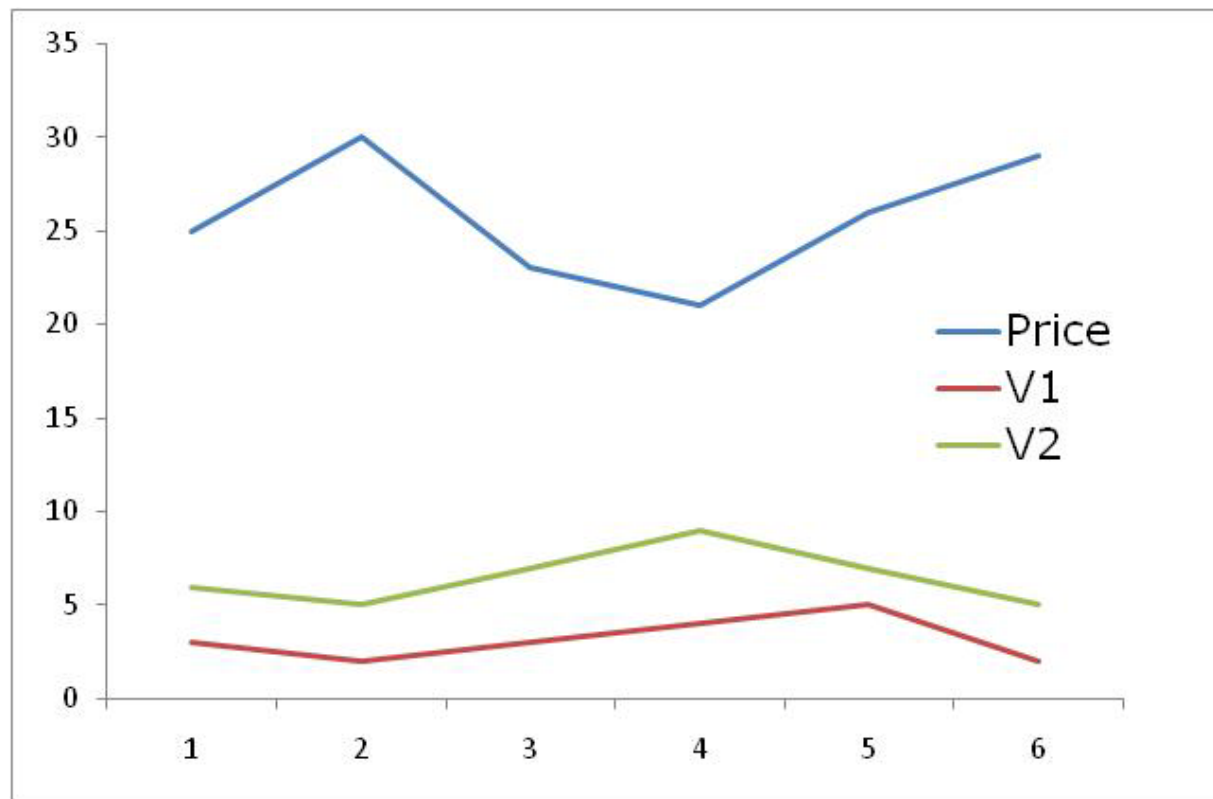
- Self-scheduling of hydroproducer

	t1	t2	t3	t4	t5	t6
Price (€/MWh)	25	30	23	21	26	29

	t1	t2	t3	t4	t5	t6
Q1 (Hm3/h)	-	2	-	-	-	4
Q2 (Hm3/h)	-	5	-	-	4	8
V1 (Hm3)	3	2	3	4	5	2
V2 (Hm3)	6	5	7	9	7	5

Hydroelectric producer

- Self-scheduling of hydroproducer



Hydroelectric producer

- Hydroproducer (stochastic)

$$\text{Maximize} \quad \sum_{t=1}^T \sum_{g=1}^G \lambda_t P_{t,g}^G$$

$$S.T. \quad P_{t,g}^G = \rho_g Q_{t,g} \quad \forall t, g$$

$$0 \leq Q_{t,g} \leq Q_g^{\max} \quad \forall t, g$$

$$V_g^{\min} \leq V_{t,g} \leq V_g^{\max} \quad \forall t, g$$

$$V_{t,1} = V_{t-1,1} - Q_{t,1} + I_t^1 \quad \forall t$$

$$V_{t,2} = V_{t-1,2} - Q_{t,2} + Q_{t-1,1} + I_t^2 \quad \forall t$$

Hydroelectric producer

- Hydroproducer (stochastic)

$$\text{Maximize} \quad \sum_{w=1}^W \sum_{t=1}^T \sum_{g=1}^G \pi_w \lambda_{tw} P_{t,g}^G$$

$$S.T. \quad P_{t,g}^G = \rho_g Q_{t,g} \quad \forall t, g$$

$$0 \leq Q_{t,g} \leq Q_g^{\max} \quad \forall t, g$$

$$V_g^{\min} \leq V_{t,g} \leq V_g^{\max} \quad \forall t, g$$

$$V_{t,1} = V_{t-1,1} - Q_{t,1} + I_t^1 \quad \forall t$$

$$V_{t,2} = V_{t-1,2} - Q_{t,2} + Q_{t-1,1} + I_t^2 \quad \forall t$$

Hydroelectric producer

- Self-scheduling of hydroproducer

Prices	t1	t2	t3	t4	t5	t6	Prob
Scenario 1	40	20	40	20	40	20	0.5
Scenario 2	10	15	10	15	10	15	0.5

Hydroelectric producer

- Self-scheduling of hydroproducer

Prices	t1	t2	t3	t4	t5	t6	Prob
Scenario 1	40	20	40	20	40	20	0.5
Scenario 2	10	15	10	15	10	15	0.5

$\alpha = 0$	t1	t2	t3	t4	t5	t6
Q1 (Hm3/h)	0	0	3	0	2	1
Q2 (Hm3/h)	3	0	7	0	6	3
V1 (Hm3)	3	4	2	3	2	2
V2 (Hm3)	5	7	5	7	5	5

Hydroelectric producer

- Self-scheduling of hydroproducer

Prices	t1	t2	t3	t4	t5	t6	Prob
Scenario 1	40	20	40	20	40	20	0.5
Scenario 2	10	15	10	15	10	15	0.5

$\alpha = 0.9$	t1	t2	t3	t4	t5	t6
Q1 (Hm3/h)	0	0	0	4	0	2
Q2 (Hm3/h)	0	1	0	8	0	8
V1 (Hm3)	3	4	5	2	3	2
V2 (Hm3)	6	7	9	7	9	5

Hydroelectric producer

- Self-scheduling of hydroproducer

	Profit		Expected profit
$\alpha = 0$	w1	6060	3932.5
	w2	1805	
$\alpha = 0.9$	w1	3320	2905.0
	w2	2490	



Thanks for your attention!