

TOMA DE DECISIONES BAJO INCERTIDUMBRE EN MERCADOS ELÉCTRICOS

CLASE 5: “SHORT-TERM TRADING FOR A WIND POWER PRODUCER”

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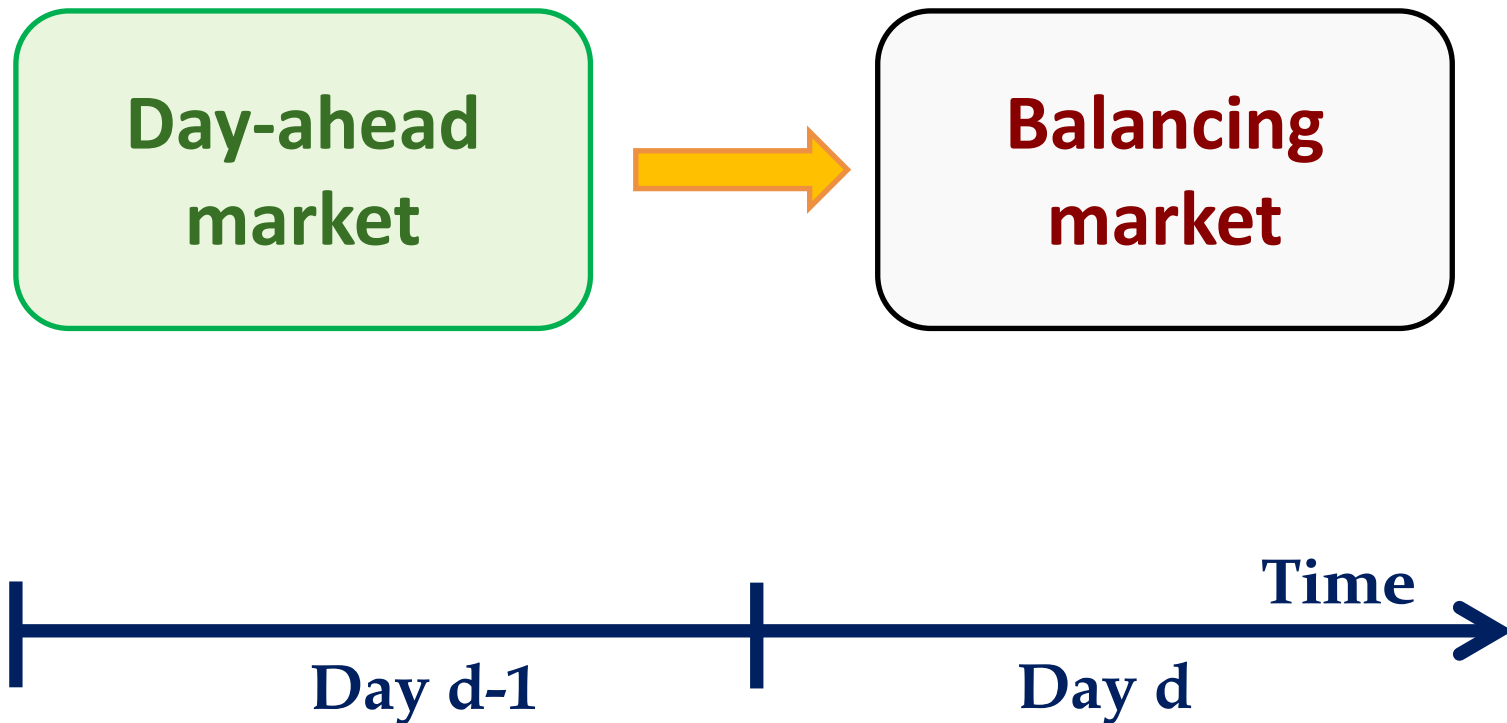
 **DTU Electrical Engineering**
Department of Electrical Engineering



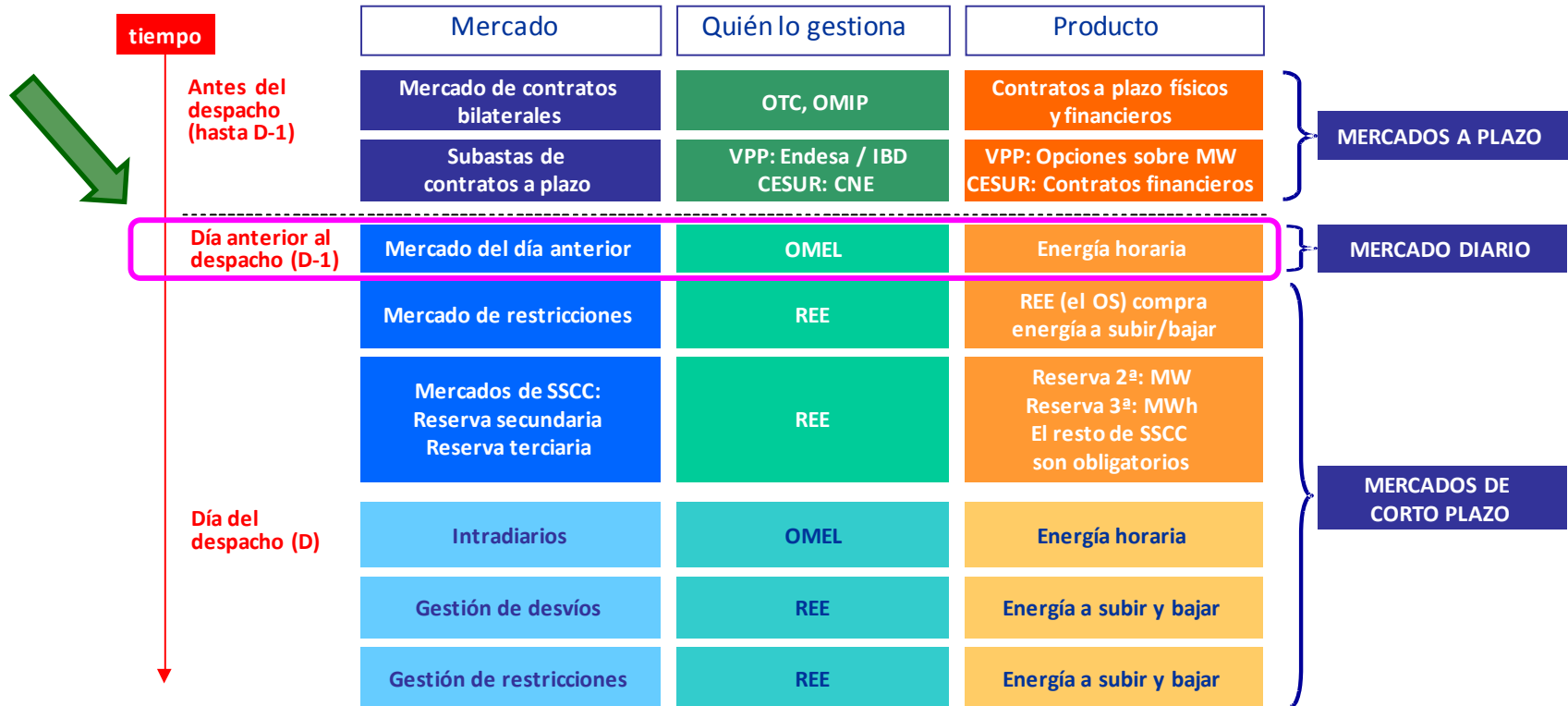
Outline

- 1) Motivation
- 2) Imbalance cost
- 3) Certainty gain process
- 4) Mathematical formulation
- 5) Example
- 6) Case study

Wind Producer Problem (Motivation)

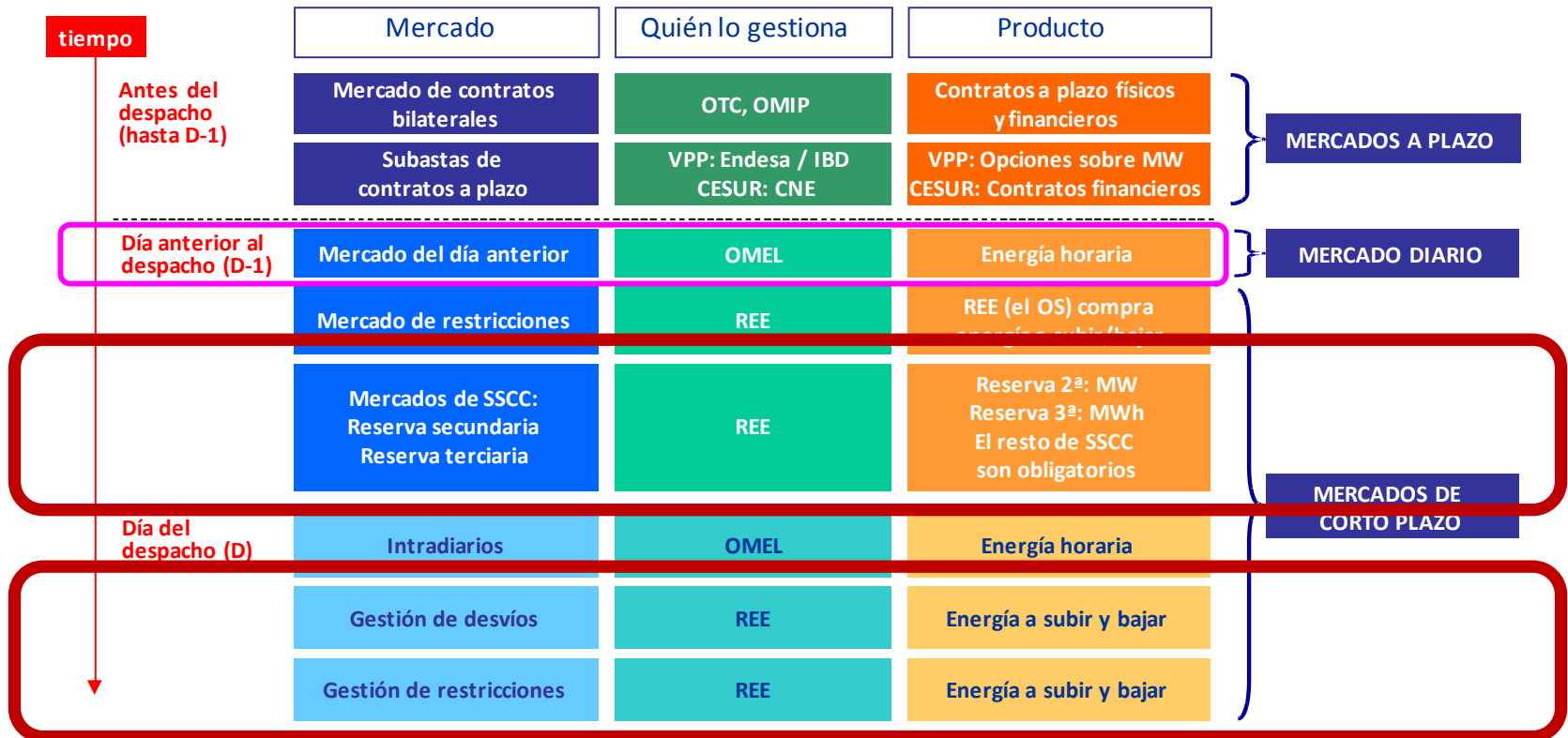


Wind Producer Problem (Motivation)



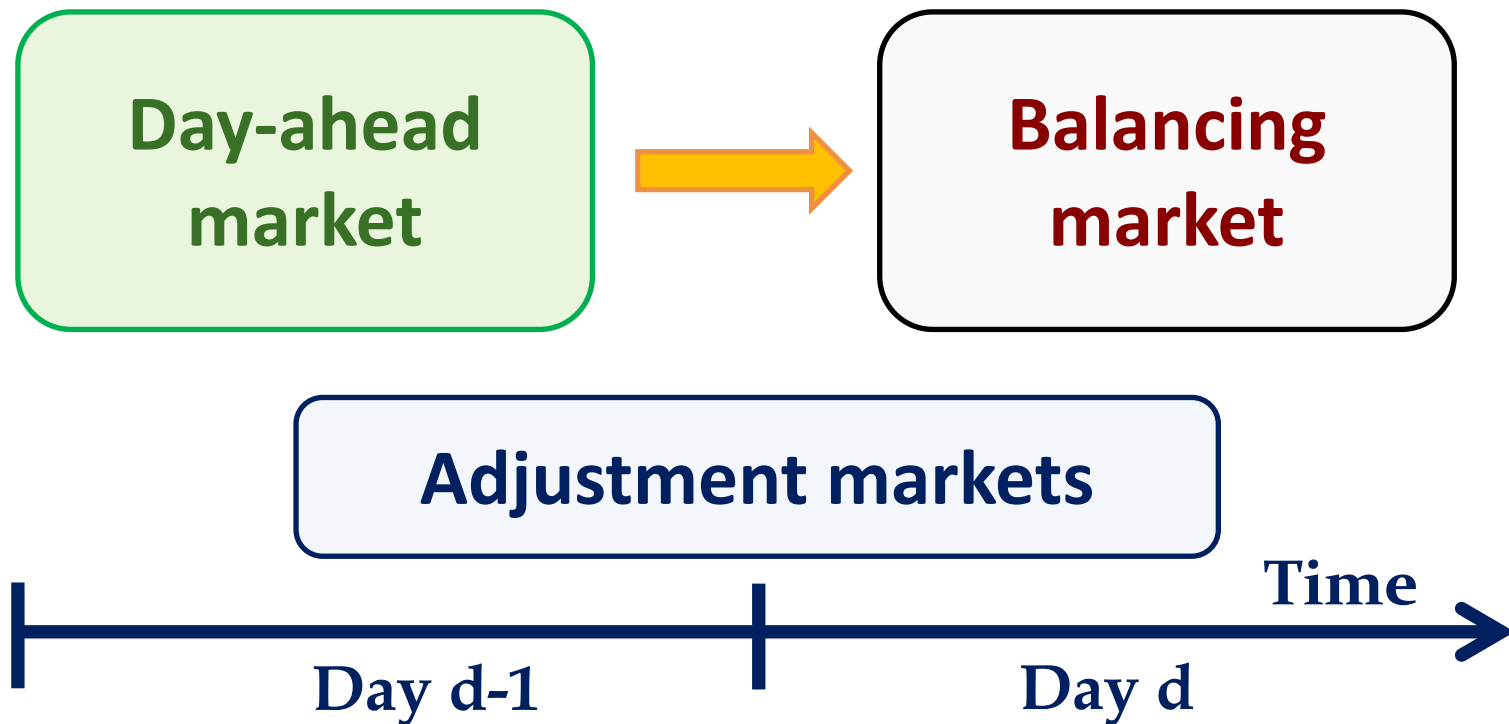
Day-ahead market

Wind Producer Problem (Motivation)

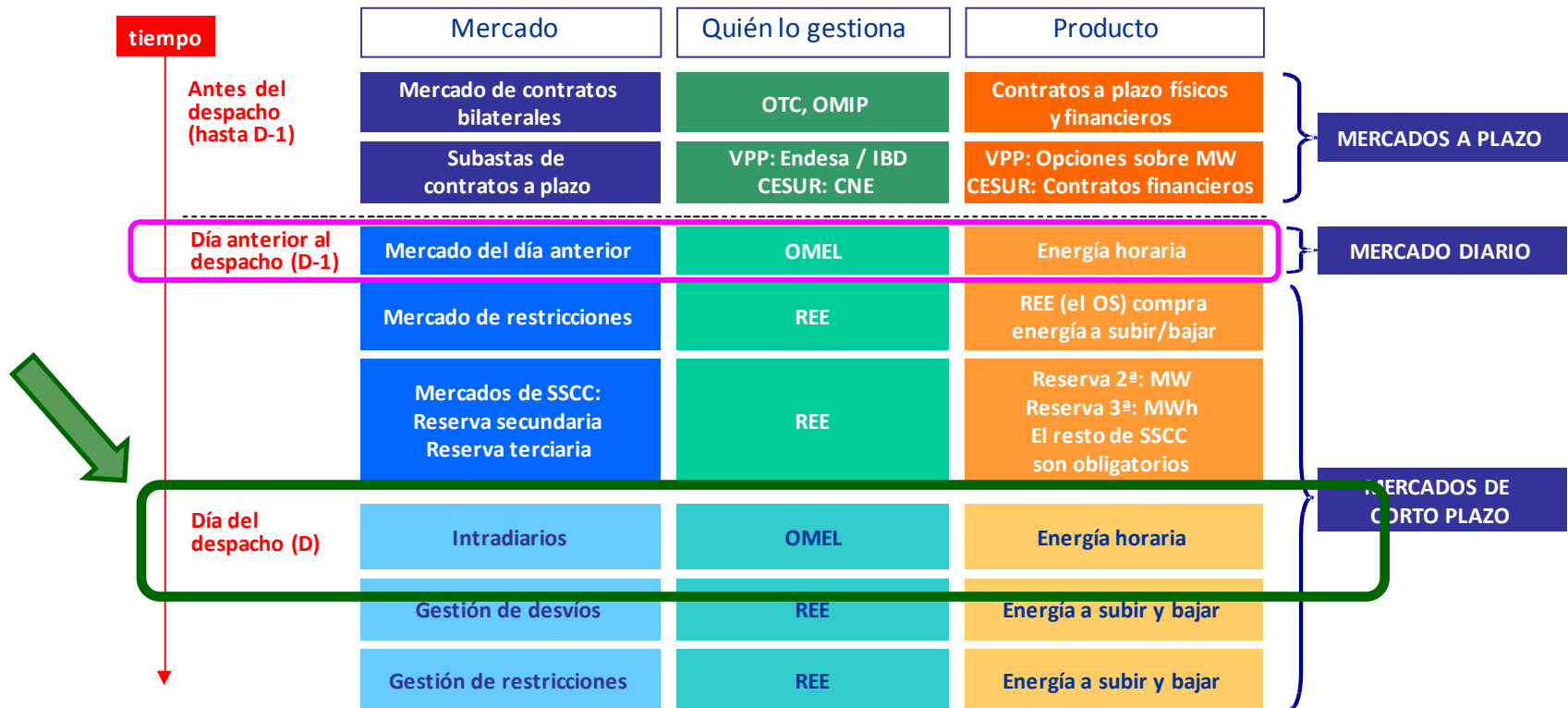


Balancing market

Wind Producer Problem (Motivation)



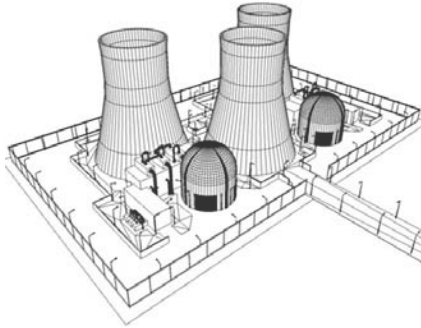
Wind Producer Problem (Motivation)



Adjustment market

Wind Producer Problem (Motivation)

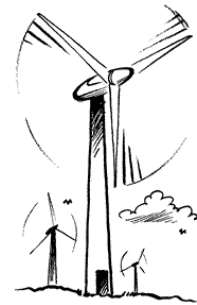
**Day-ahead
market**



**Inflexible units
(need advance planning)**



**Balancing
market**

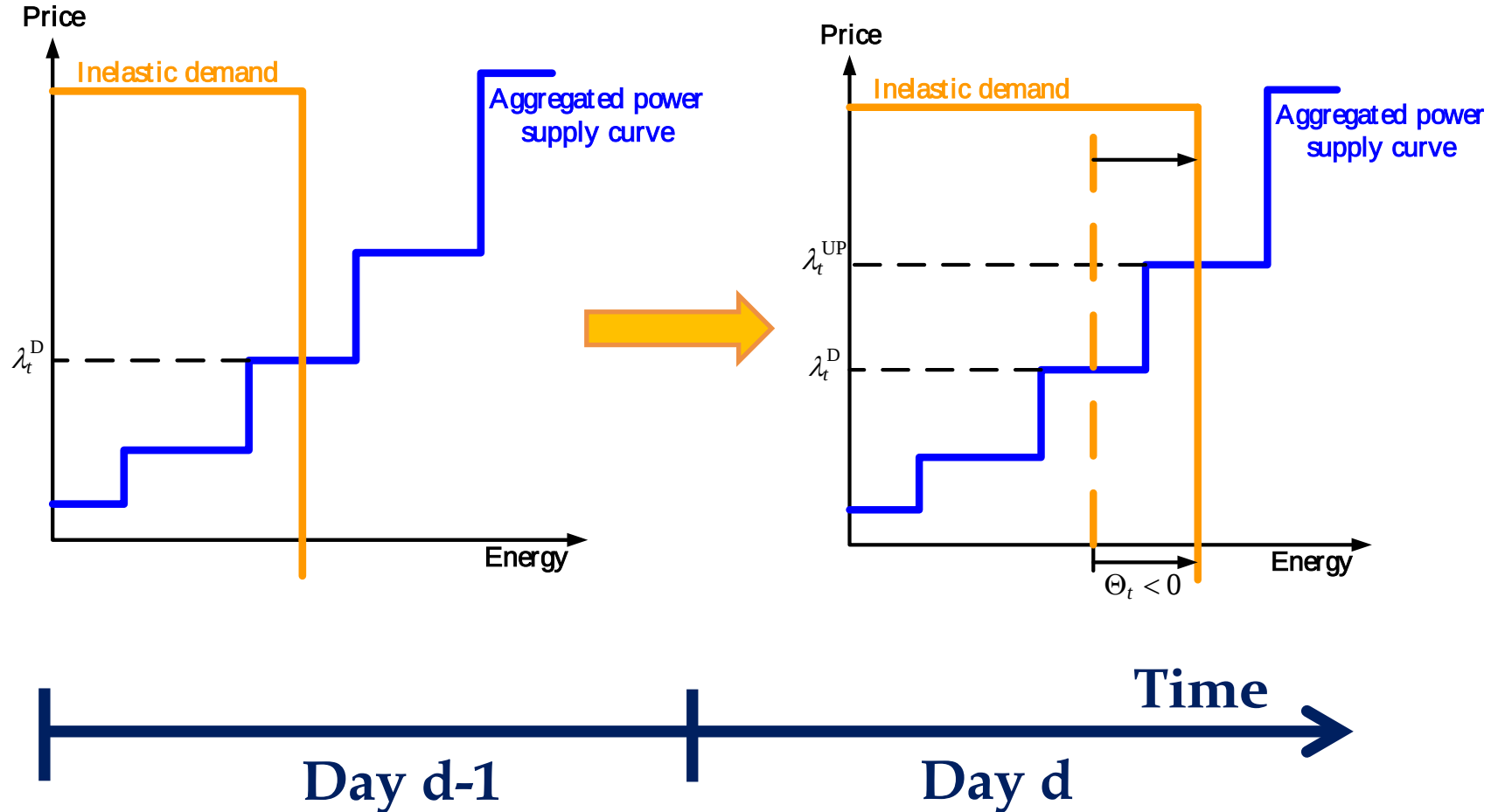


**Wind producers/consumers
(need balancing energy)**

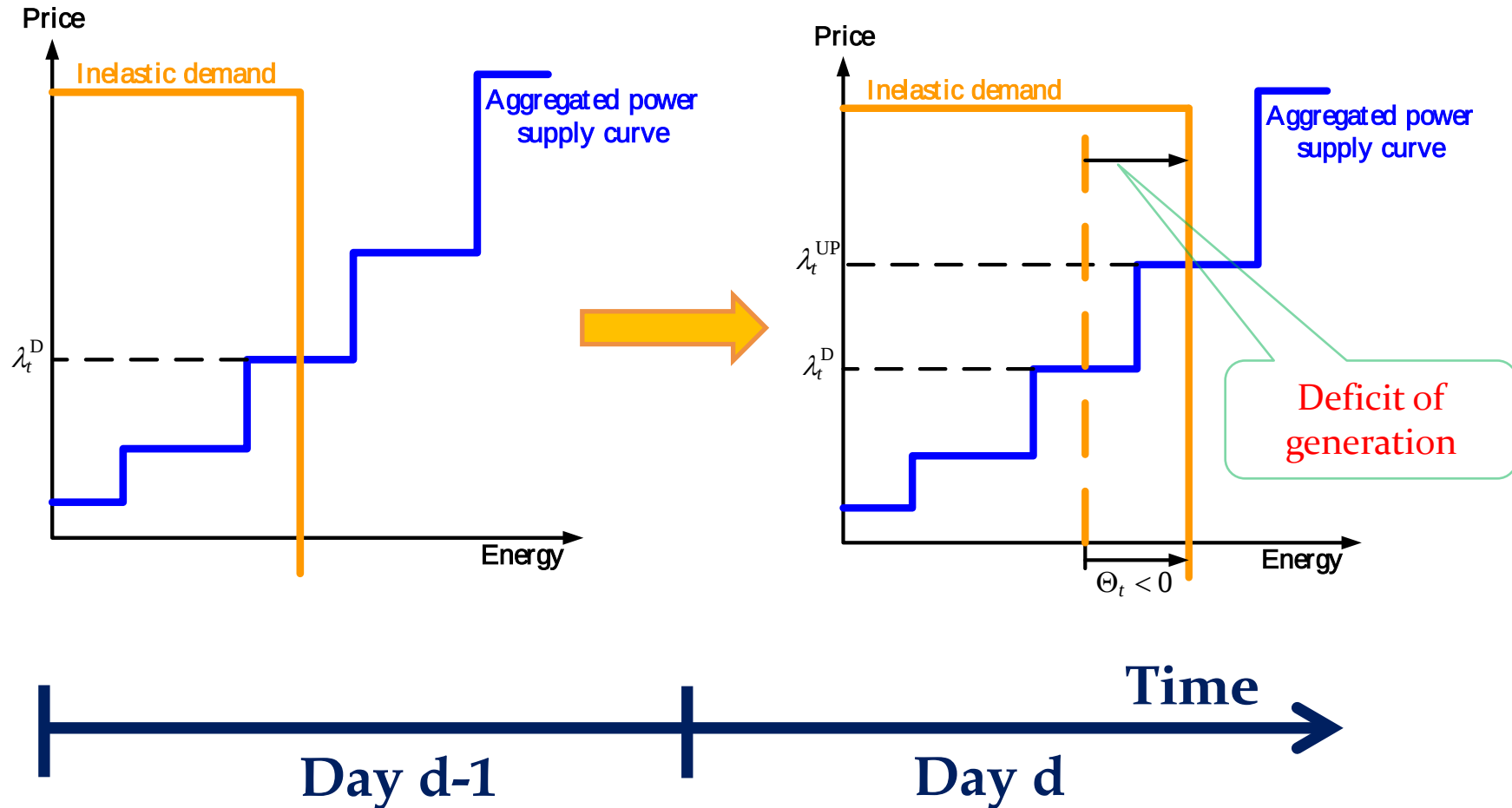
Wind Producer Problem (Motivation)

- ✓ A balancing mechanism is required to cope with unexpected energy deviations
- ✓ Positive (negative) deviation: higher (lower) production or lower (higher) consumption than scheduled in forward markets

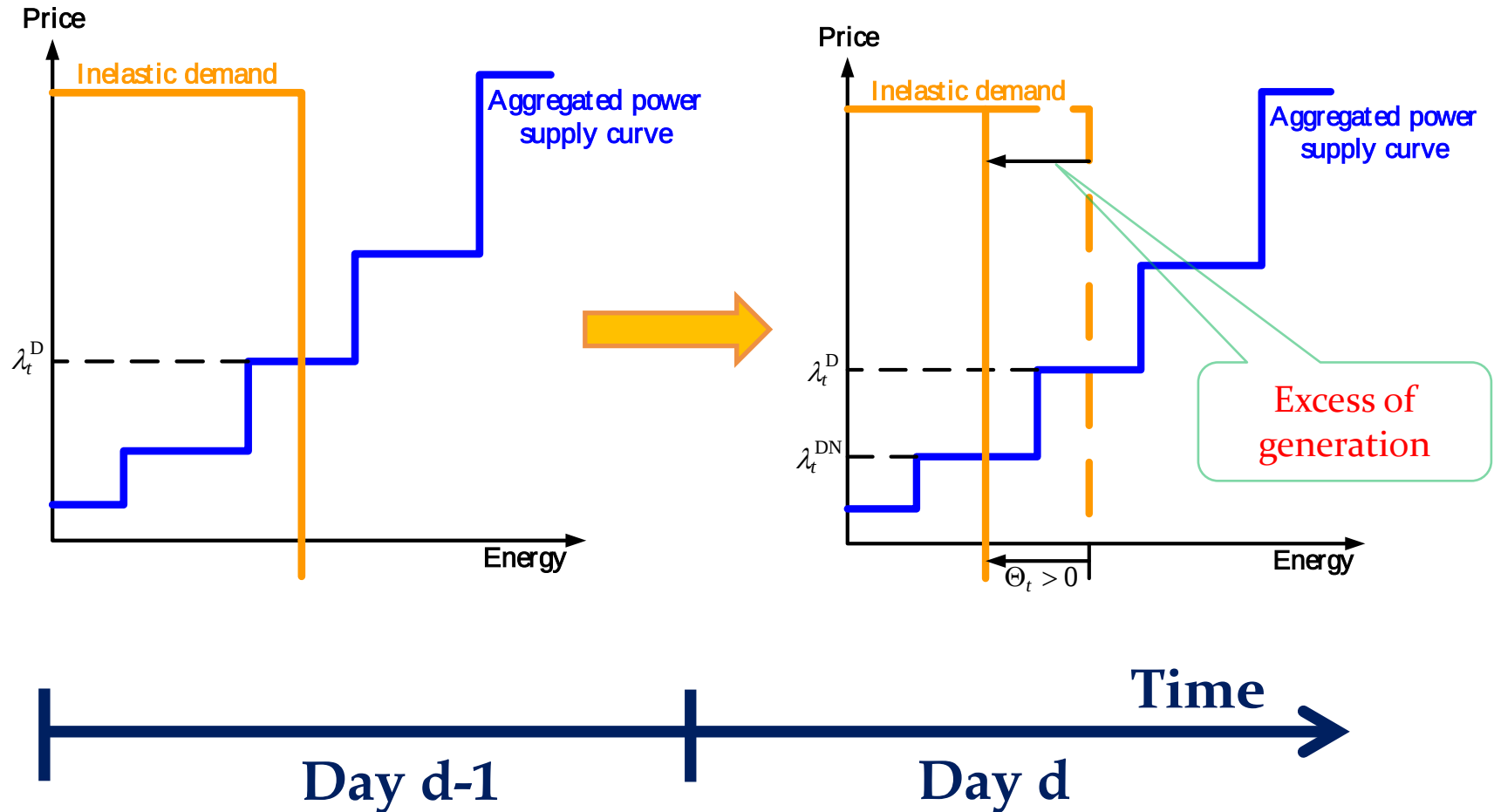
Wind Producer Problem (Motivation)



Wind Producer Problem (Motivation)



Wind Producer Problem (Motivation)



Wind Producer Problem (Motivation)

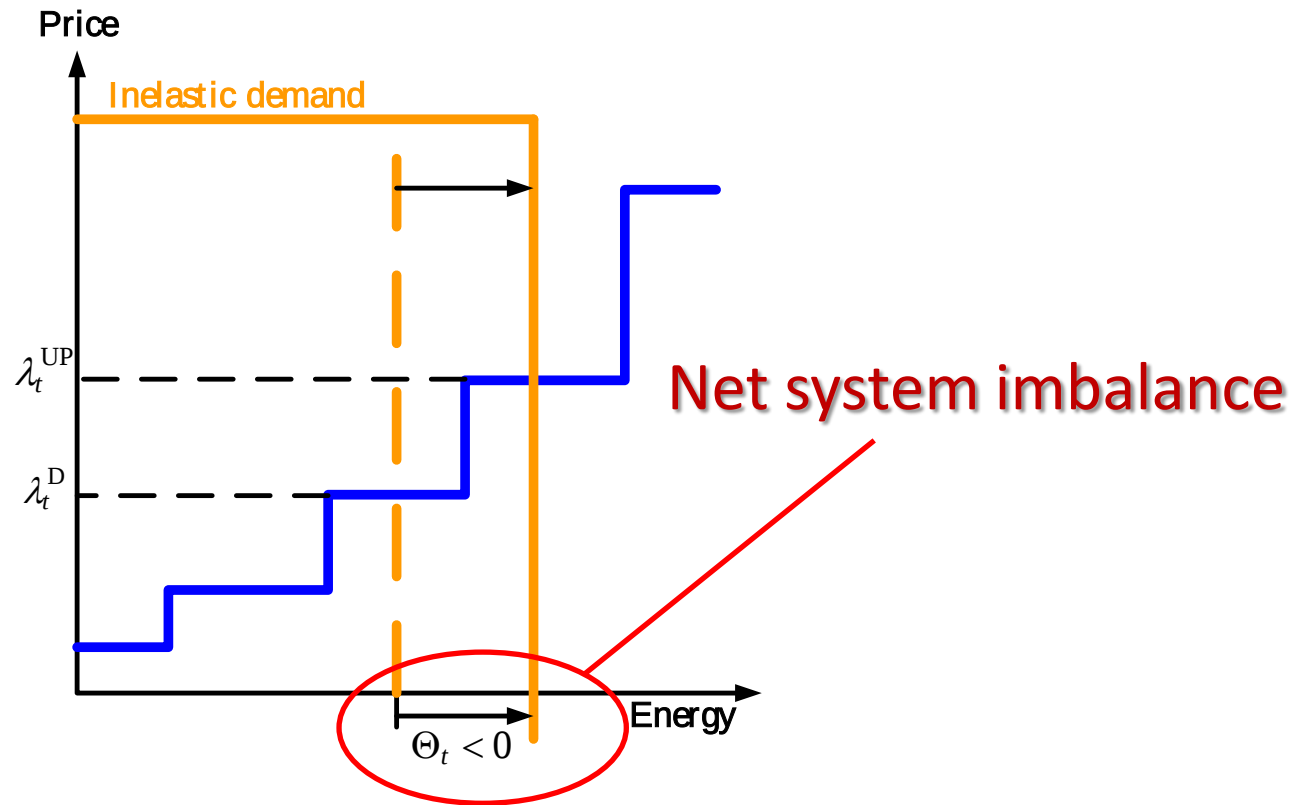
- ✓ Competitiveness damaged by uncertain wind availability for two primary reasons:

?

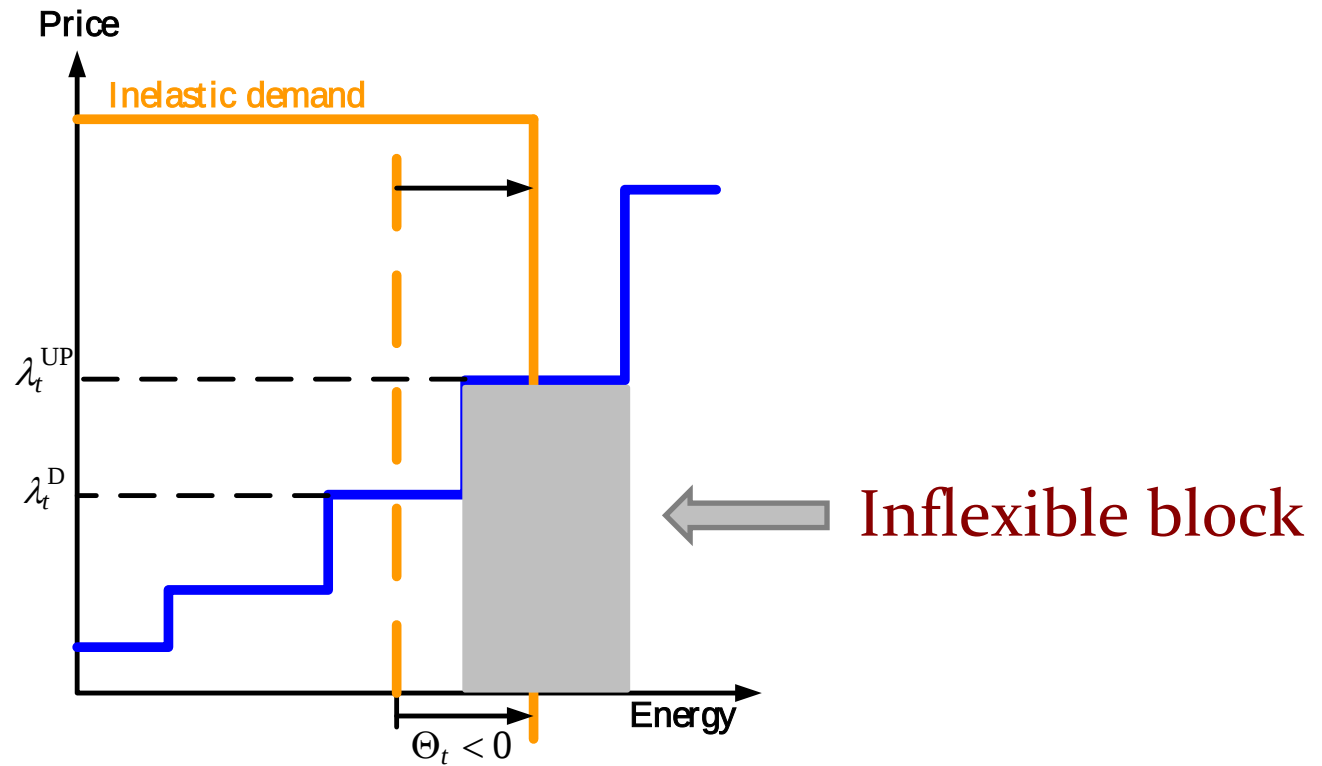
Wind Producer Problem (Motivation)

- ✓ Competitiveness damaged by uncertain wind availability for two primary reasons:
 - 1) Imbalances covered by *flexible*, but *expensive* energy sources through the balancing mechanism

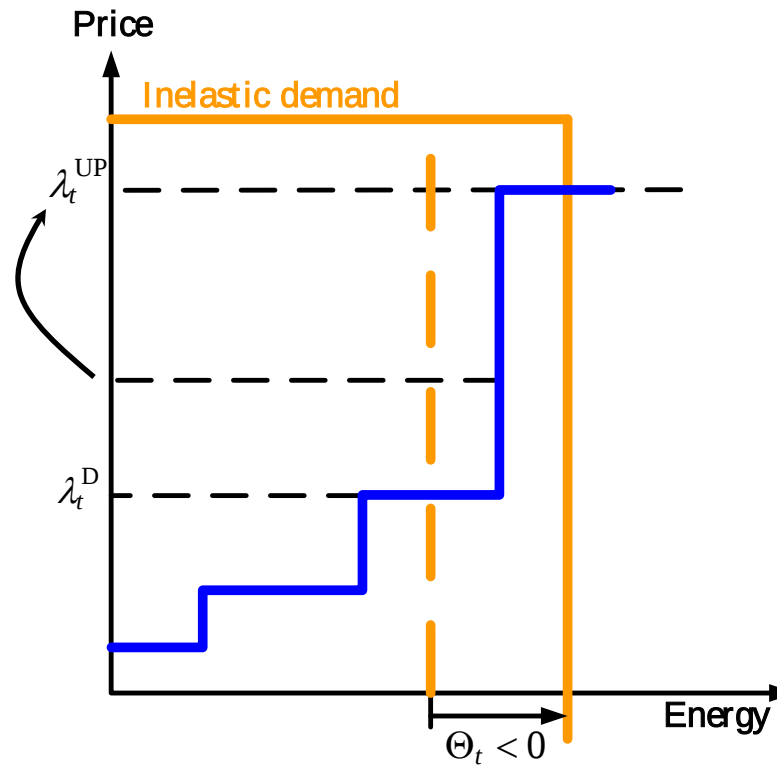
Wind Producer Problem (Motivation)



Wind Producer Problem (Motivation)



Wind Producer Problem (Motivation)



Wind Producer Problem (Motivation)

- ✓ Competitiveness damaged by uncertain wind availability for two primary reasons:
 - 1) Imbalances covered by *flexible*, but *expensive* energy sources through the balancing mechanism
 - The volatility of balancing prices is higher



Trading balancing energy is riskier!

Wind Producer Problem (Motivation)

- ✓ Competitiveness damaged by uncertain wind availability for two primary reasons:
 - 2) Some market designs “penalize” deviators (**dual-price balancing settlements**)
 - Price for positive deviations: λ_t^+
 - Price for negative deviations: λ_t^-
 - Cost of the energy required to counteract the net system imbalance.

Remark: In a single-price balancing settlement $\lambda_t^+ = \lambda_t^-$

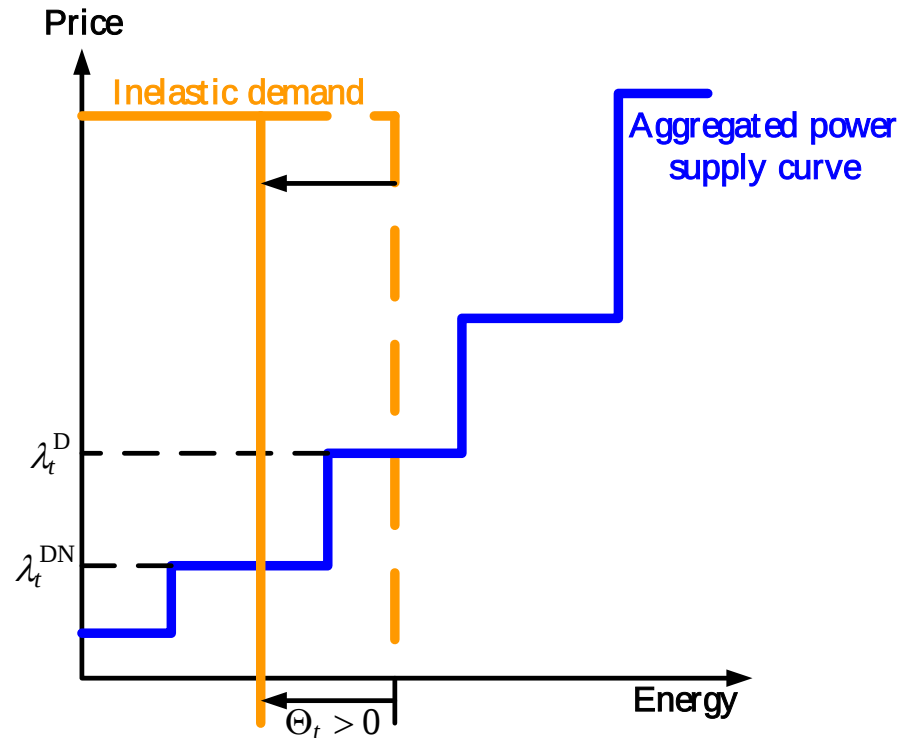
Wind Producer Problem

("One-sided penalty")

If the system imbalance > 0 (excess of generation):

$$\lambda_t^+ = \min(\lambda_t^D, \lambda_t^{DN})$$

$$\lambda_t^- = \lambda_t^D$$



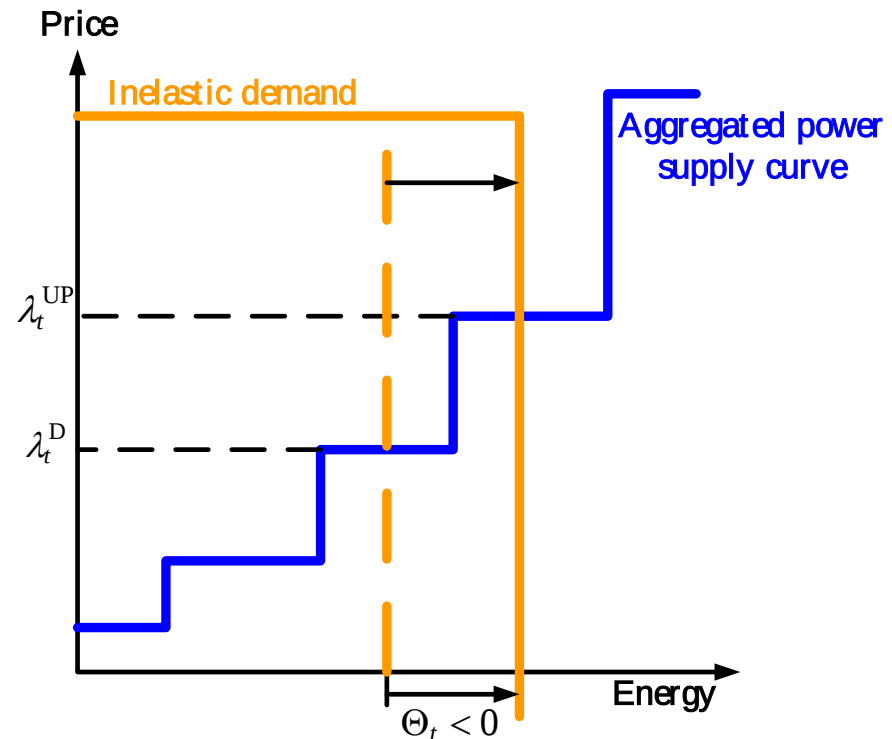
Wind Producer Problem

("One-sided penalty")

If the system imbalance < 0 (deficit of generation):

$$\lambda_t^+ = \lambda_t^D$$

$$\lambda_t^- = \max(\lambda_t^D, \lambda_t^{UP})$$



Wind Producer Problem (Motivation)

- ✓ Competitiveness damaged by uncertain wind availability for two primary reasons:
 - 2) Some market designs “penalize” deviators (**dual-price balancing settlements**)
 - It holds that $\lambda_t^+ \leq \lambda_t^D$ and $\lambda_t^- \geq \lambda_t^D$



Imbalance cost!

By construction, trading in the balancing market is less beneficial than trading in the day-ahead market

Wind Producer Problem (Imbalance cost)

An opportunity cost

- ✓ Loss of profit resulting from not having traded the energy deviation in the day-ahead market

If we define:

$$r_t^+ = \frac{\lambda_t^+}{\lambda_t^D}, \quad r_t^+ \leq 1$$
$$r_t^- = \frac{\lambda_t^-}{\lambda_t^D}, \quad r_t^- \geq 1$$

Wind Producer Problem

(Imbalance cost)

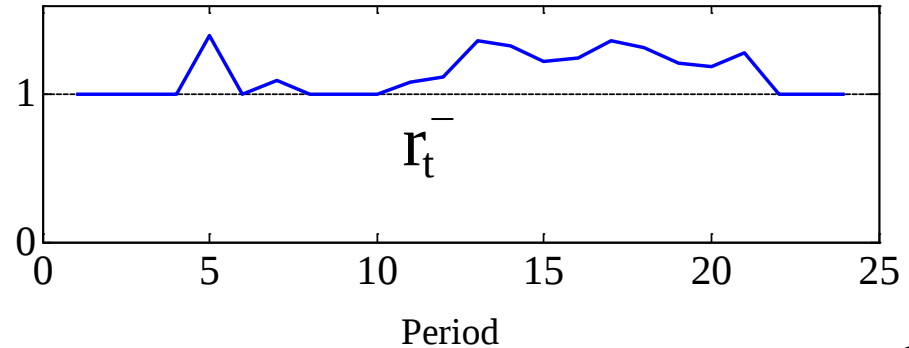
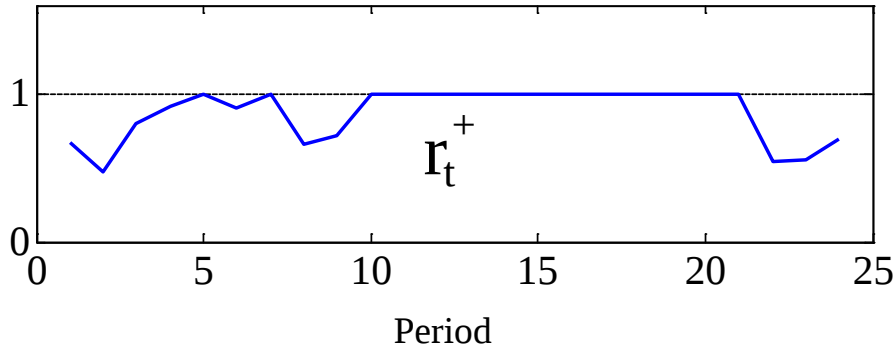
Then, the imbalance cost is given by:

$$I_t = \begin{cases} \lambda_t^D (1 - r_t^+) \Delta_t, & \Delta_t \geq 0 \\ -\lambda_t^D (r_t^- - 1) \Delta_t, & \Delta_t < 0 \end{cases}$$

Total energy deviation
incurred by the wind
producer

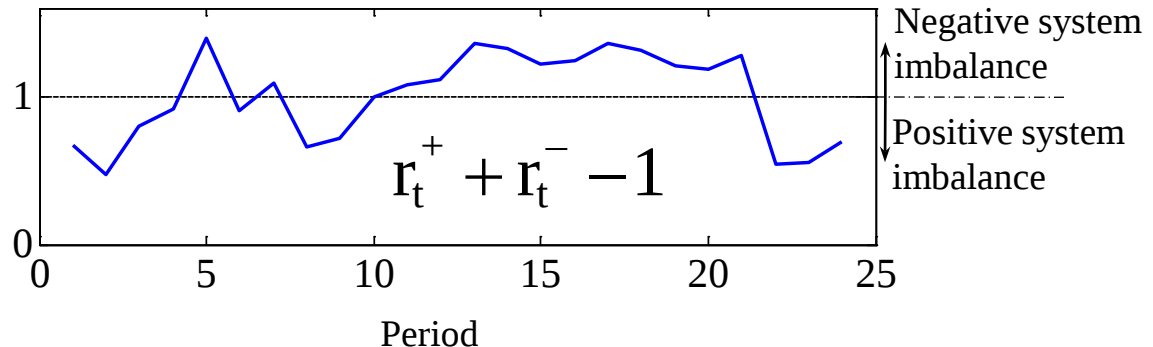
Wind Producer Problem

(Imbalance cost)



One-sided penalty!

Superimposing



Wind Producer Problem (Aim)

Designing a stochastic programming model to build offers for wind producers to trade in different short-term markets (pool) within a fully-fledged electricity market.



Wind Producer Problem (Aim)

- ✓ The wind producer offer strategy should:
 - Be profit effective.
 - Limit profit variability.
 - Minimize the need for balancing energy.

Wind Producer Problem (Market framework)

✓ Three independent and successive markets:

- Day-ahead market
- Adjustment market
- Balancing market



✓ No market power capability by the wind producer in any of these markets

Wind Producer Problem (Uncertainty sources)

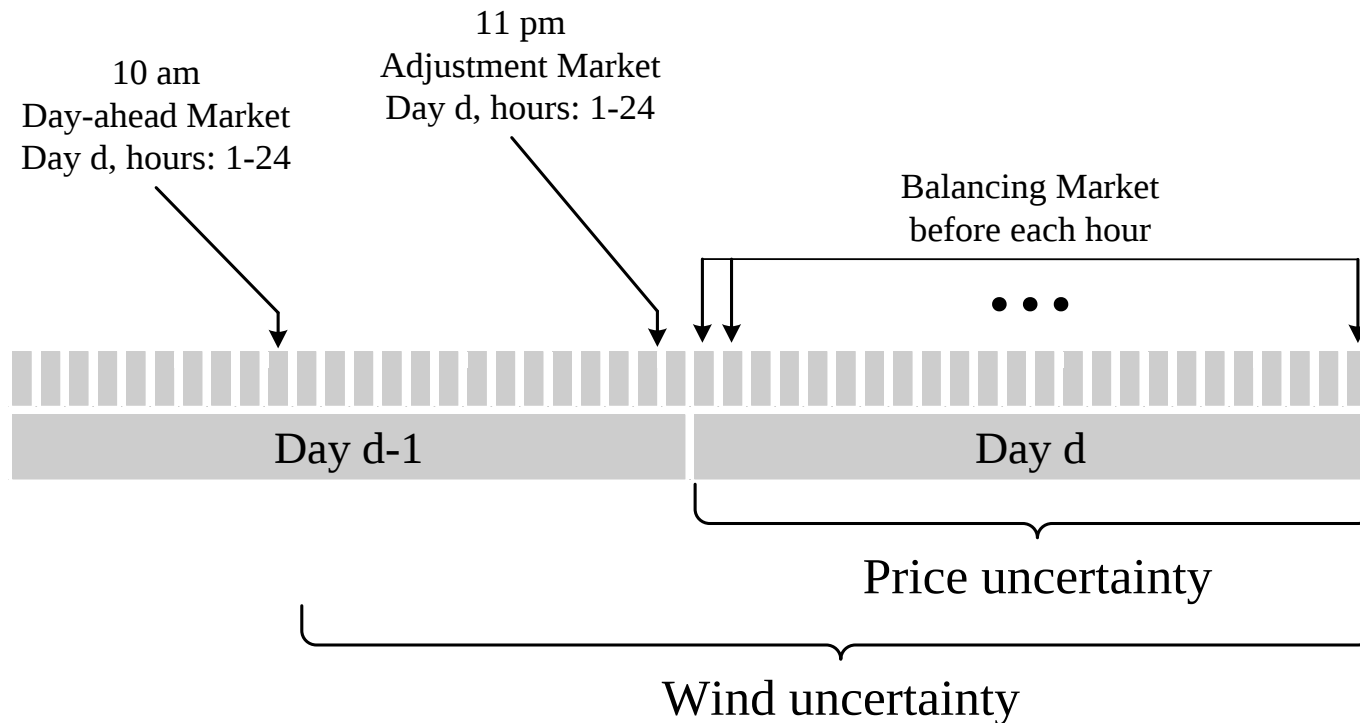
- ✓ Wind generation availability
- ✓ Day-ahead market prices
- ✓ Adjustment market prices: $\lambda_t^A - \lambda_t^D$
- ✓ Imbalance price ratios

$$r_t^+ = \frac{\lambda_t^+}{\lambda_t^D}, \quad r_t^+ \leq 1$$

$$r_t^- = \frac{\lambda_t^-}{\lambda_t^D}, \quad r_t^- \geq 1$$

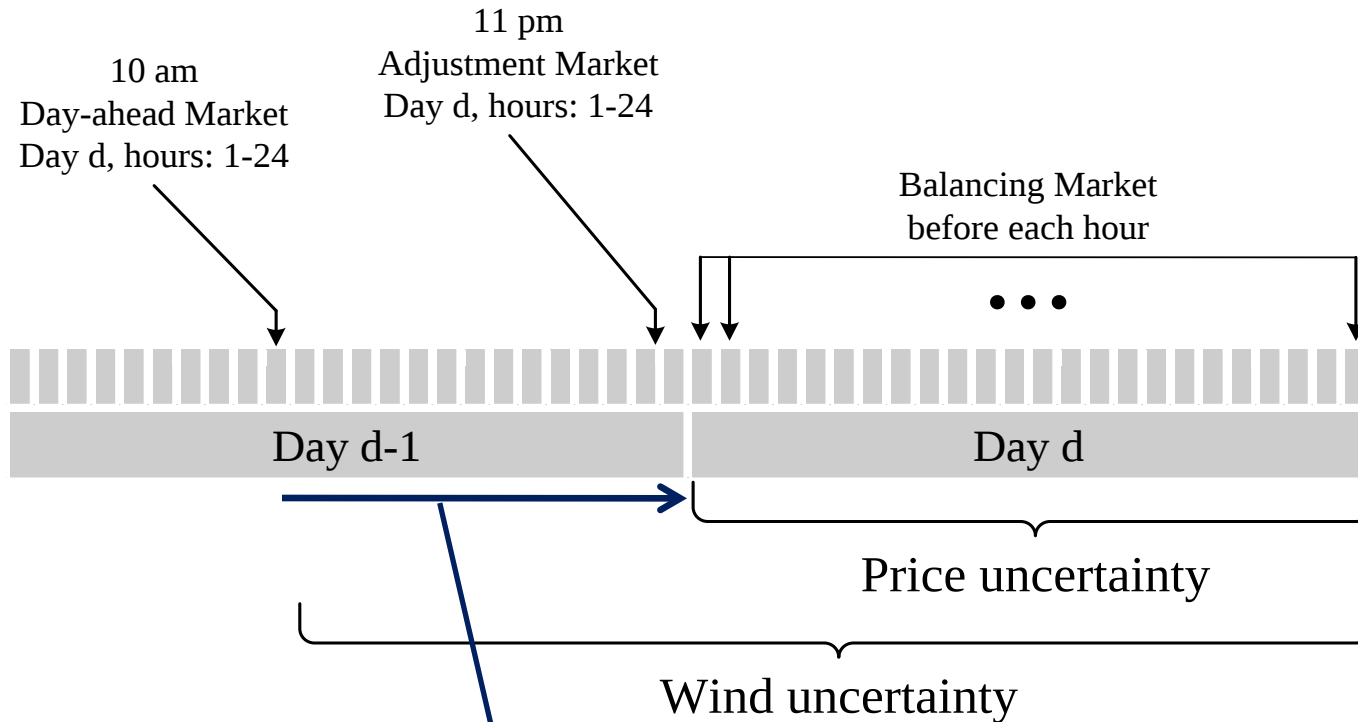
Wind Producer Problem

(Certainty gain process)



Wind Producer Problem

(Certainty gain process)



Certainty gain

Knowledge gained on wind power stochastic behavior

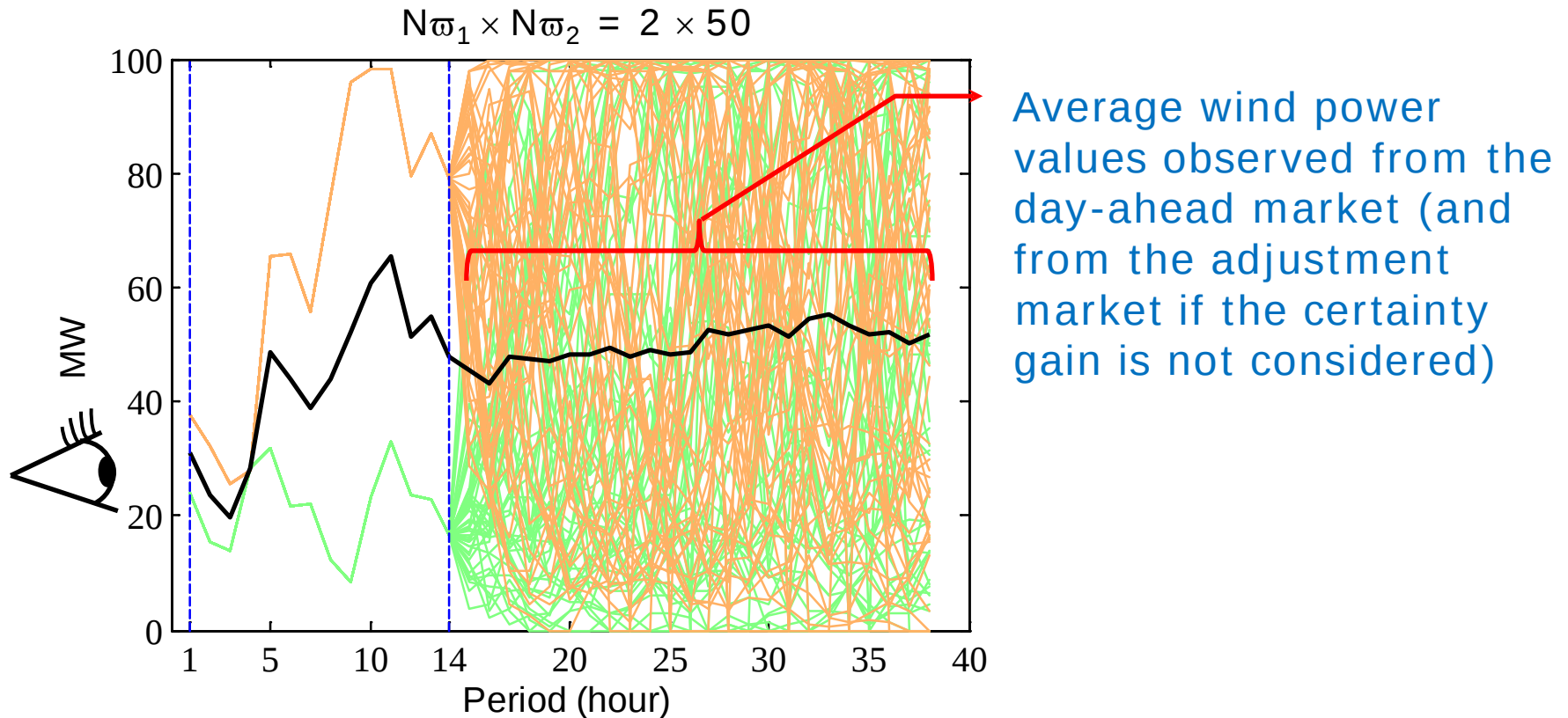
Wind Producer Problem

(Certainty gain process)

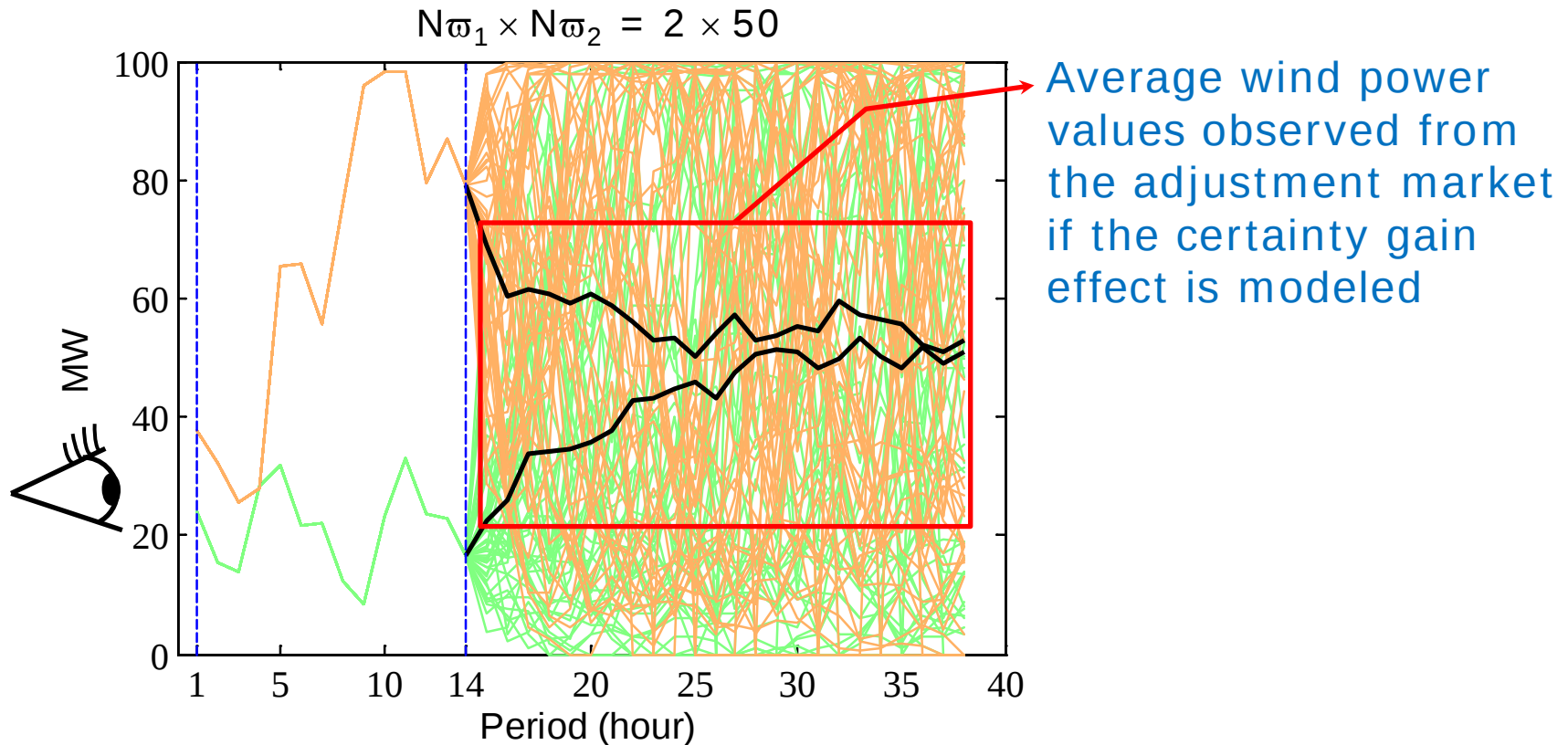
- ✓ The generation of wind power scenarios should account for the certainty gain phenomenon.
 1. N_{ϖ_1} scenarios between day-ahead and adjustment market.
 2. N_{ϖ_2} scenarios after the adjustment market.

Wind Producer Problem

(Certainty gain process)



Wind Producer Problem (Certainty gain process)



Wind Producer Problem (Mathematical modeling)

How many stages do we have?

Wind Producer Problem (Mathematical modeling)

Three-stage stochastic programming model:

- ✓ **First-stage variables:** Energy sold in the day-ahead market
- ✓ **Second-stage variables:** Energy traded in the adjustment market
- ✓ **Third-stage variables:** Deviations and their associated cost

Wind Producer Problem (Mathematical modeling)

Three-stage stochastic programming model:

- ✓ **First-stage variables:** Energy sold in the day-ahead market
 - ✓ **Second-stage variables:** Energy traded in the adjustment market
 - ✓ **Third-stage variables:** Deviations and their associated cost
- Decisions we are interested in!**

Day-ahead market

Uncertainty:

$$P_{\tau}^W, \forall \tau$$

$$\lambda_t^D, \lambda_t^A, P_t^W, r_t^+, r_t^-, \forall t$$

$$\lambda_t^D, \forall t; P_{\tau}^W, \forall \tau = 1, \dots, N_{T_1}$$

Adjustment market

Uncertainty:

$$P_t^W, \lambda_t^A, r_t^+, r_t^-, \forall t$$

$$\lambda_t^A, P_t^W, r_t^+, r_t^-, \forall t = 1, \dots, N_T$$

Balancing
market
(I_t)

Stochastic programming approach

Three stages, each one representing a market

Wind Producer Problem (Mathematical modeling)

- ✓ Maximize *Expected profit* + $\beta \times CVaR$
- ✓ Subject to constraints associated with:
 - Linearization of imbalance income
 - Non-anticipatory character of information
 - CVaR

Linear
programming
problem

The tradeoff between expected profit and risk is enforced through the weighting factor $\beta \in [0, \infty)$.

Wind Producer Problem (Mathematical modeling)

$$E\{\text{profit}\} = E\{$$

Revenue from trading in the day-ahead market

+ Revenue from trading in the adjustment market

+ Imbalance income } =

$$= \sum_{\omega=1}^{N_{\Omega}} \sum_{t=1}^{N_T} \pi_{\omega} \left[\lambda_{t\omega}^D P_{t\omega}^D d_t + \lambda_{t\omega}^A P_{t\omega}^A d_t + I_{t\omega}^I \right]$$

Wind Producer Problem

(Mathematical modeling)

$$E\{\text{profit}\} = E\{$$

Revenue from trading in the day-ahead market

+ Revenue from trading in the adjustment market

+ Imbalance income } =

$$= \sum_{\omega=1}^{N_{\Omega}} \sum_{t=1}^{N_T} \pi_{\omega} \left[\lambda_{t\omega}^D P_{t\omega}^D d_t + \lambda_{t\omega}^A P_{t\omega}^A d_t + I_{t\omega}^I \right]$$

Wind Producer Problem

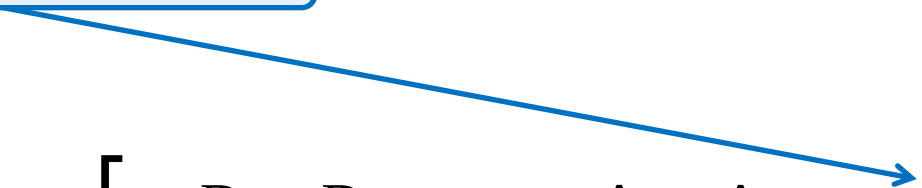
(Mathematical modeling)

$$E\{\text{profit}\} = E\{$$

Revenue from trading in the day-ahead market

+ Revenue from trading in the adjustment market

+ Imbalance income } =

$$= \sum_{\omega=1}^{N_{\Omega}} \sum_{t=1}^{N_T} \pi_{\omega} \left[\lambda_{t\omega}^D P_{t\omega}^D d_t + \lambda_{t\omega}^A P_{t\omega}^A d_t + I_{t\omega}^I \right]$$


Wind Producer Problem

(Linearization of the imbalance income)

$$I_{t\omega}^I = \begin{cases} \lambda_{t\omega}^D r_{t\omega}^+ \Delta_{t\omega}, & \Delta_{t\omega} \geq 0 \\ \lambda_{t\omega}^D r_{t\omega}^- \Delta_{t\omega}, & \Delta_{t\omega} < 0 \end{cases}$$

Linearization $\longrightarrow$

$$I_{t\omega}^I = \lambda_{t\omega}^D (r_{t\omega}^+ \Delta_{t\omega}^+ - r_{t\omega}^- \Delta_{t\omega}^-)$$

$$\Delta_{t\omega} = d_t (P_{t\omega} - P_{t\omega}^D - P_{t\omega}^A)$$

$$\Delta_{t\omega} = \Delta_{t\omega}^+ - \Delta_{t\omega}^-$$

$$0 \leq \Delta_{t\omega}^+ \leq P_{t\omega} d_t$$

$$0 \leq \Delta_{t\omega}^- \leq P^{\max} d_t$$

Total deviation decomposed into positive and negative deviations

Wind Producer Problem (Non-anticipativity constraints)

Which decisions must be unique and independent of the uncertainty outcome?

Wind Producer Problem

(Non-anticipativity constraints)

$$P_{t\omega}^D = P_{t\omega'}^D, \quad \forall t, \forall \omega, \omega'$$

Wind Producer Problem (Non-anticipativity constraints)

Relaxed to obtain offer curves!

$$P_{t\omega}^D = P_{t\omega'}^D, \quad \forall t, \forall \omega, \omega': \lambda_{t\omega}^D = \lambda_{t\omega'}^D$$

Power traded in day-ahead market can be different
for different price realizations!



Pairs $(P_{t\omega}^D, \lambda_{t\omega}^D)$ making up an offer curve

Wind Producer Problem

(Non-anticipativity constraints)

$$P_{t\omega}^A = P_{t\omega'}^A, \quad \forall t, \forall \omega, \omega': (\lambda_{t\omega}^D = \lambda_{t\omega'}^D, \forall t)$$

$$\text{and } (P_{t\omega} = P_{t\omega'}, \forall t = 1, 2, \dots, N_{T_1})$$

To model the certainty gain effect!

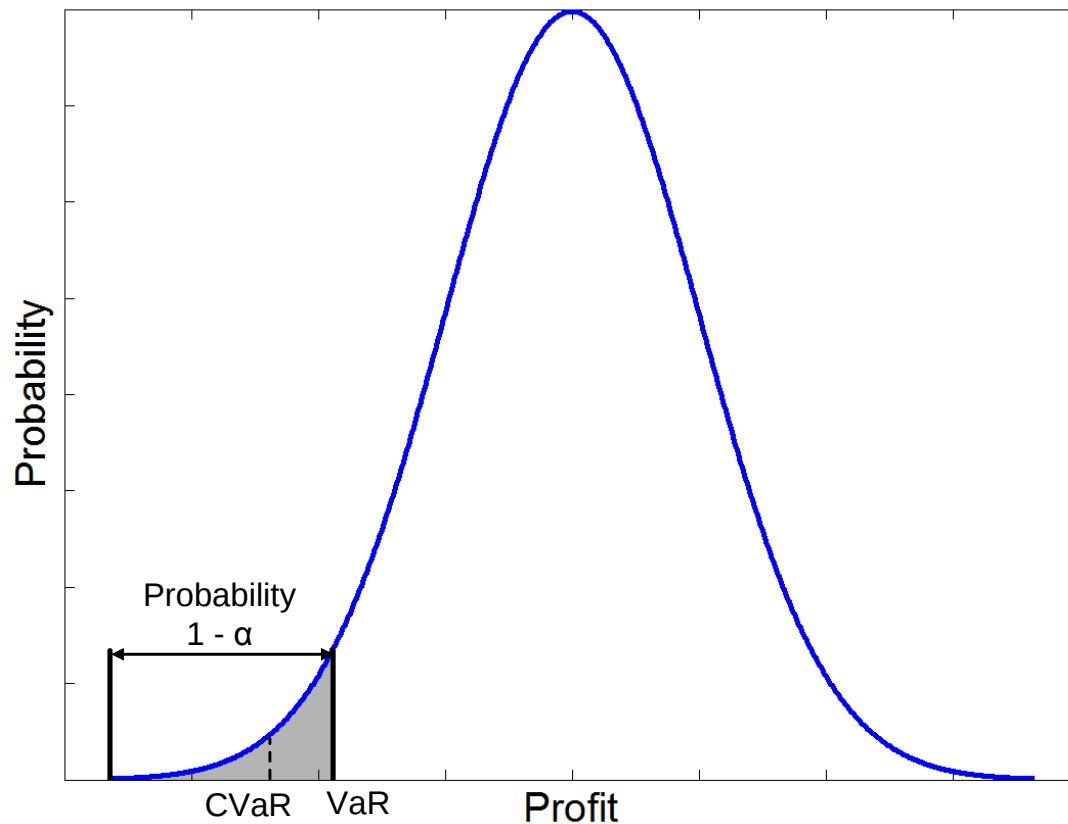
The power traded in the adjustment market can be different depending on the wind realization between the closure of the day-ahead and adjustment markets!

Wind Producer Problem

(Risk management)

1. Tradeoff between expected profit and risk due to profit variability
2. Risk measure: CVaR (average profit in scenarios with lowest profit)
3. CVaR advantage: linear formulation

Wind Producer Problem (CVaR modeling)



Wind Producer Problem

(CVaR modeling)

$$\text{CVaR} = \xi - \frac{1}{1-\alpha} \sum_{\omega \in \Omega} \pi_{\omega} \eta_{\omega}$$

$$\begin{aligned}
 & - \sum_{t=1}^{N_T} [\lambda_{t\omega}^D P_{t\omega}^D d_t + \lambda_{t\omega}^A P_{t\omega}^A d_t + \lambda_{t\omega}^D (r_{t\omega}^+ \Delta_{t\omega}^+ - r_{t\omega}^- \Delta_{t\omega}^-)] \\
 & + \xi - \eta_{\omega} \leq 0 \quad \forall \omega
 \end{aligned}$$

$$\eta_{\omega} \geq 0 \quad \forall \omega$$

Wind Producer Problem (CVaR modeling)

Does it make sense to consider RISK
AVERSION in this problem?

Wind Producer Problem

(Other constraints)

Non-decreasing condition

$$P_{t\omega}^D - P_{t\omega'}^D \leq 0, \quad \forall t, \forall \omega, \omega': O(\lambda_{t\omega}^D) + 1 = O(\lambda_{t\omega'}^D)$$

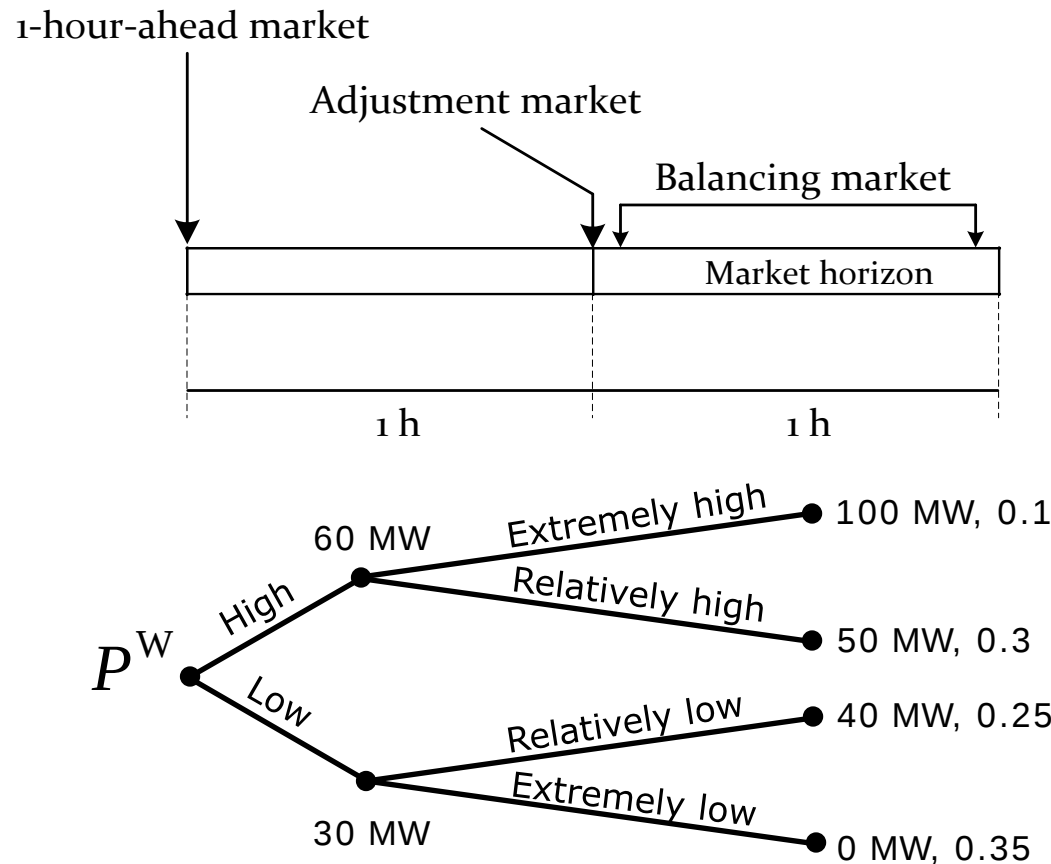
Bounds

$$0 \leq P_{t\omega}^D \leq P^{\max}, \quad \forall t, \forall \omega$$

$$0 \leq P_{t\omega}^D + P_{t\omega}^A \leq P^{\max}, \quad \forall t, \forall \omega$$

Wind Producer Problem

(Example: Wind production data)



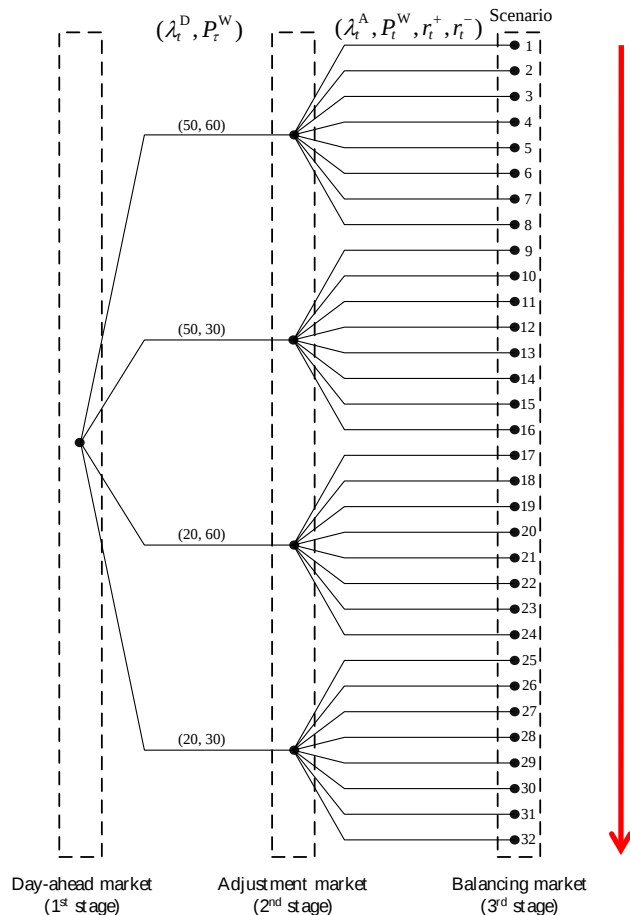
Wind Producer Problem

(Example: Price data)

	λ^D (€/MWh)		$\Delta\lambda$ (€/MWh)		(r^+, r^-)	
Value	50	20	-10	3	(1, 1.5)	(0.9, 1)
Prob.	0.40	0.60	0.35	0.65	0.7	0.3

Wind Producer Problem

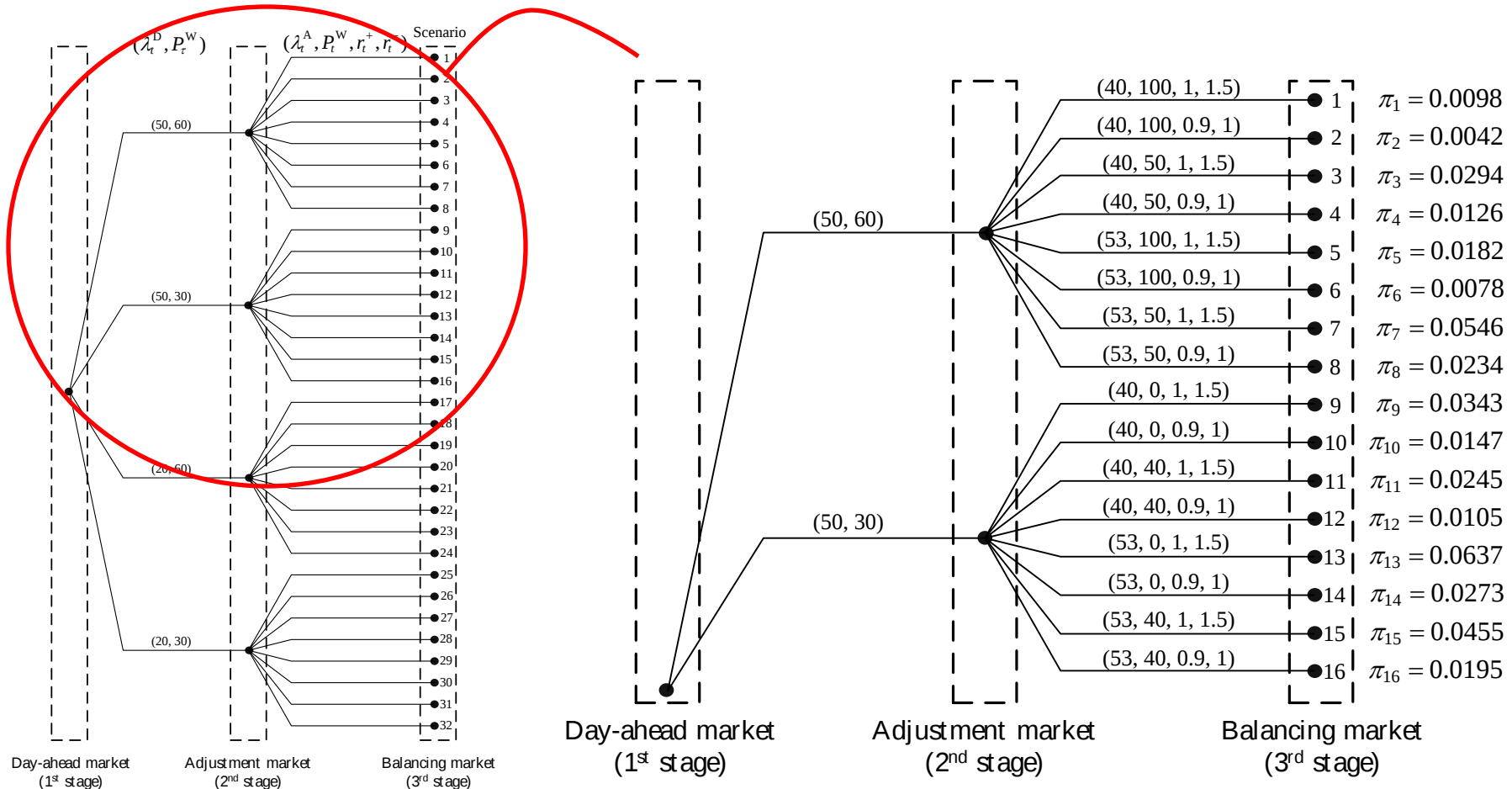
(Example: Scenario tree)



32
scenarios

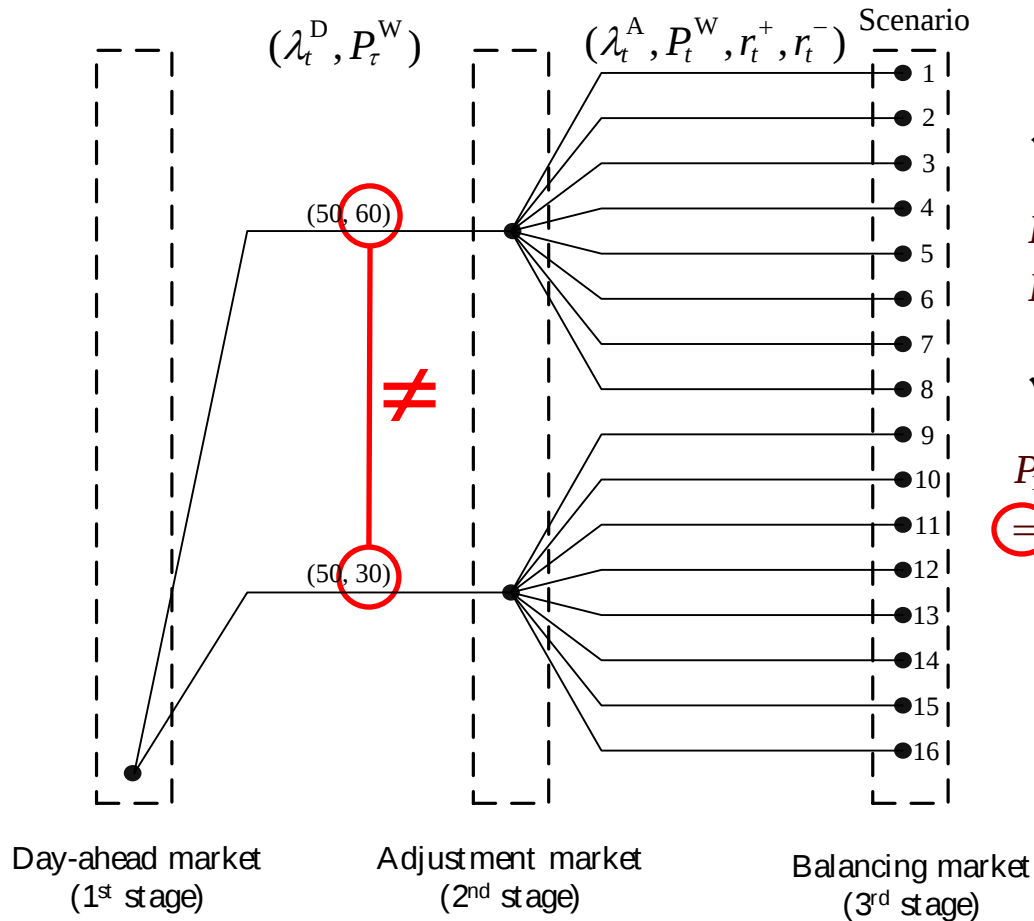
Wind Producer Problem

(Example: Scenario tree)



Wind Producer Problem

(Example: Certainty gain modeling)



✓ Modeling the certainty gain

$$P_1^A = P_2^A = P_3^A = P_4^A = P_5^A = P_6^A = P_7^A = P_8^A, \\ P_9^A = P_{10}^A = P_{11}^A = P_{12}^A = P_{13}^A = P_{14}^A = P_{15}^A = P_{16}^A$$

✓ Not modeling the certainty gain

$$P_1^A = P_2^A = P_3^A = P_4^A = P_5^A = P_6^A = P_7^A = P_8^A = \\ = P_9^A = P_{10}^A = P_{11}^A = P_{12}^A = P_{13}^A = P_{14}^A = P_{15}^A = P_{16}^A$$

More constrained!

Wind Producer Problem

(Example: Certainty gain effect)

✓ If

	(r^+, r^-)	
Value	(1, 1.5)	(0.9, 1)
Prob.	0.7	0.3



Expected profit: $\uparrow 0\%$

✓ If

	(r^+, r^-)	
Value	(1, 1.5)	(0.1, 1)
Prob.	0.7	0.3



Expected profit: $\uparrow 14.03\%$

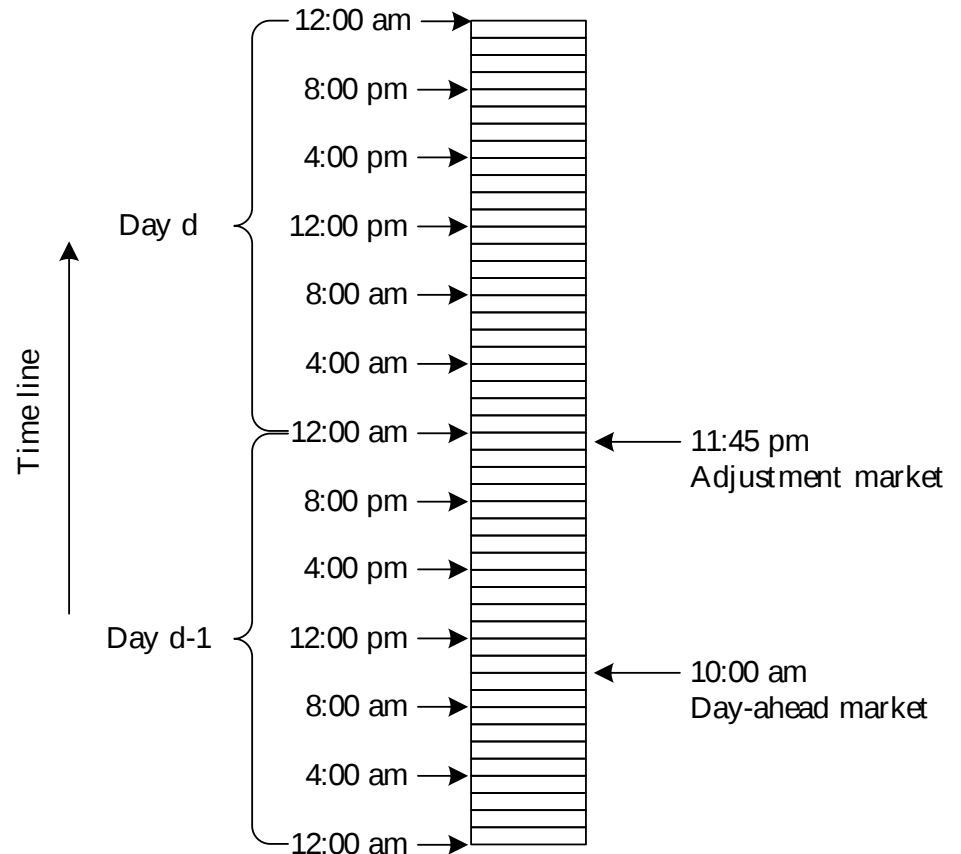


Very unfavorable imbalance prices!

Wind Producer Problem

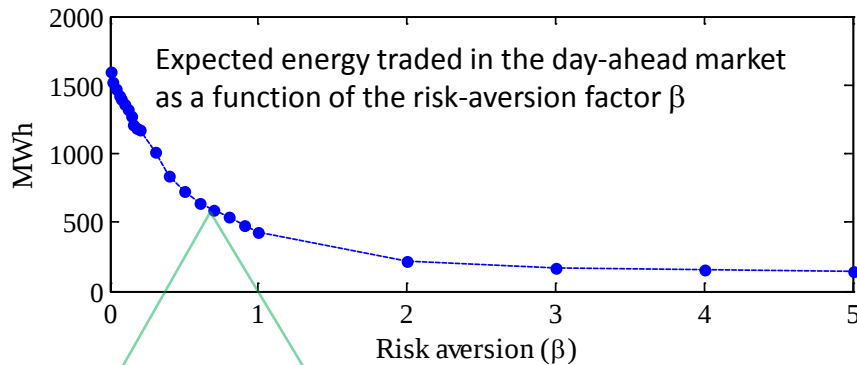
(Case study)

- ✓ Price data from Iberian Peninsula market.
- ✓ Wind speed data from a location in Kansas (US).
- ✓ 1 day.



Wind Producer Problem

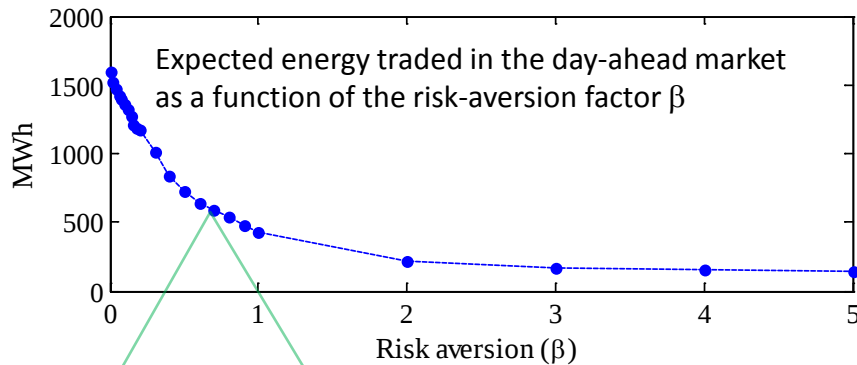
(Case study: No adjustment market)



Reducing the energy traded in the day-ahead market in the hope of selling in the balancing market at a competitive price

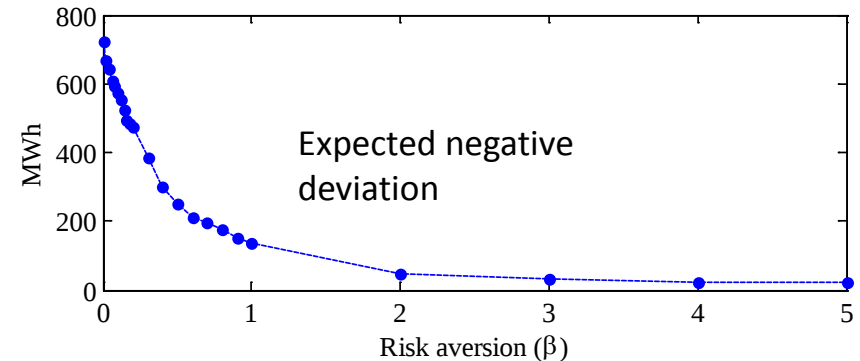
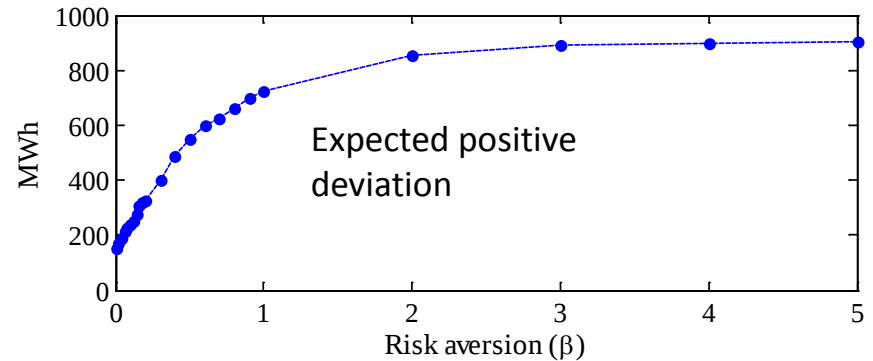
Wind Producer Problem

(Case study: No adjustment market)



Reducing the energy traded in the day-ahead market in the hope of selling in the balancing market at a competitive price

$$\beta \uparrow \Rightarrow E\{P^D\} \downarrow \Rightarrow \begin{cases} E\{\Delta^+\} \uparrow \\ E\{\Delta^-\} \downarrow \end{cases}$$

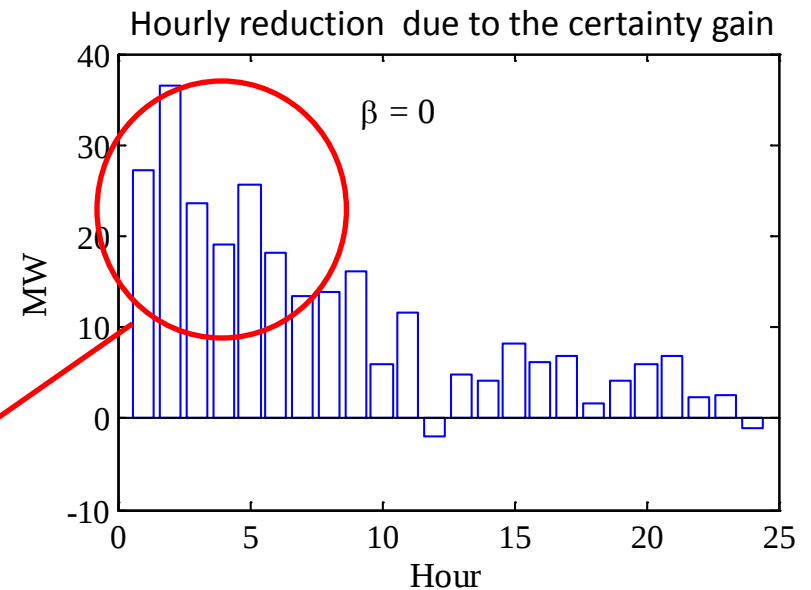
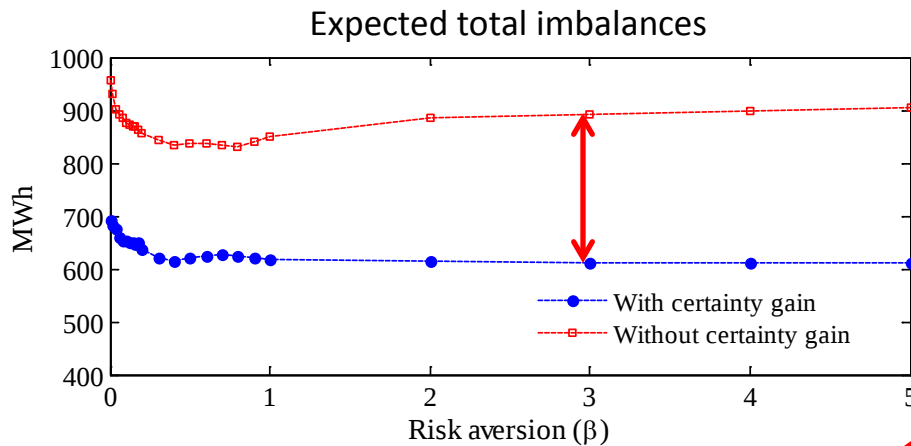


Negative deviations are more harmful to the wind producer than positive deviations (assuming that $r^+ \geq 0$)

Wind Producer Problem

(Case study: Adjustment market)

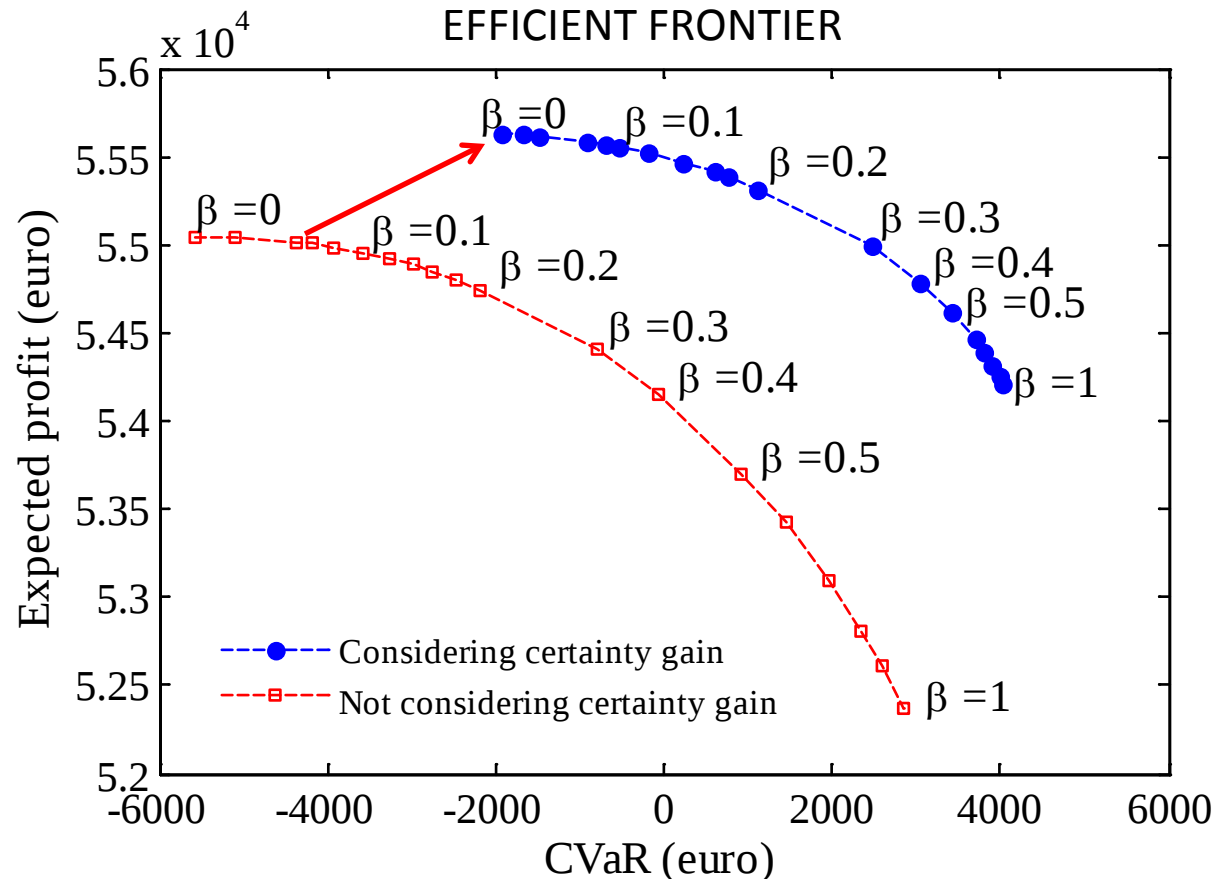
✓ Certainty gain effect!



A significant reduction for the first few hours

Wind Producer Problem

(Case study: Certainty gain effect)



Wind Producer Problem

(Case study: Certainty gain effect)

- ✓ No adjustment market

$$VSS = 1.87\%$$

Better not to offer forecasts!

- ✓ Adjustment market, no certainty gain effect

$$VSS = 2.58\% (\uparrow 0.71\%)$$

A new market $\Rightarrow$ new trading options

- ✓ Adjustment market, certainty gain effect

$$VSS = 3.61\% (\uparrow 1.03\%)$$

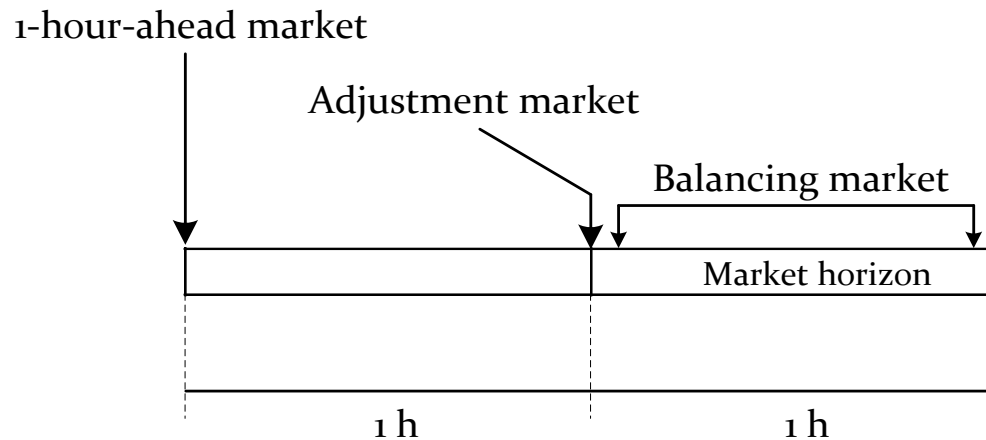
Good to have markets close to power delivery!



Thanks for your attention!

Wind Producer Problem (Exercise)

Market framework:



Wind Producer Problem (Exercise)

It is known that:

1. The price in the 1-h ahead market is equal to 50 €/MWh with a probability of 0.40 and equal to 20 €/MWh with a probability of 0.60
2. The price in the adjustment market is identical to the 1-h ahead market price
3. The quantity of power produced by a certain 100-MW wind farm during the hour between the closures of the 1-h ahead and adjustment markets may be *high* (60 MW) with a probability of 0.4 or *low* (30 MW) with a probability of 0.6

Wind Producer Problem (Exercise)

It is known that:

4. If the wind power production is *high* (60 MW), the amount of power produced during the 1-h market horizon may be *extremely high* (100 MW) with a probability of 0.75 or *relatively high* (50 MW) with a probability of 0.25
5. If the wind power production is *low* (30 MW), the amount of power produced during the 1-h market horizon may be *extremely low* (0 MW) or *relatively low* (40 MW), both with a probability of 0.5

Wind Producer Problem (Exercise)

It is known that:

6. Dual-price balancing settlement, two-sided penalty:
 - a) The price of the energy required to cover generation shortages is 20% higher than the 1-h ahead market price
 - b) Generation surpluses can be sold in the balancing market at a price 50% smaller than the 1-h ahead market price

Wind Producer Problem (Exercise)

Things to do:

1. Build the corresponding scenario tree (graphically)
2. Ignore the adjustment market. Compute:
 - a) Optimal bid in the 1-h ahead market
 - b) VSS and EVPI (please, provide absolute figures and percentages)
 - c) Power sold in the 1-h ahead market as a function of the risk aversion of the wind producer (graphically)

Wind Producer Problem (Exercise)

Things to do:

3. Consider the adjustment market. Compute:
 - a) Optimal bid in both the 1-h ahead and adjustment markets
 - b) Economic improvement due to the certainty gain effect