EcoGrid EU: A real-time market demonstration

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Centre for Electric Technology

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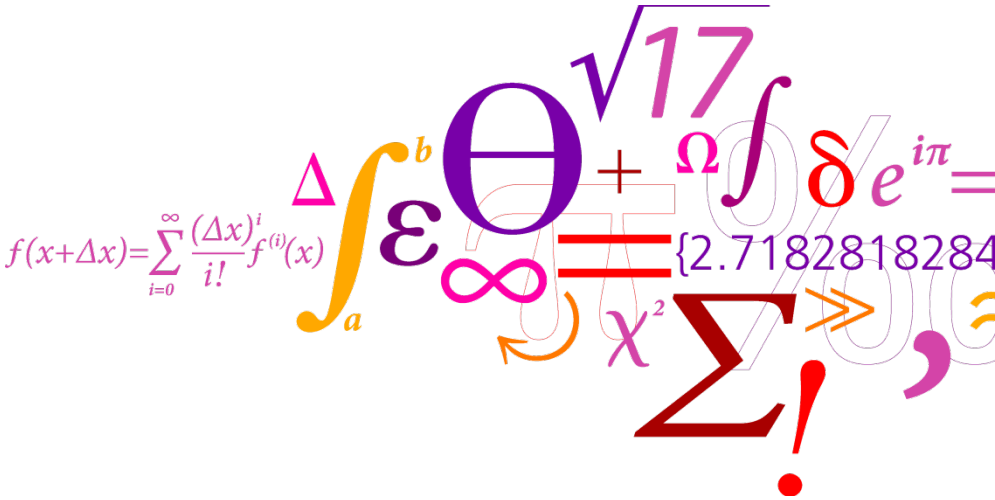
Journal club



DTU Electrical Engineering
Department of Electrical Engineering

Introduction

Power Systems

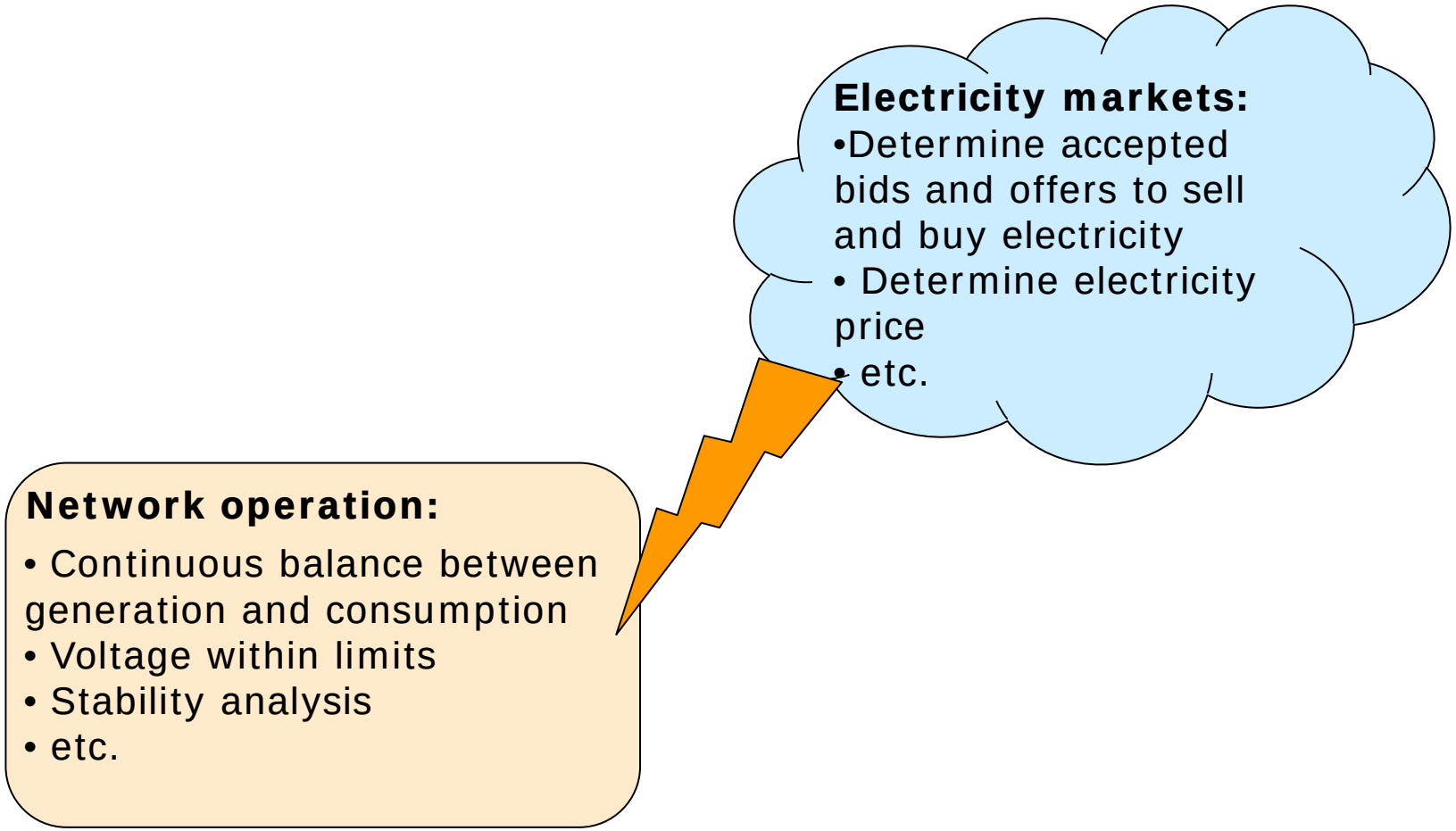
Network operation:

- Continuous balance between generation and consumption
- Voltage within limits
- Stability analysis
- etc.

Electricity markets:

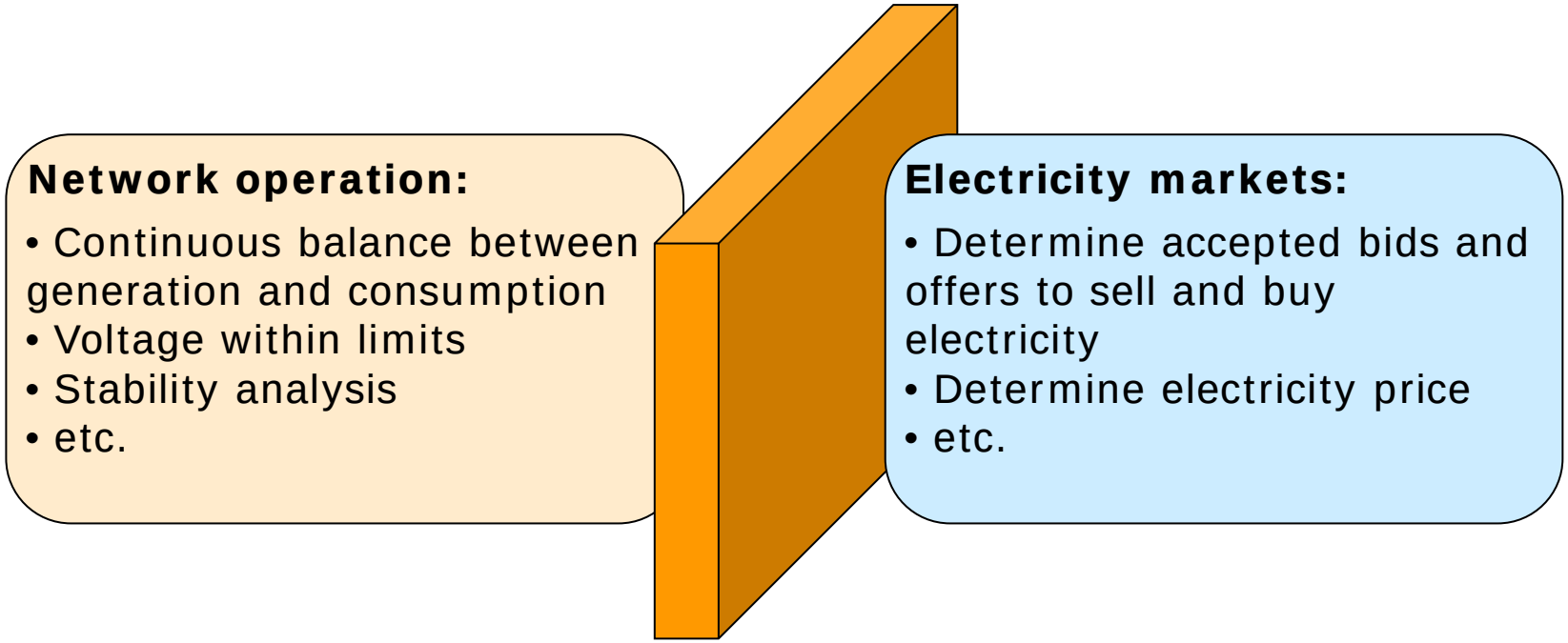
- Determine accepted bids and offers to sell and buy electricity
- Determine electricity price
- etc.

Introduction



Introduction

- Current design:



Old / Current electricity market

- Large centralize fossil-fuel generating units to take advantage of economies of scale
- Unflexible generating units.
- Generating units far from the consumption centers: electricity must be transmitted long distances through network
- Electricity end-consumers treated as passive participants
- High accuracy to forecast demand
- Considering these facts, how do we operate the market?

Old / Current electricity market

1. Power producers submit their bids to sell electricity

Unit type	Quantity (MW)	Price (€/MWh)
Hydro	200	0
Nuclear	400	6
Coal	350	15
Gas	100	30

Old / Current electricity market

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Unit	Q (MW)	P (€/MWh)
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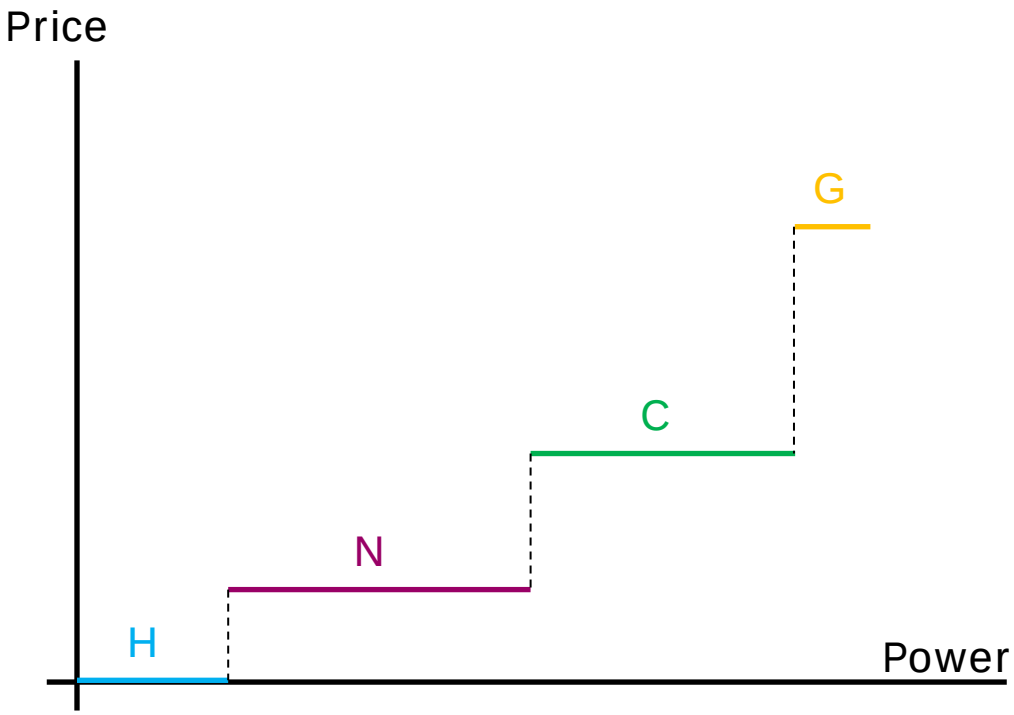
Gas	100	30



Old/Current electricity market

2. Forecast electricity demand

   Demand forecast = 700 MW

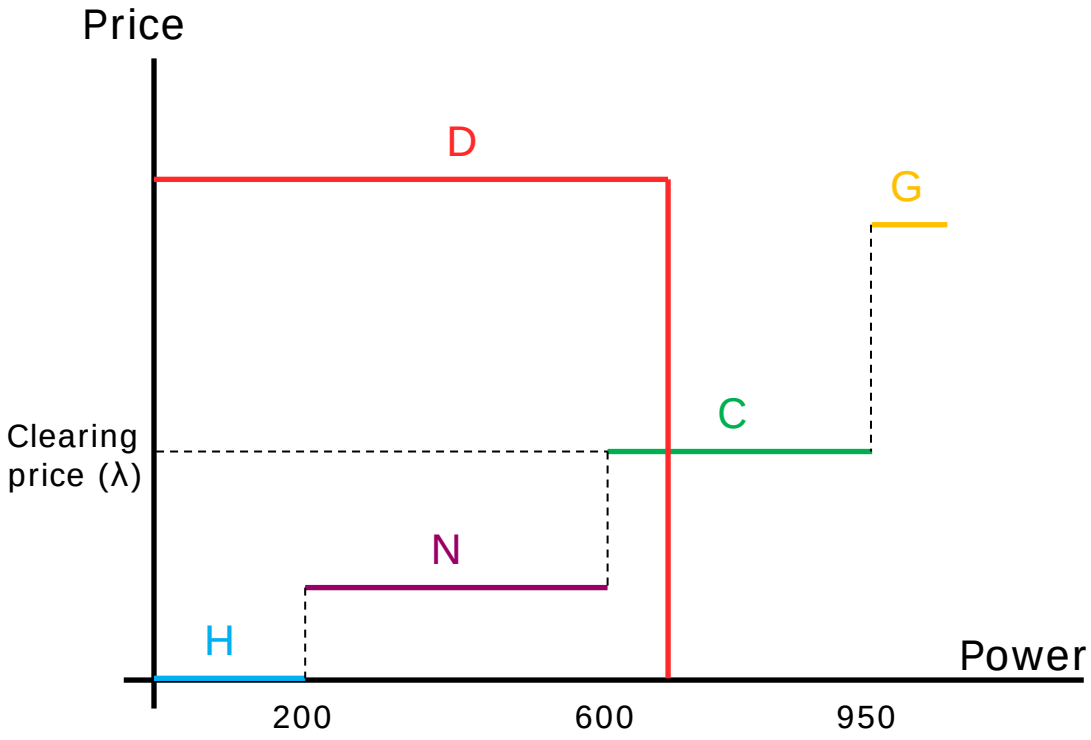
Old / Current electricity market

3. Clear the market

Demand forecast = 700 MW

Unit	Q (MW)
Hydro	200
Nuclear	400
Coal	100
Gas	0

Clearing price = 15 €/MWh

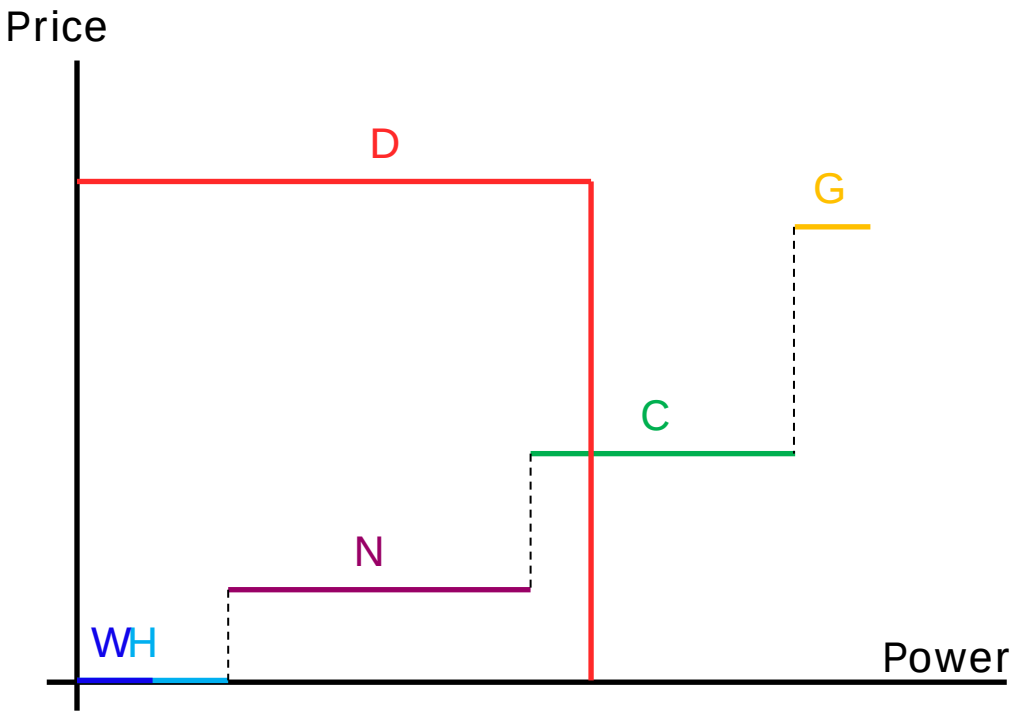


Old / Current electricity market

- However, CO2 emissions need to be reduced
- Renewable production comes into scene!

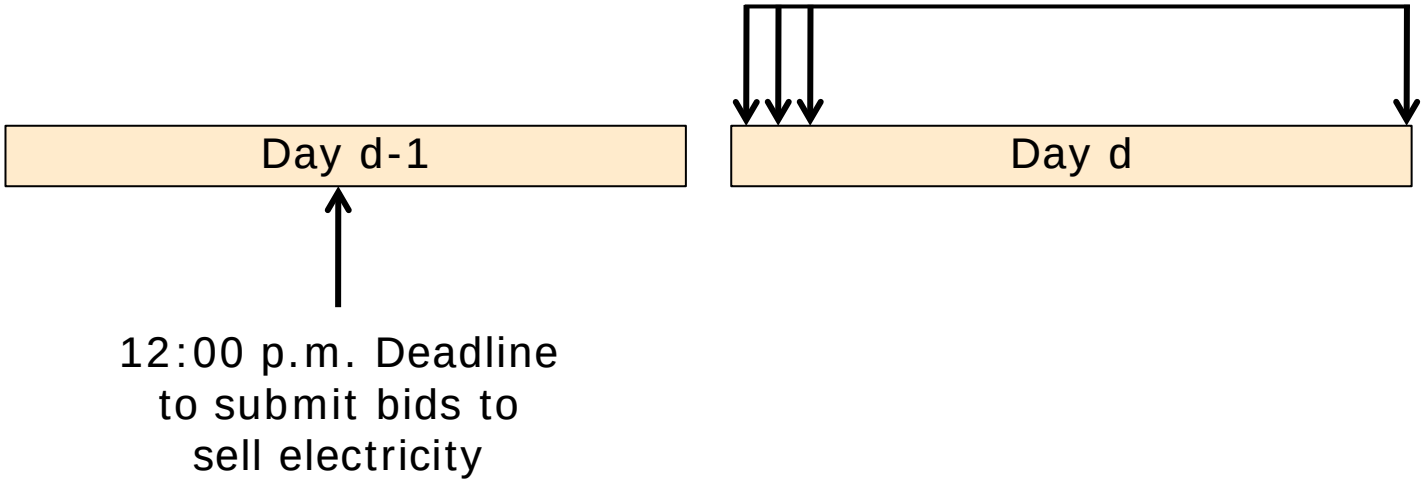
Unit	Q (MW)	P (€/MWh)
Hydro	200	0
Wind	100	0
Nuclear	400	6
Coal	350	15
Gas	100	30

Price reduction due to wind power production !!



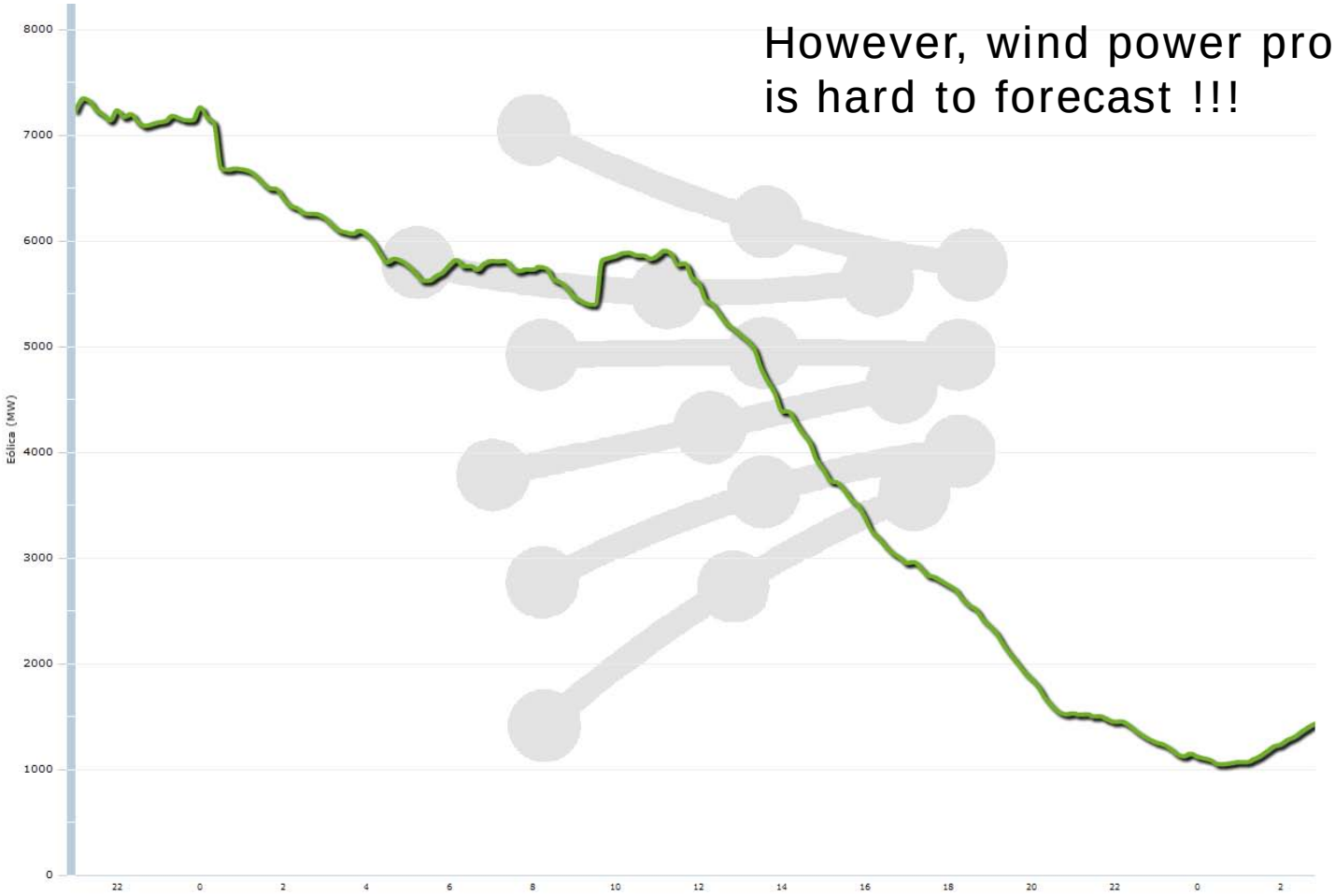
Old/Current electricity market

- What is the problem then?
  - Day-ahead market is cleared once for the 24 hours of the following day.



  - Wind power production need to be forecasted 36 hours in advance

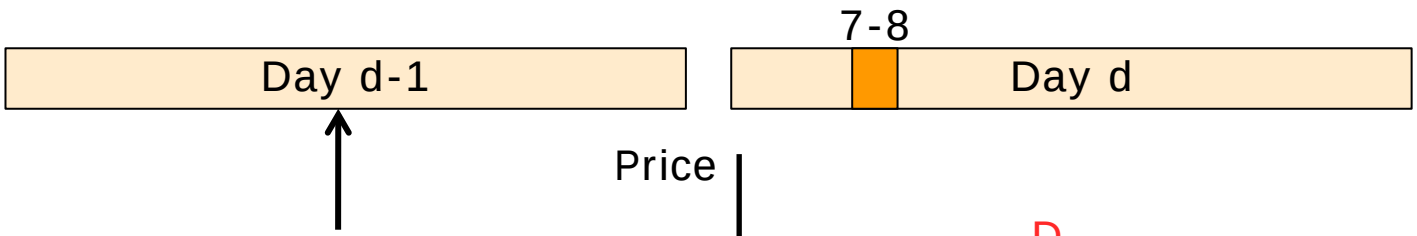
Old/Current electricity market



However, wind power production is hard to forecast !!!

Old/Current electricity market

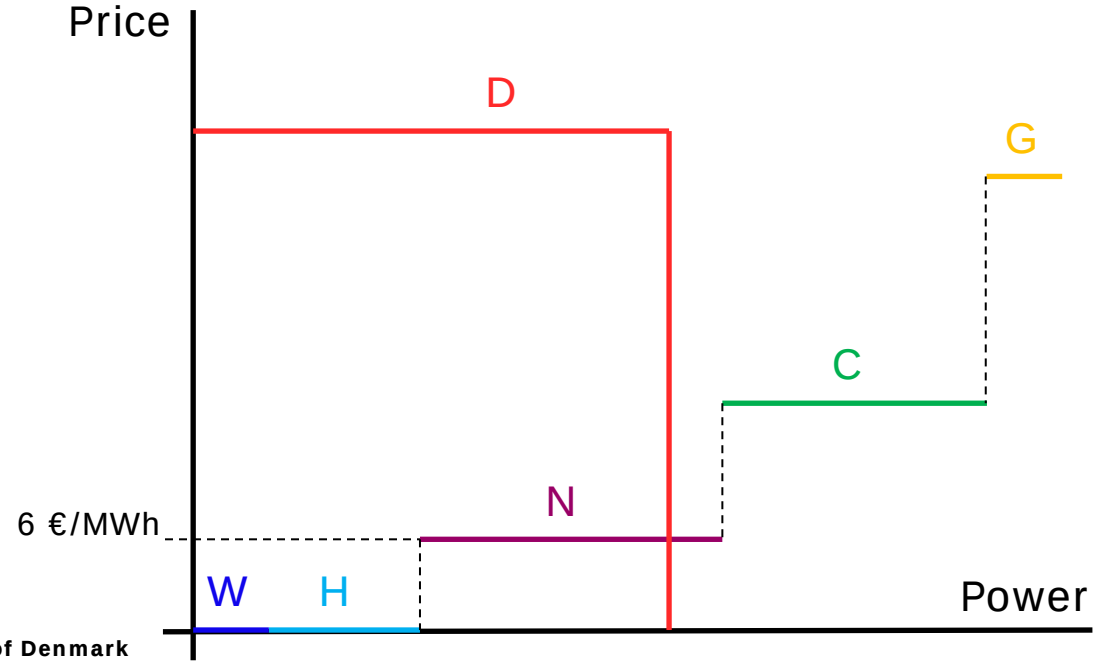
- There exist other market mechanisms to balance wind power production: regulating market.



At 12:00 p.m. the previous day:

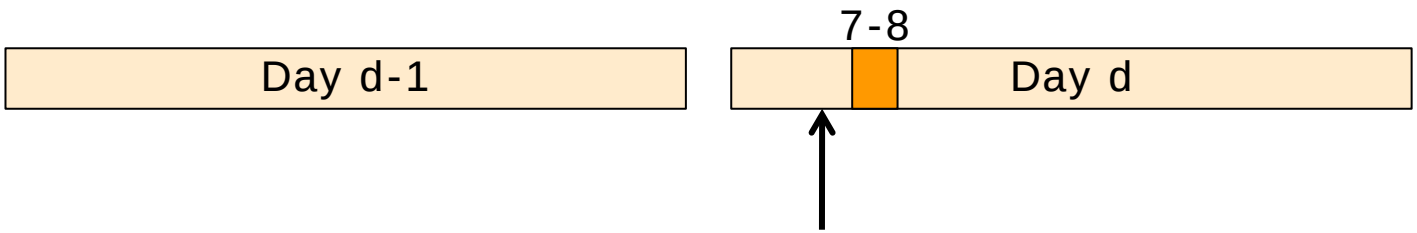
✓ Collect bids for hour 7-8 (wind producers have to forecast their production 20 hours in advance)

✓ Forecast demand at hour 7-8



Old/Current electricity market

- There exist other market mechanisms to balance wind power production: intra-day markets and the balancing market.



At 6:15 a.m. the opeartion day:

✓ Collect bids for hour 7-8 for up and down regulate

Unit	Down
Hydro	200 / 5
Wind	100 / 4
Nuclear	0 / 0
Coal	-
Gas	-

Old/Current electricity market

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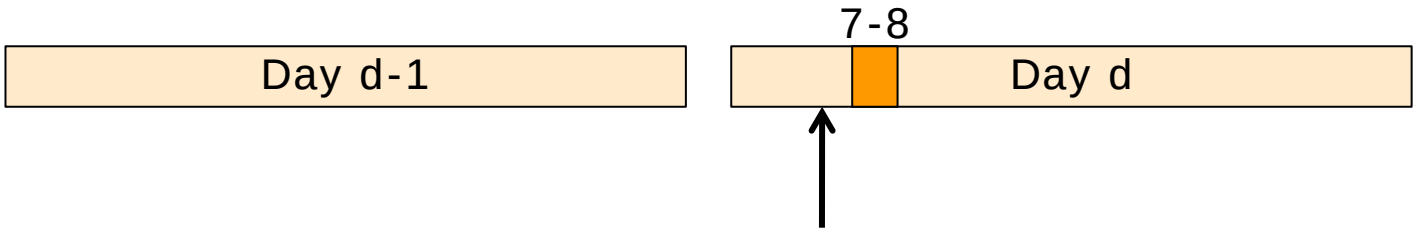

At 6:15 a.m. the operation day:

✓ Collect bids for hour 7-8 for up and down regulate

Unit	Down	Up
Hydro	200 / 5	-
Wind	100 / 4	-
Nuclear	0 / 0	0 / 0
Coal	-	350 / 15
Gas	-	100 / 30

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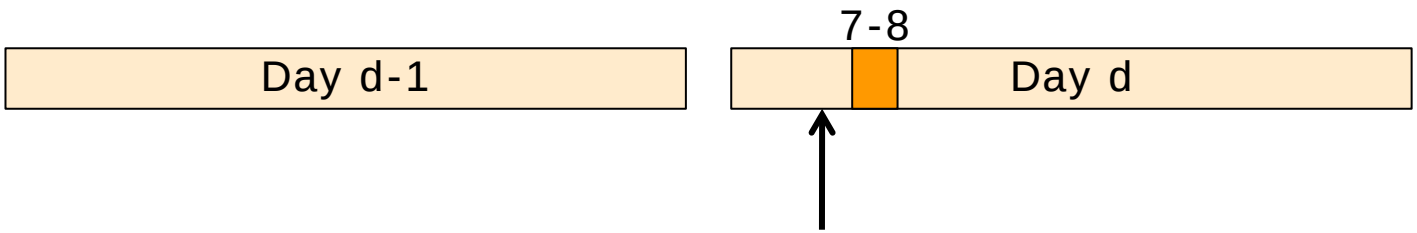

At 6:15 a.m. the operation day:

✓ Collect bids for hour 7-8 for up and down regulate

✓ Update demand forecast (we assume that demand error is 0)

✓ Update wind power production forecast

Unit	Down	Up
Hydro	200 / 5	-
Wind	100 / 4	-
Nuclear	0 / 0	0 / 0
Coal	-	350 / 15
Gas	-	100 / 30

Old / Current electricity market

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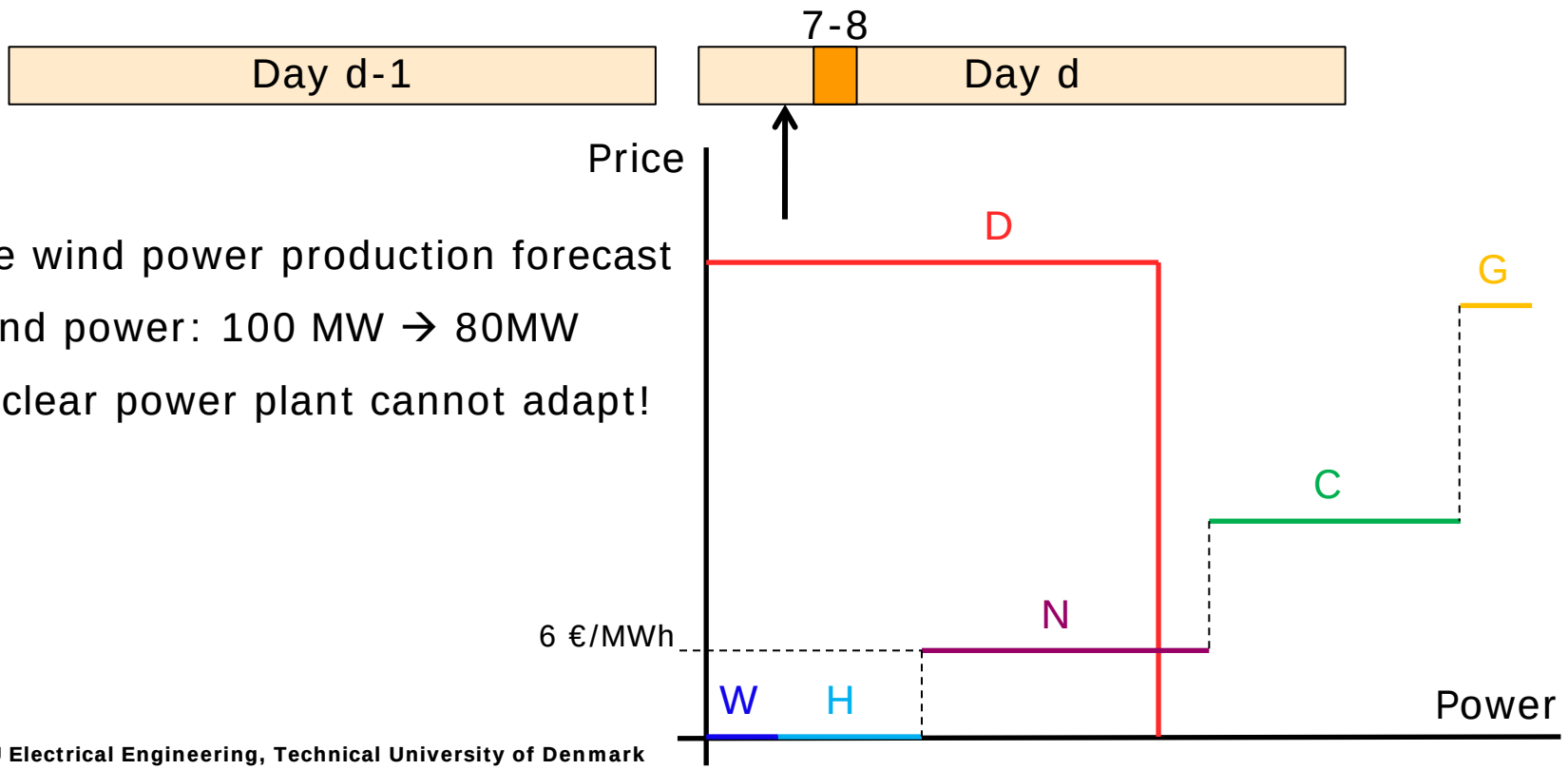

✓ Update wind power production forecast

- Wind power: 100 MW → 80MW
- Nuclear power plant cannot adapt!

Old / Current electricity market

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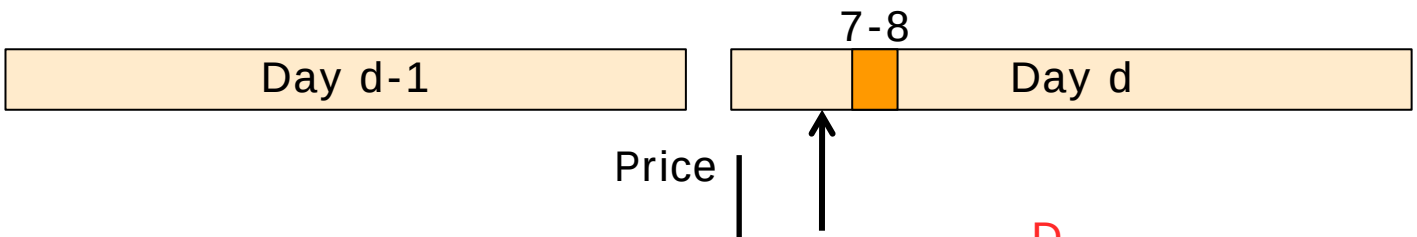
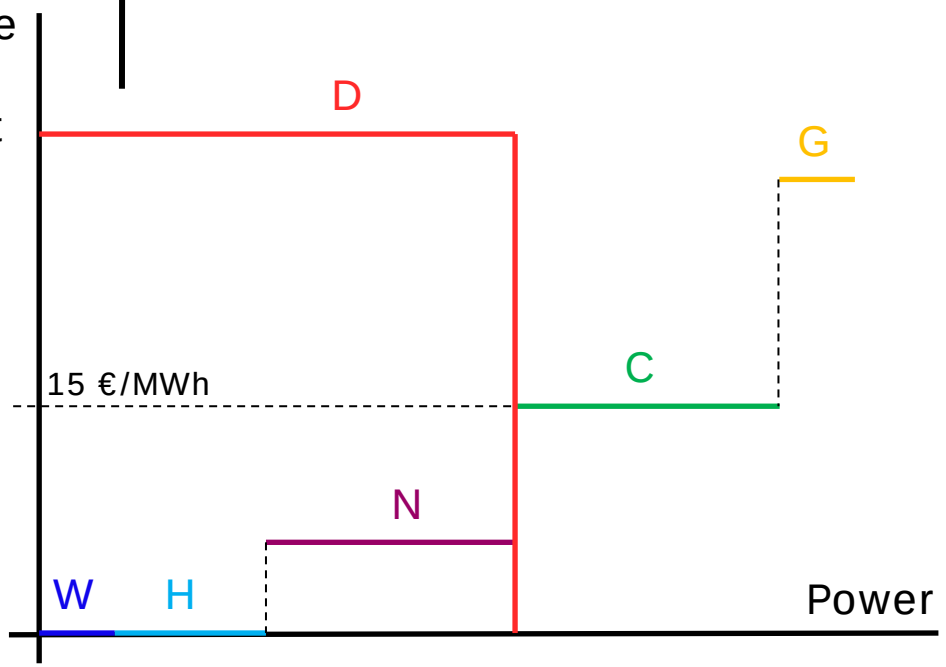


✓ Update wind power production forecast

- Wind power: 100 MW → 80MW
- Nuclear power plant cannot adapt!
- Wind producer has to buy 20 MW at 15€/MWh
- Losses = 20x6 – 20x15 = -180€
- It could be worse!



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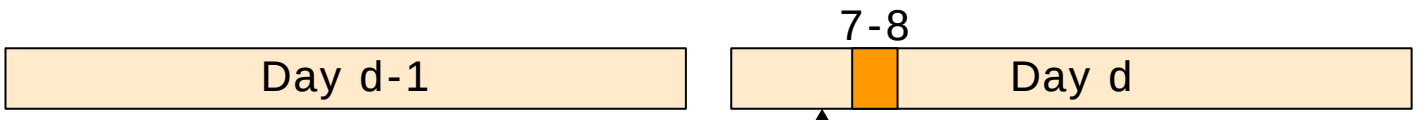

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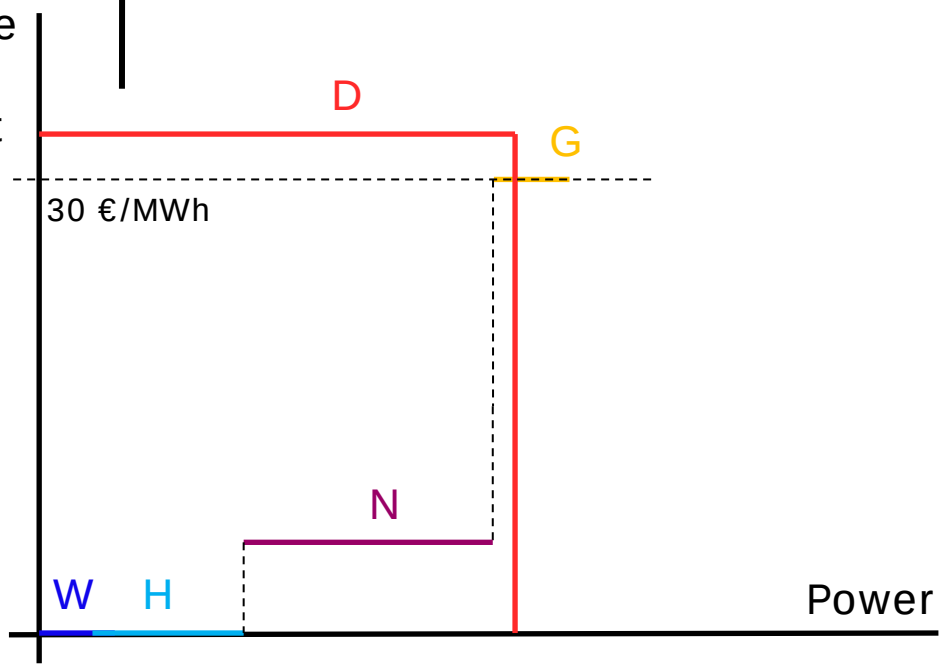

Old / Current electricity market

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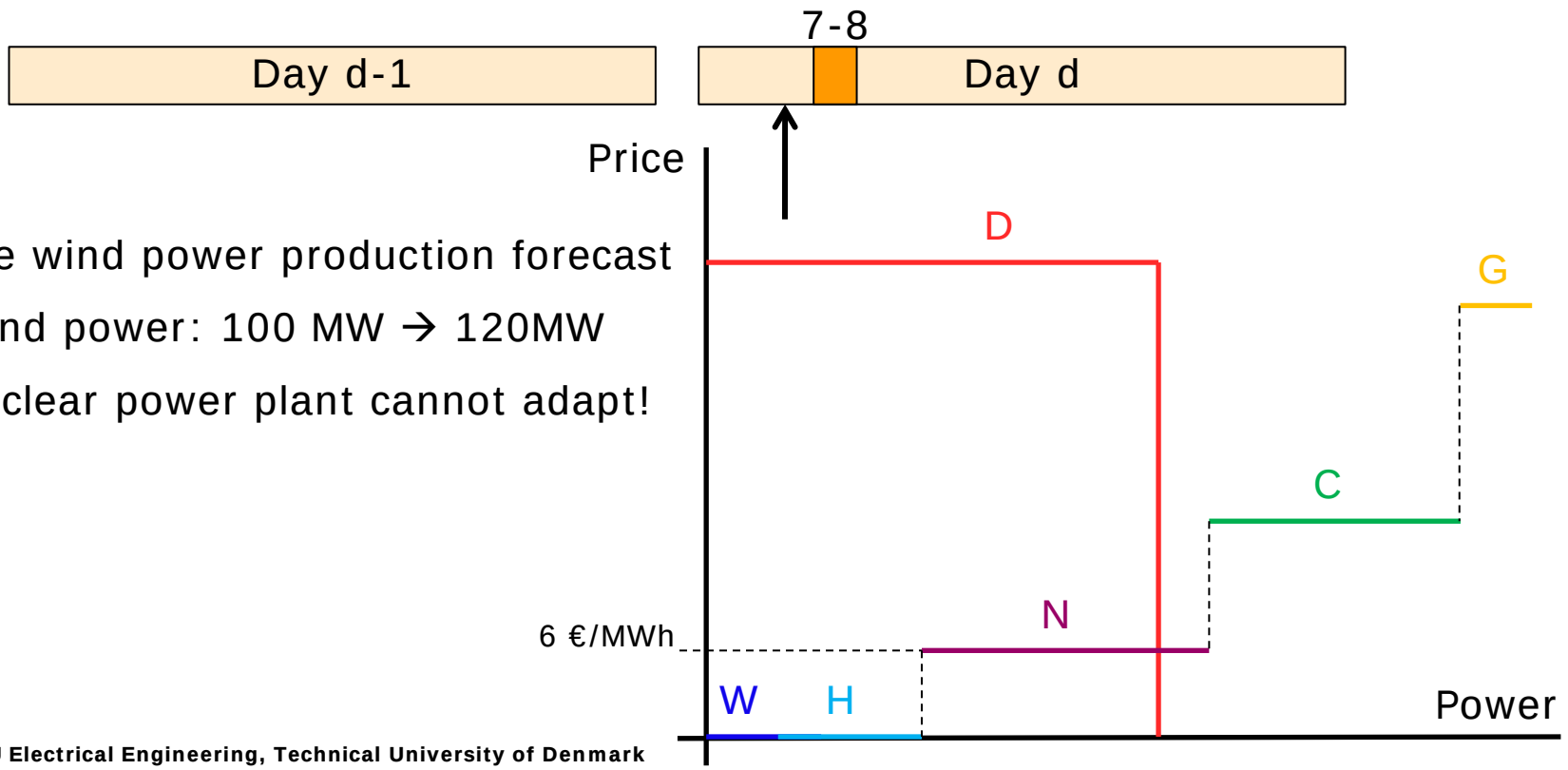
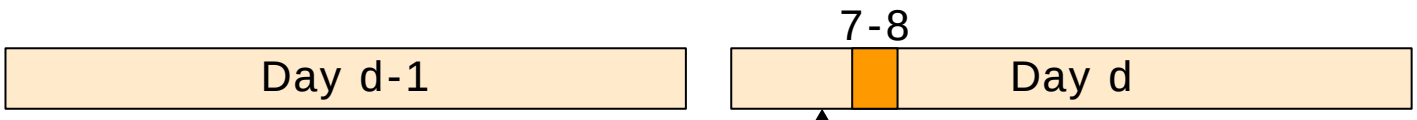


✓ Update wind power production forecast

- Wind power: 100 MW → 120MW
- Nuclear power plant cannot adapt!

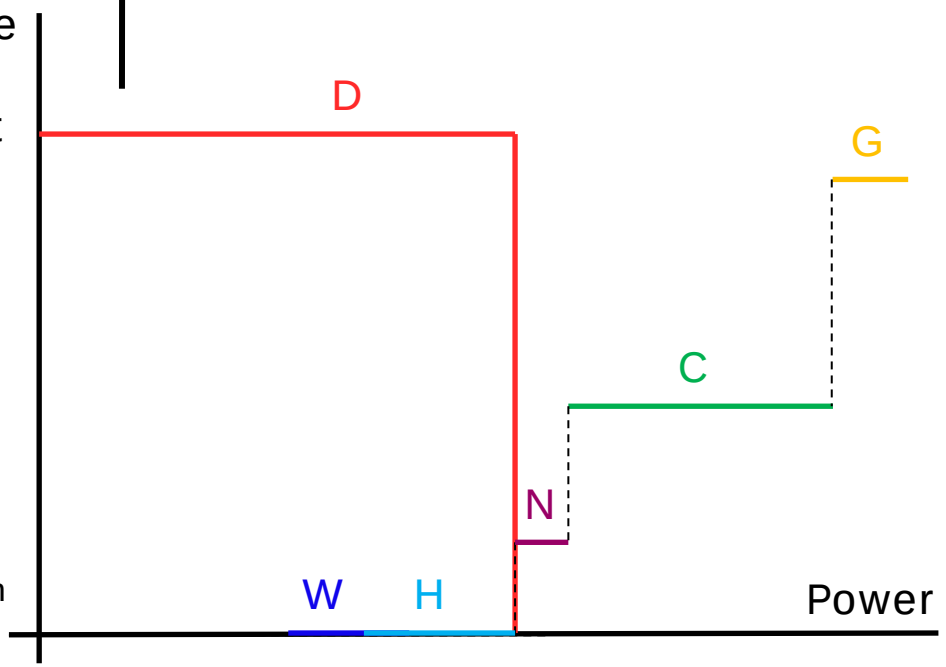
Old / Current electricity market

- There exist other market mechanisms to balance wind power production: intra-day markets and the balancing market.



✓ Update wind power production forecast

- Wind power: 100 MW → 120MW
- Nuclear power plant cannot adapt!
- We reduce hydro power production
- Wind producer is selling the extra 20 MW at 0 €/MWh
- Opportunity cost!



Old/Current electricity market

- Conclusion:
  - ✓ Most electricity is traded through a day-ahead market that is cleared well in advance (usually the day before)
    - This design benefit large and inflexible units since they can efficiently adjust their production levels.
    - This design involves significant losses for producers with uncertain power production.
  - ✓ If the current design is maintained considering the increase of renewable generation:
    - High investment of flexible generation
    - Financial instrument for wind producers to hedge against the price risk in the short-term.
  - ✓ New market designs:

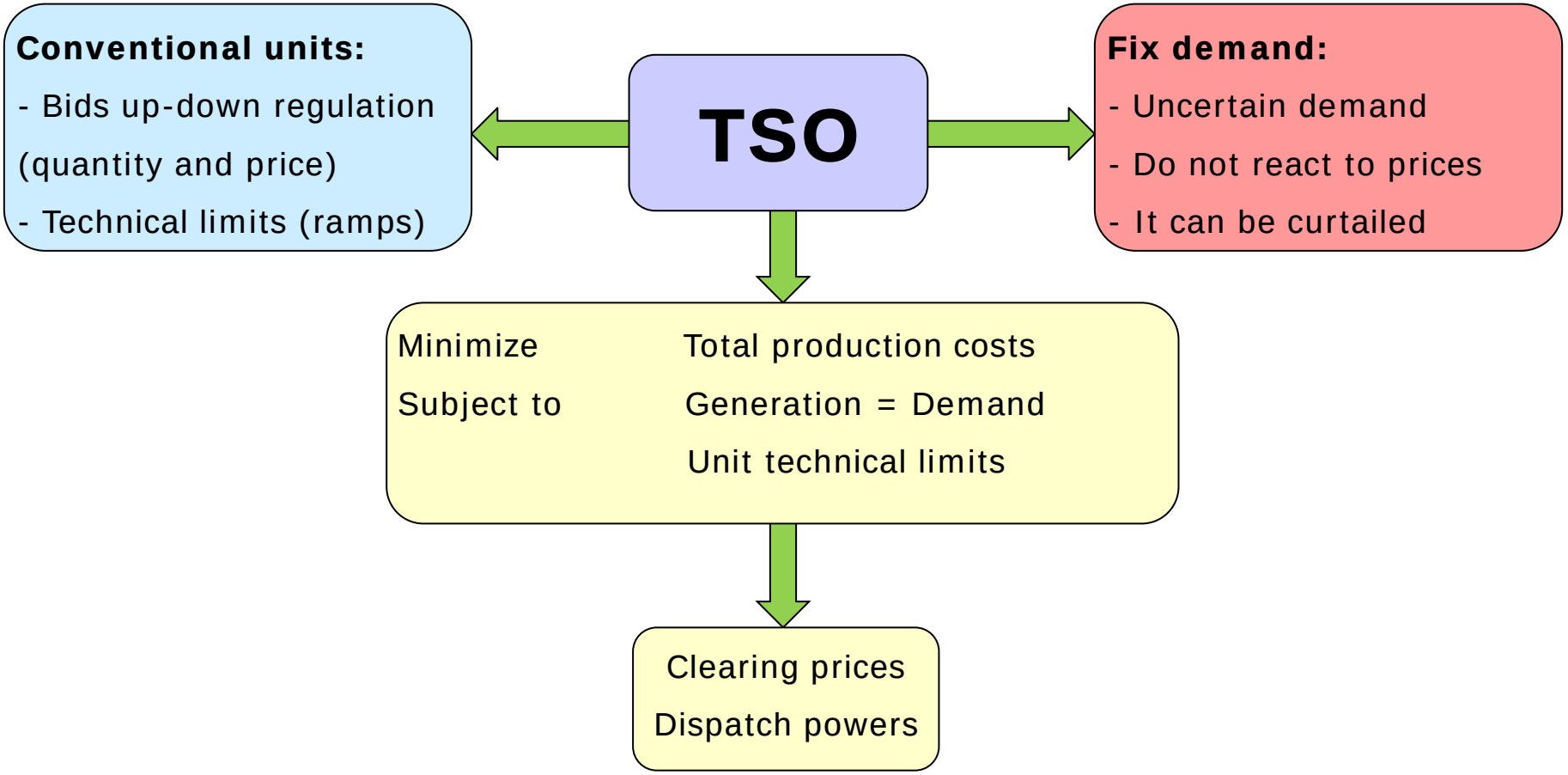
EcoGrid eu
www.eu-ecogrid.net

EcoGrid EU Market Concept

- Motivation:
  - ✓ Balance variation of wind power production (and others) through a simple and transparent market floor.
  - ✓ Facilitate the integration of renewable and small generation units into the power system.
  - ✓ Make use of the flexible demand to balance the system and reduce customers' bill.
- A priori design:
  - ✓ Publish the electricity price every five minutes so that small producers and flexible consumers can react to it.
  - ✓ Simple and transparent: no need for bids to the market. Market agents pay or get pay the EcoGrid EU prices times the power they consume or produce, respectively.

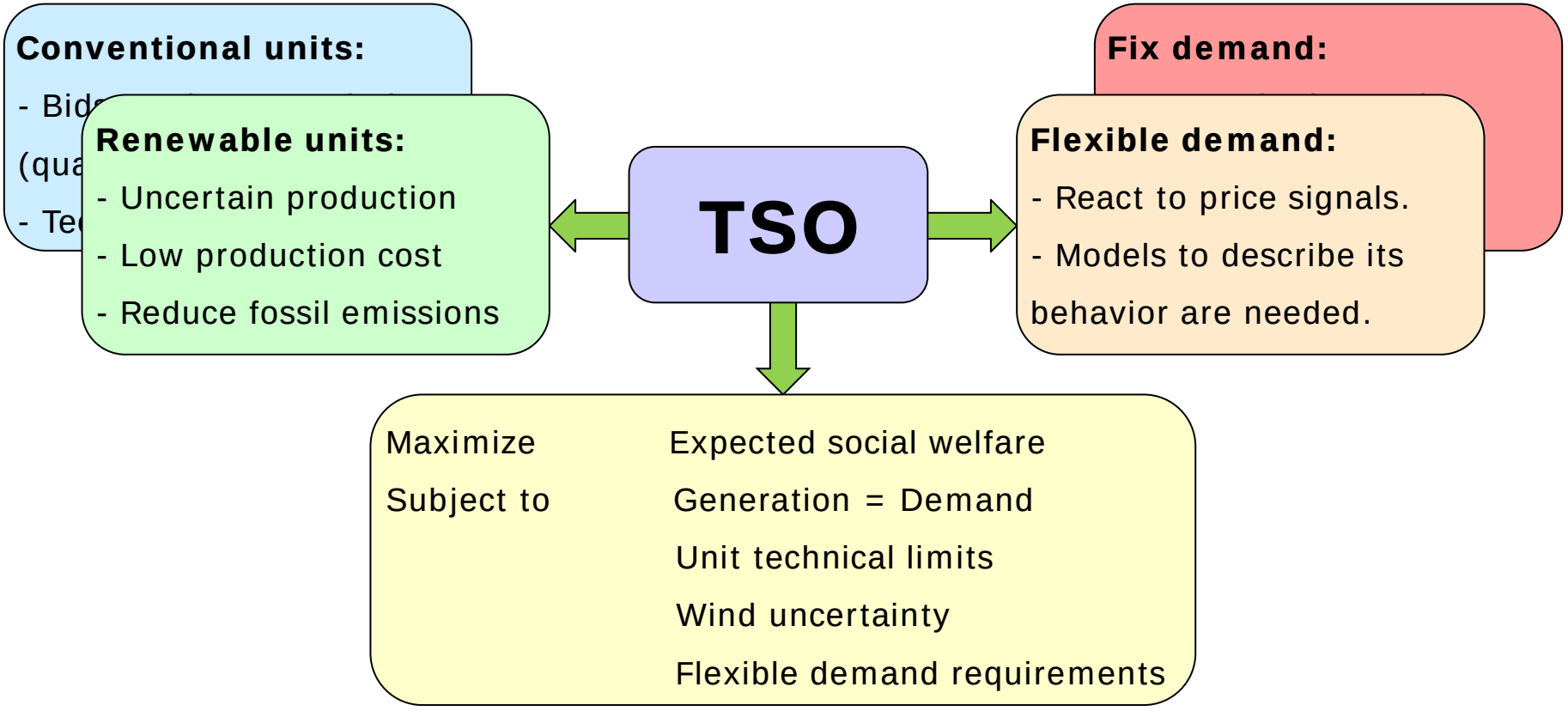
EcoGrid EU Market Concept

- Current market clearing:



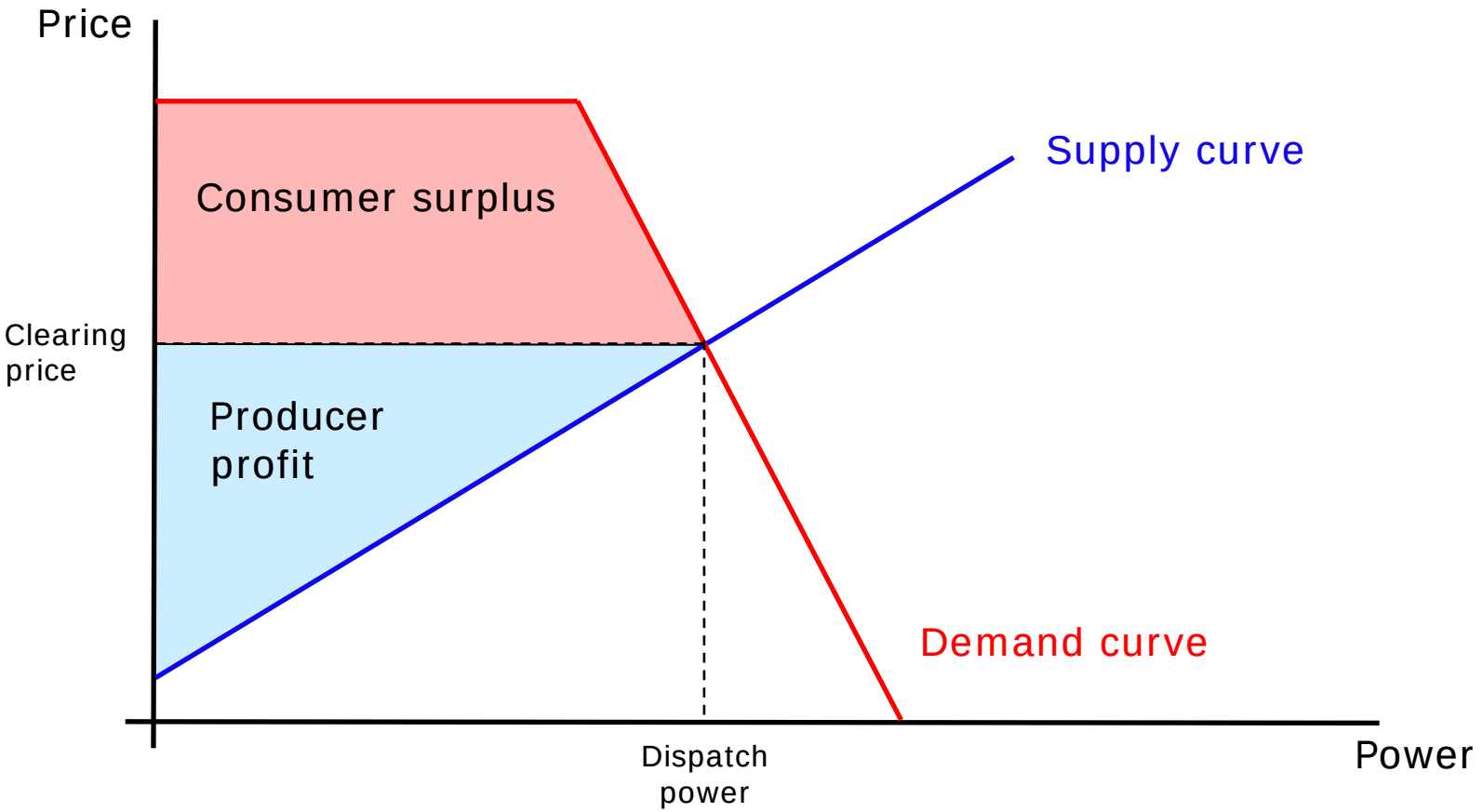
EcoGrid EU Market Concept

- EcoGrid EU concept:



EcoGrid EU Market Concept

- Social welfare:



EcoGrid EU Market Concept

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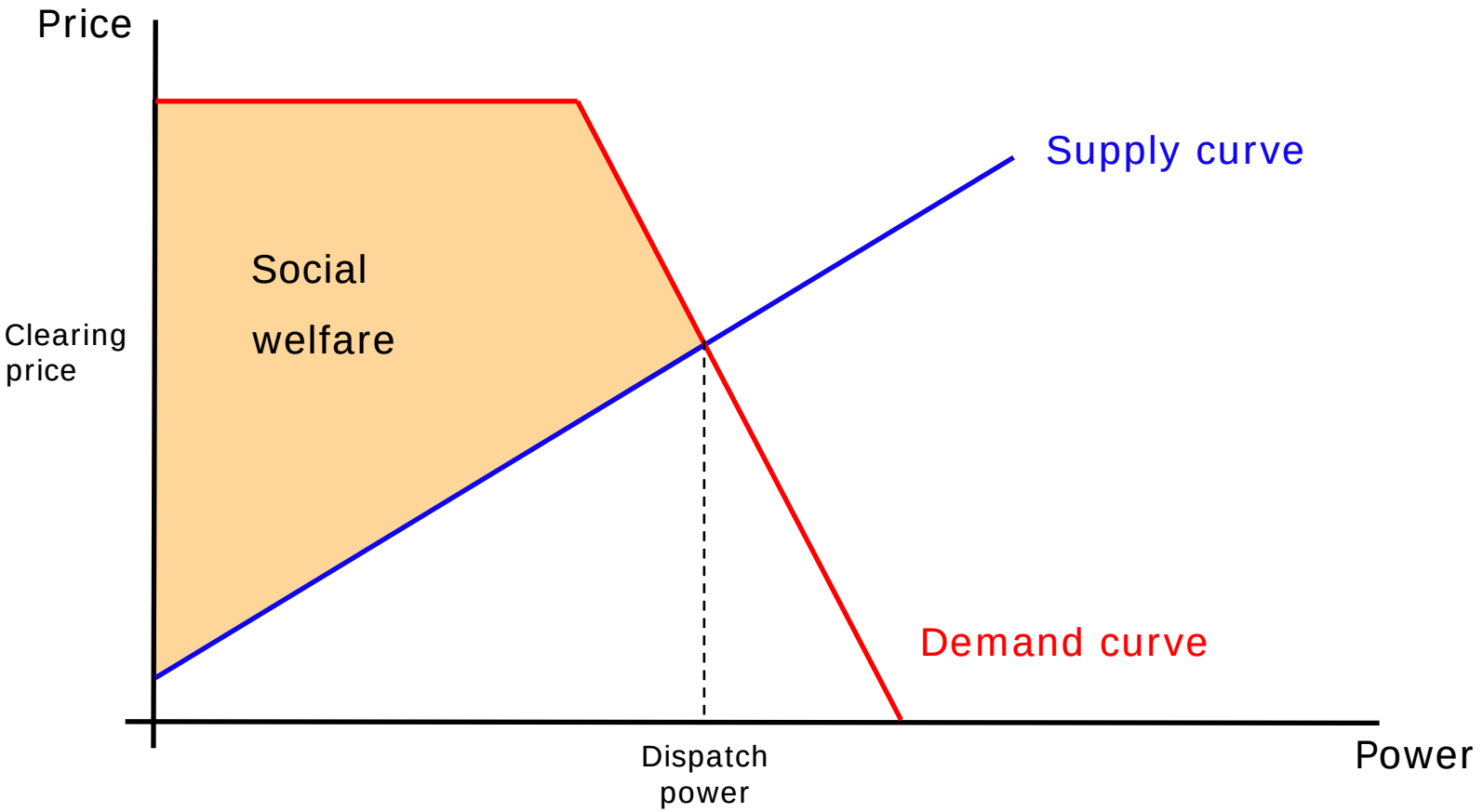
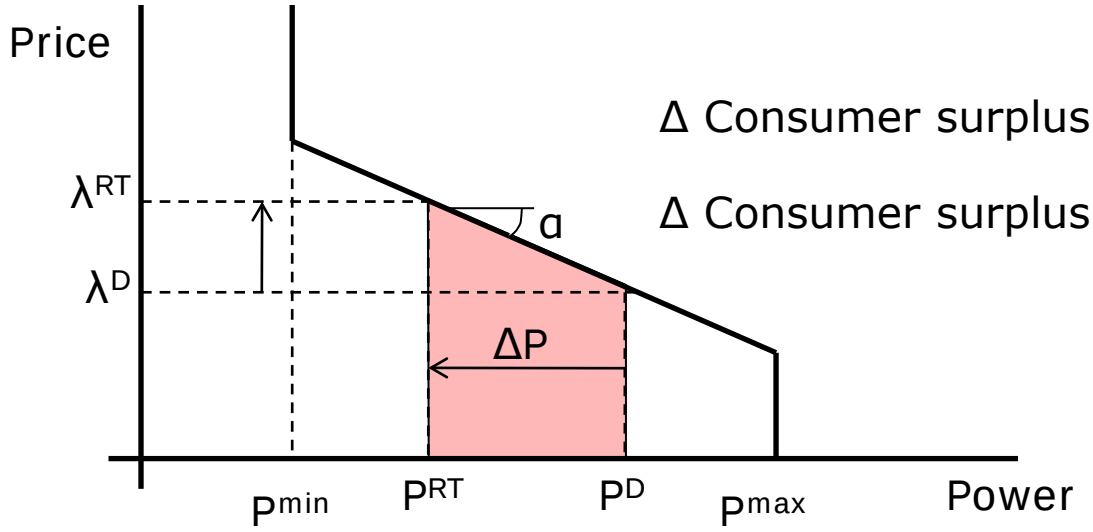


EcoGrid EU Market Concept

- Determining 5-minute prices (known wind production):

Maximize	Δ Consumer surplus – Δ Production cost
Subject to	Generation = Demand
	Unit technical limits
	Flexible demand requirements



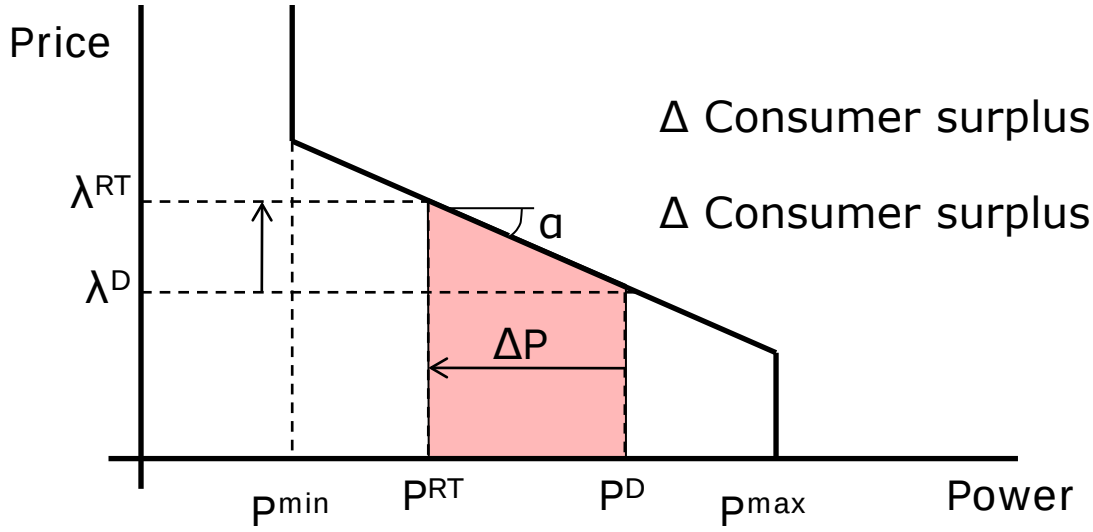
$$\Delta \text{ Consumer surplus} = -\lambda^{D} \cdot \Delta P + 0.5 \cdot \Delta P \cdot (\lambda^{RT} - \lambda^{D})$$

$$\Delta \text{ Consumer surplus} = -\lambda^{D} \cdot \Delta P + 0.5 \cdot \Delta P \cdot \alpha \cdot \Delta P$$

EcoGrid EU Market Concept

- Determining 5-minute prices (known wind production):

Maximize	$\lambda^D \cdot \Delta P^L - 0.5 \cdot \Delta P^L \cdot a \cdot \Delta P^L$ – Δ Production cost
Subject to	Generation = Demand
	Unit technical limits
	Flexible demand requirements



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EcoGrid EU Market Concept

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Subject to	Generation = Demand
	Unit technical limits
	Flexible demand requirements

Each generator:

- Up regulating bids = $P^{UP,max}$, λ^{UP}
- Down regulating bids = $P^{DO,max}$, λ^{DO}

EcoGrid EU Market Concept

- Determining 5-minute prices (known wind production):

Maximize	$\lambda^{D} \cdot \Delta P^{L} - 0.5 \cdot \Delta P^{L} \cdot \alpha \cdot \Delta P^{L} - \lambda^{UP} \cdot P^{UP} + \lambda^{DO} \cdot P^{DO}$
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EcoGrid EU Market Concept

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Subject to	$P^{UP} - P^{DO} + \Delta W = \Delta P^{L}$
	Unit technical limits
	Flexible demand requirements

EcoGrid EU Market Concept

- Determining 5-minute prices (known wind production):

Maximize $\lambda^{D} \cdot \Delta P^{L} - 0.5 \cdot \Delta P^{L} \cdot \alpha \cdot \Delta P^{L} - \lambda^{UP} \cdot P^{UP} + \lambda^{DO} \cdot P^{DO}$

Subject to $P^{UP} - P^{DO} + \Delta W = \Delta P^{L}$

$0 < P^{UP} < P^{UP,max}$ $0 < P^{DO} < P^{DO,max}$ RAMPS!!!!!

Flexible demand requirements

EcoGrid EU Market Concept

- Determining 5-minute prices (known wind production):

Maximize $\lambda^{D} \cdot \Delta P^{L} - 0.5 \cdot \Delta P^{L} \cdot a \cdot \Delta P^{L} - \lambda^{UP} \cdot P^{UP} + \lambda^{DO} \cdot P^{DO}$

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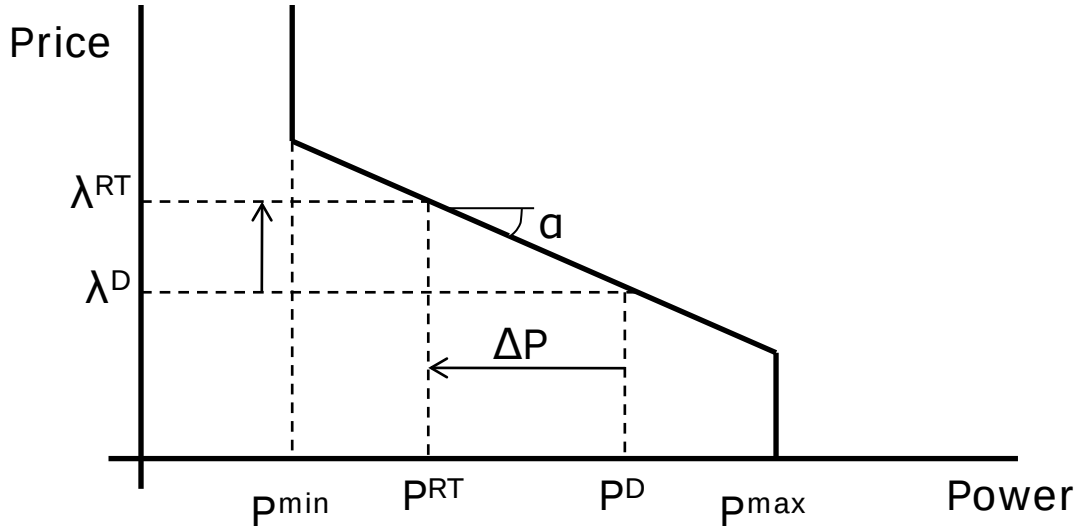
Flexible demand requirements



EcoGrid EU Market Concept

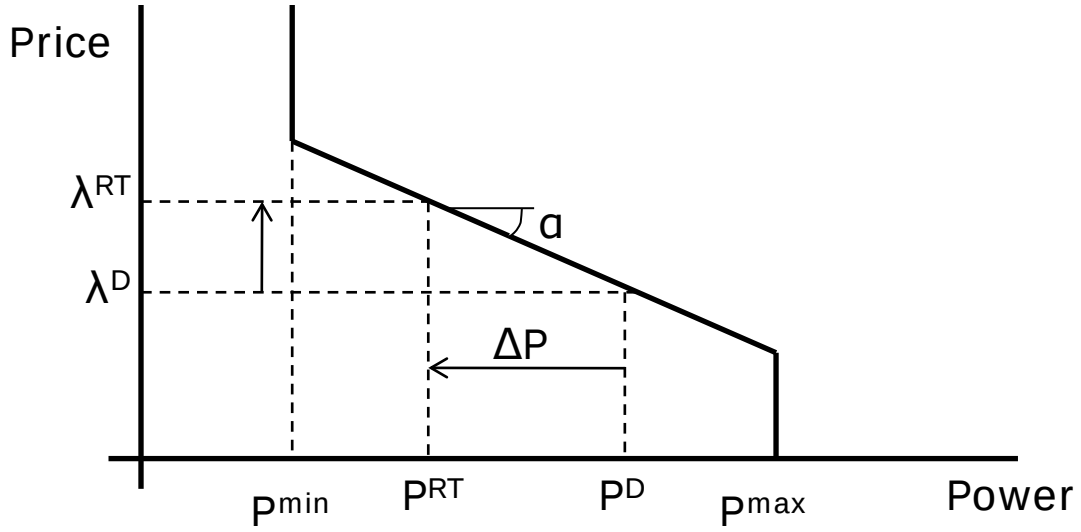
- Determining 5-minute prices (known wind production):

Maximize $\lambda^{D} \cdot \Delta P^{L} - 0.5 \cdot \Delta P^{L} \cdot a \cdot \Delta P^{L} - \lambda^{UP} \cdot P^{UP} + \lambda^{DO} \cdot P^{DO}$

Subject to $P^{UP} - P^{DO} + \Delta W = \Delta P^{L}$

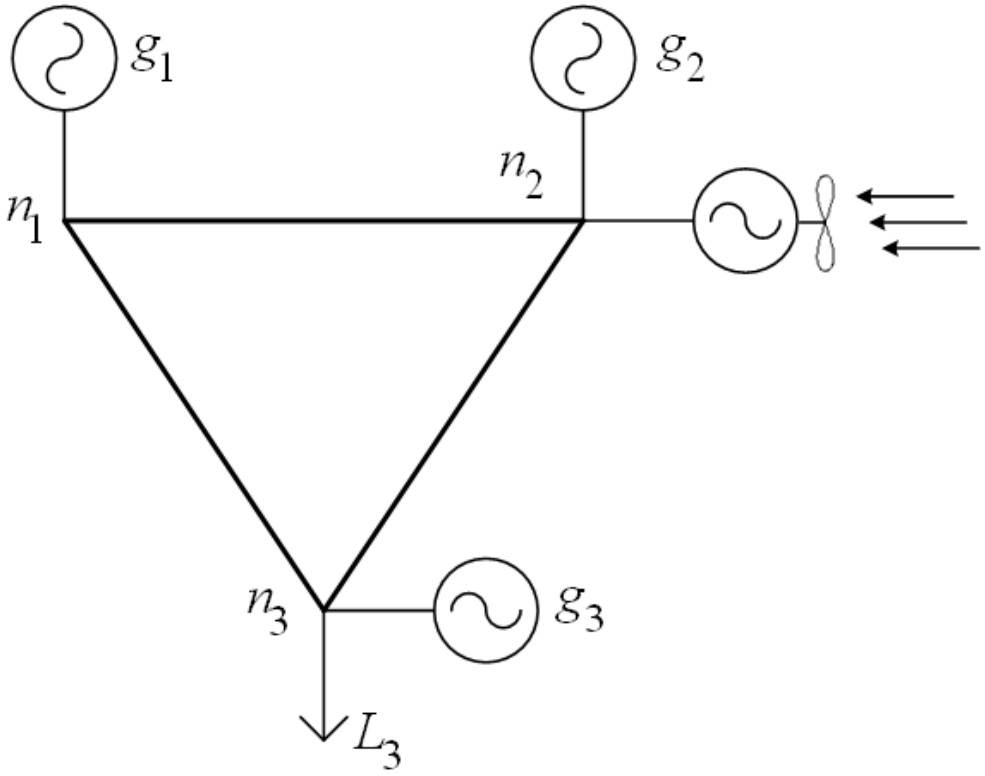
$0 < P^{UP} < P^{UP,max}$ $\quad 0 < P^{DO} < P^{DO,max}$ RAMPS!!!!!

$a \cdot \Delta P^{L} = \lambda^{D} - \lambda^{RT}$ $\quad P^{min} < P^{D} + \Delta P < P^{max}$



EcoGrid EU Market Concept

- Example (known wind production):



EcoGrid EU Market Concept

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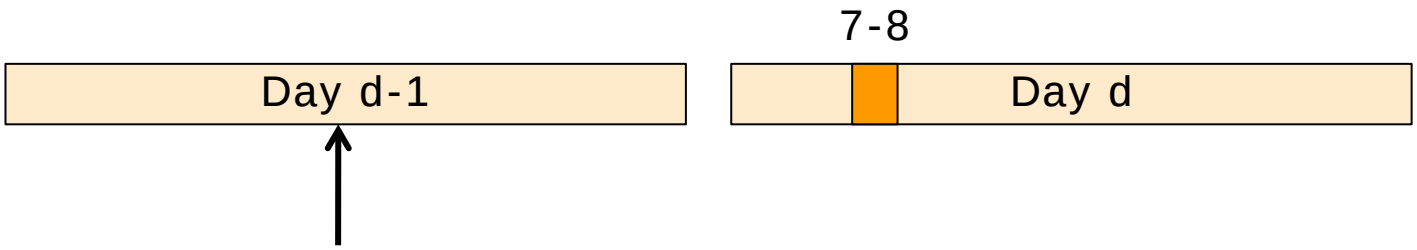
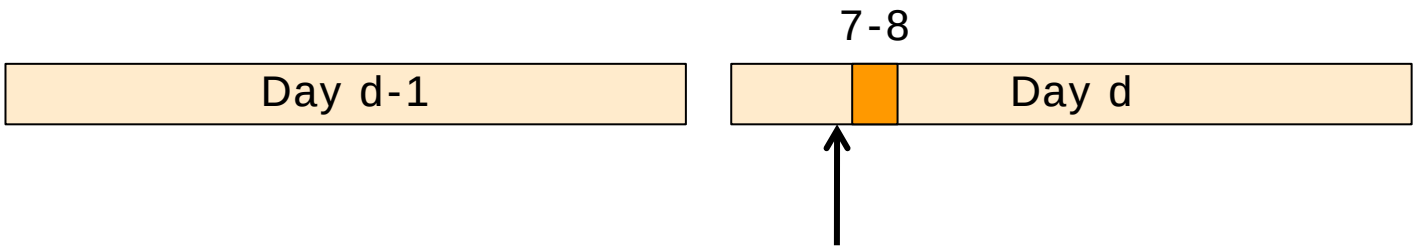


Day-ahead outcome (obtained 24 hours before):

- Unit g1 → 150 MW
- Unit g2 → 100 MW
- Unit g3 → 100 MW
- Wind forecast → 100 MW
- Load → 450 MW
- Day-ahead price → 22€/MWh

EcoGrid EU Market Concept

- Example (known wind production):

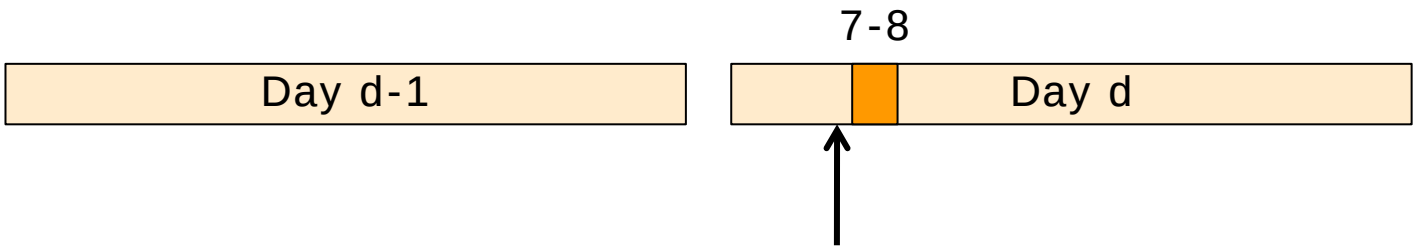


Regulating bids (collected 45 minutes before):

Unit	P^{D}	UR	DR	λ^{UP}	$P^{UP,max}$	λ^{DO}	$P^{DO,max}$
g1	150	3	3	23	10	20	10
g2	100	5	5	25	20	18	20
g3	100	10	10	27	30	16	30

EcoGrid EU Market Concept

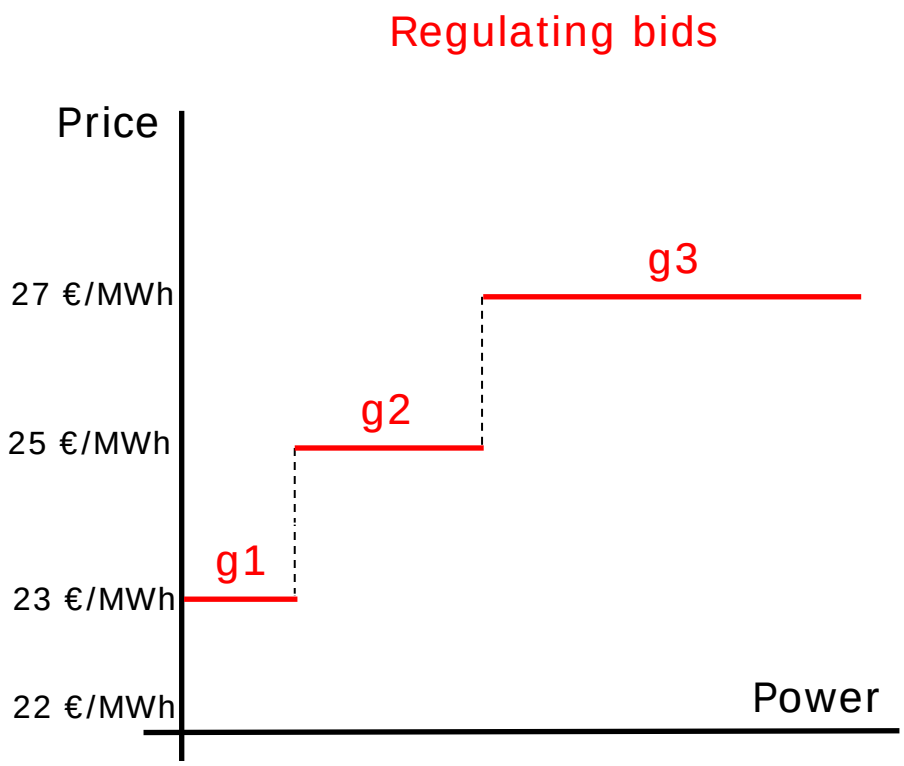
- Example (known wind production):

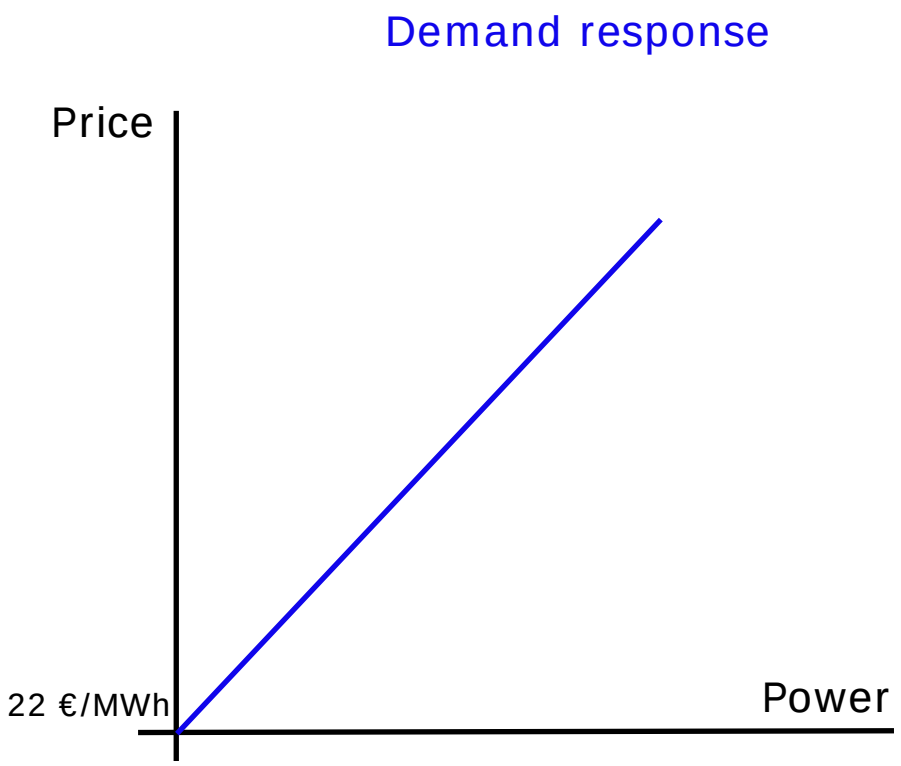


Demand modeling:

- Unflexible demand = $(1-\beta)\cdot 450$
- Flexible demand = $\beta \cdot 450$
  - $P^{min} = 0.7 \cdot \beta \cdot 450$
  - $P^{max} = 1.3 \cdot \beta \cdot 450$
  - $\beta = 0.1$ (only 10% of flexible demand)
  - $\alpha = 0.5$

EcoGrid EU Market Concept





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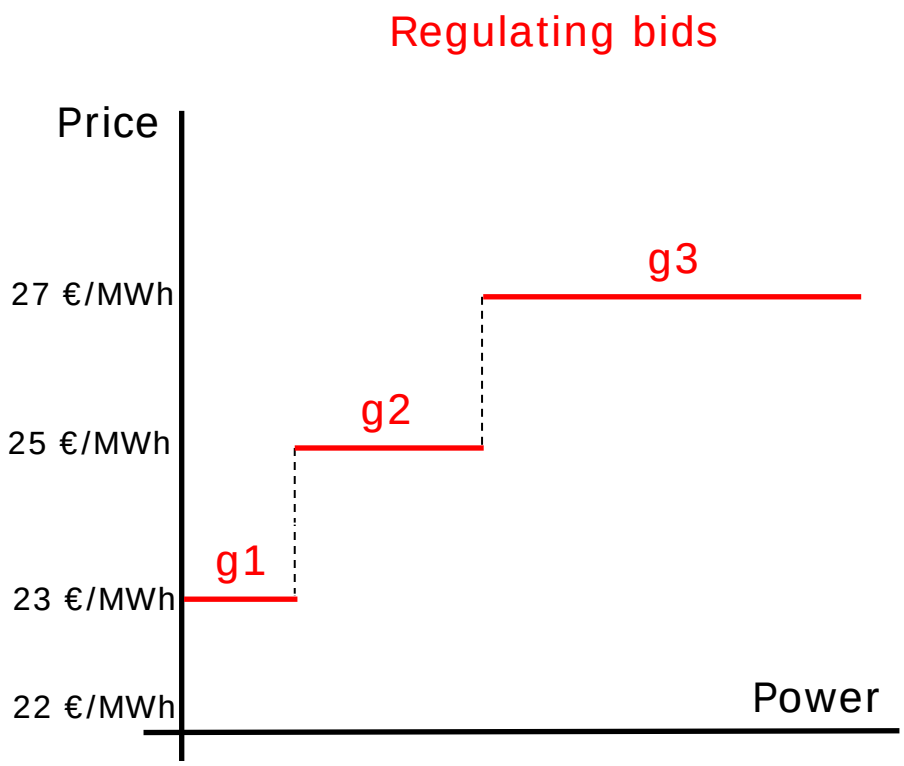
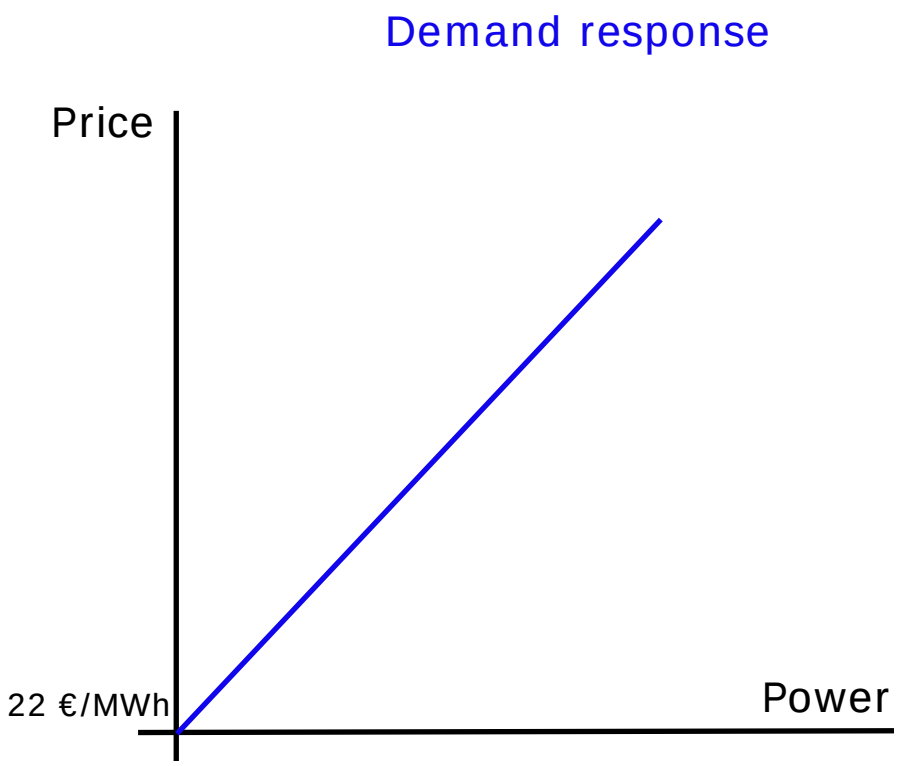
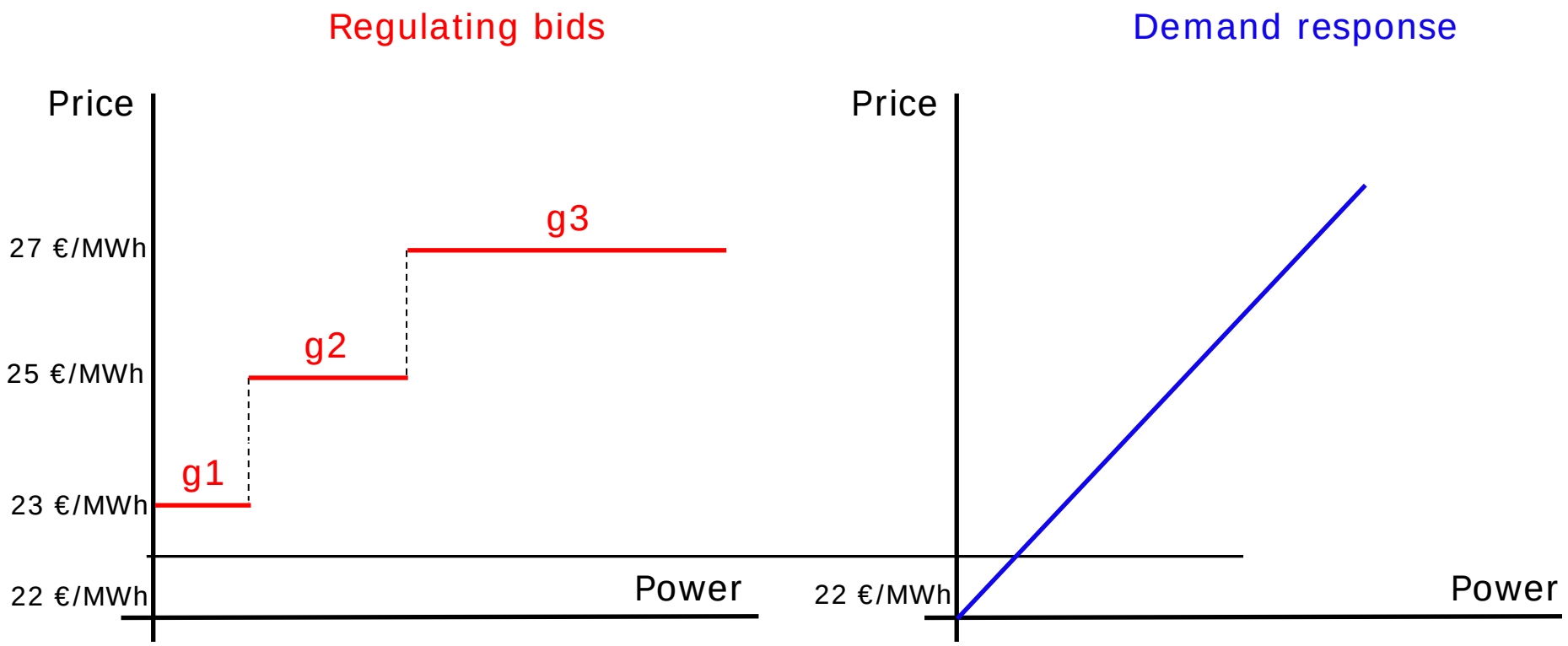




Wind production is equal to the expected one, that is, 100 MW

Real-time price = Day-ahead price

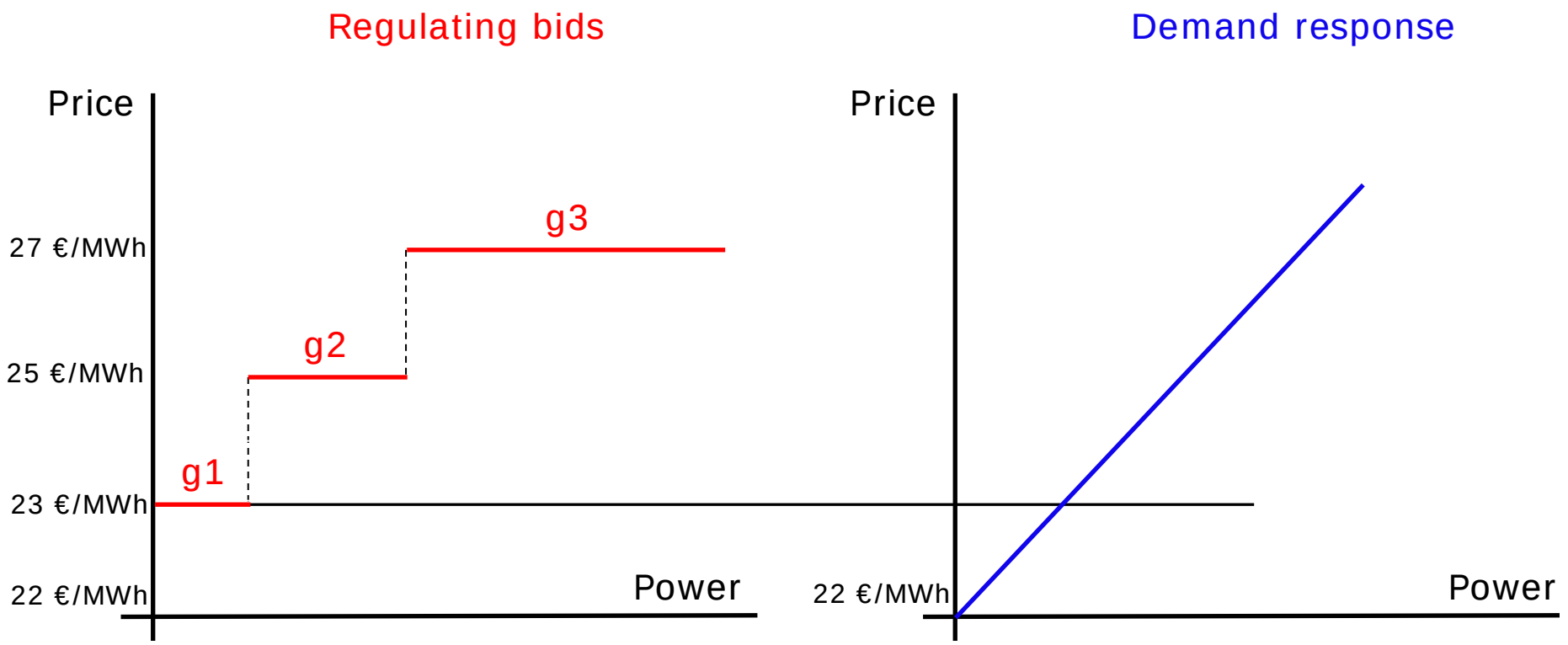
EcoGrid EU Market Concept



Wind production is 1 MW lower than expected, that is, 99 MW

$0.5 \cdot (-1) = 22 - \lambda^{RT} \rightarrow \lambda^{RT} = 22.5$ €/MWh

EcoGrid EU Market Concept

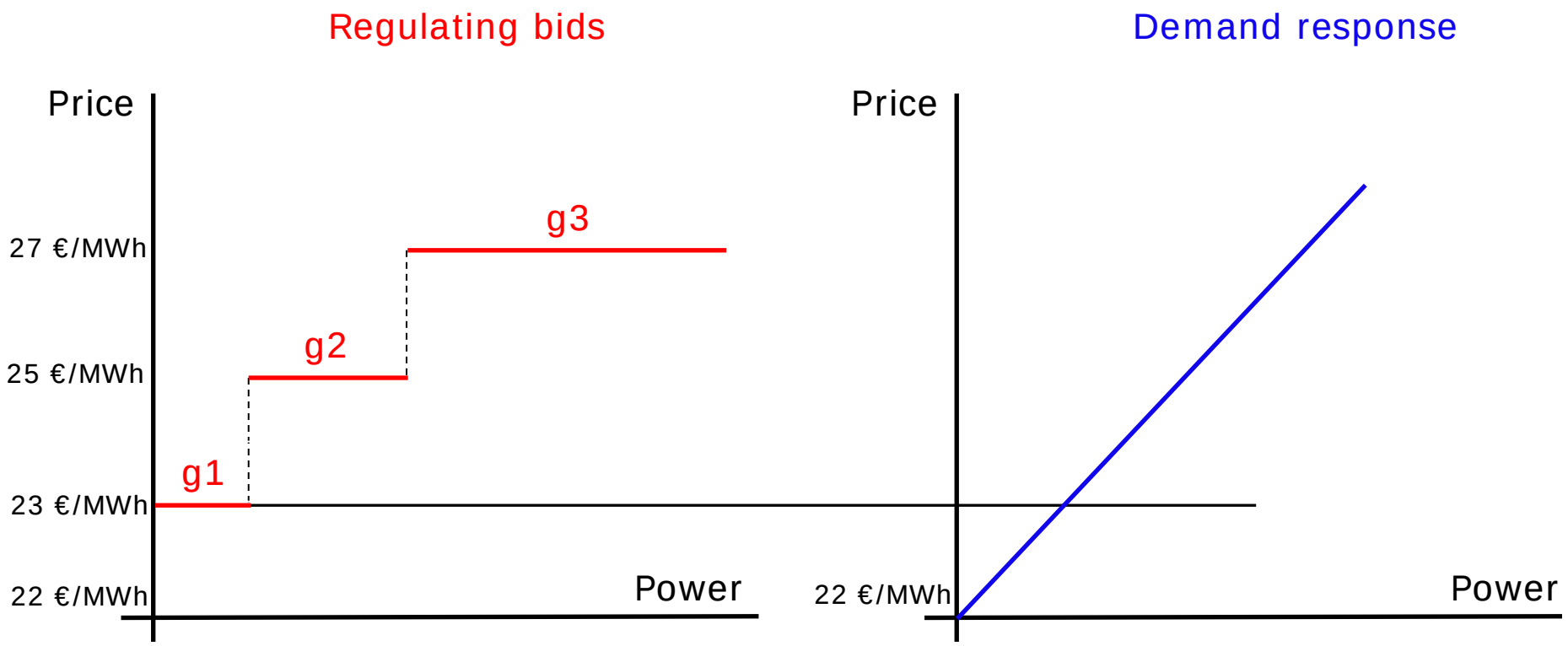


Wind production is 3 MW lower than expected, that is, 97 MW

~~$0.5 \cdot (-3) = 22 - \lambda^{RT} \rightarrow \lambda^{RT} = 23.5$ €/MWh~~

$\lambda^{RT} = 23$ €/MWh → $\Delta P^{L} = -2$MW & $P^{UP} = 1$ MW

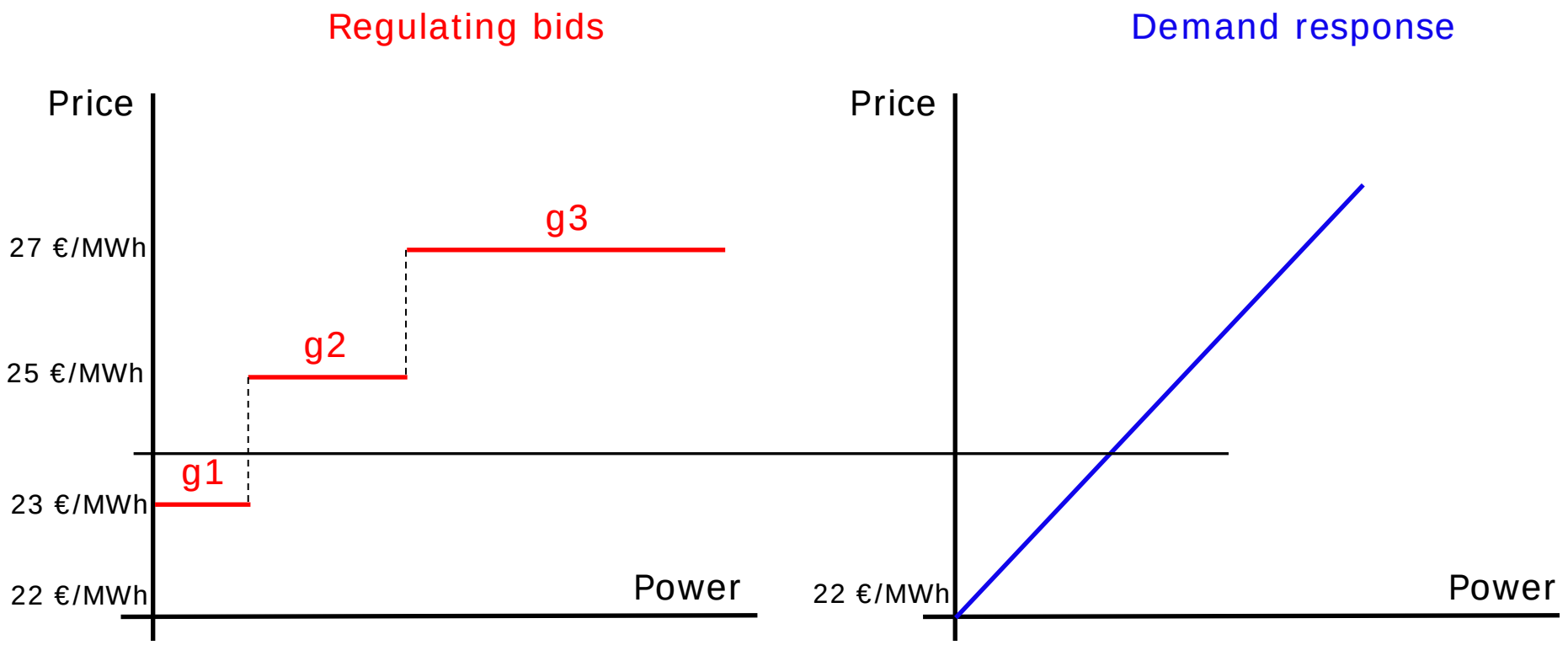
EcoGrid EU Market Concept



Wind production is 5 MW lower than expected, that is, 95 MW

λ^{RT} = 23 €/MWh → ΔP^{L} = -2MW & P^{UP} = 3 MW

EcoGrid EU Market Concept



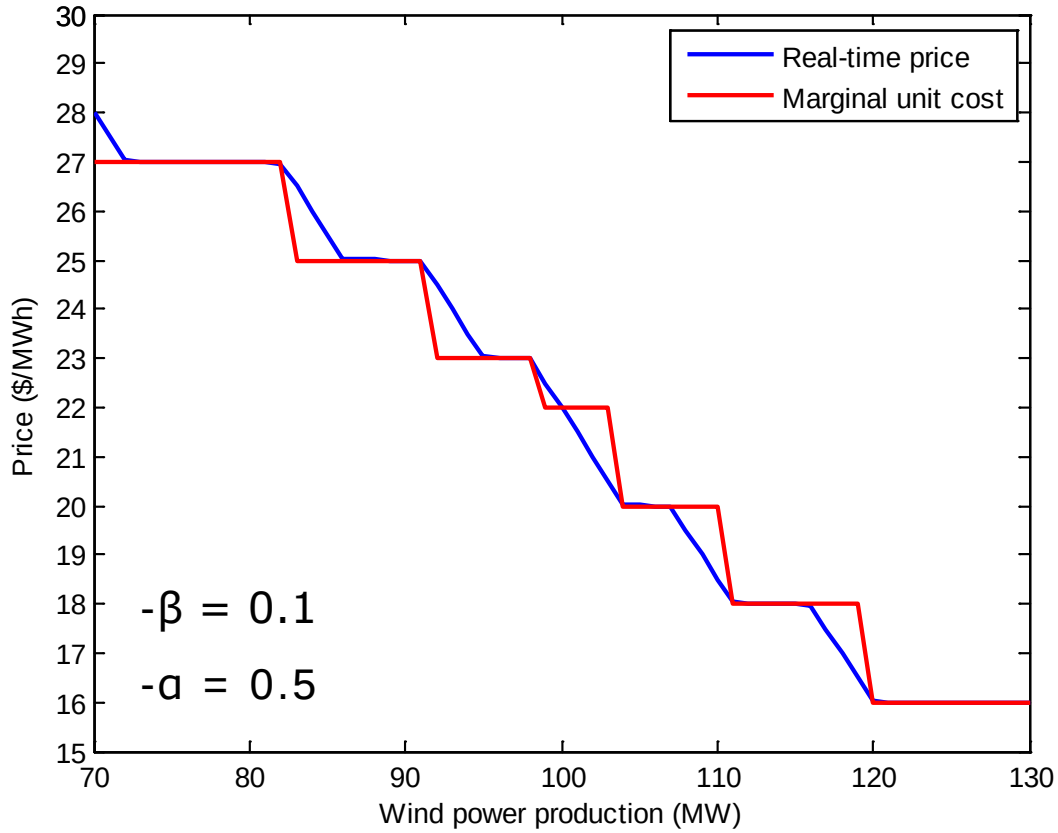
Wind production is 7 MW lower than expected, that is, 93 MW

~~λ^{RT} = 23 €/MWh → ΔP^{L} = -2MW & P^{UP} = 5 MW~~

P^{UP} = 3 MW & λ^{RT} = 24 €/MWh → ΔP^{L} = -4MW

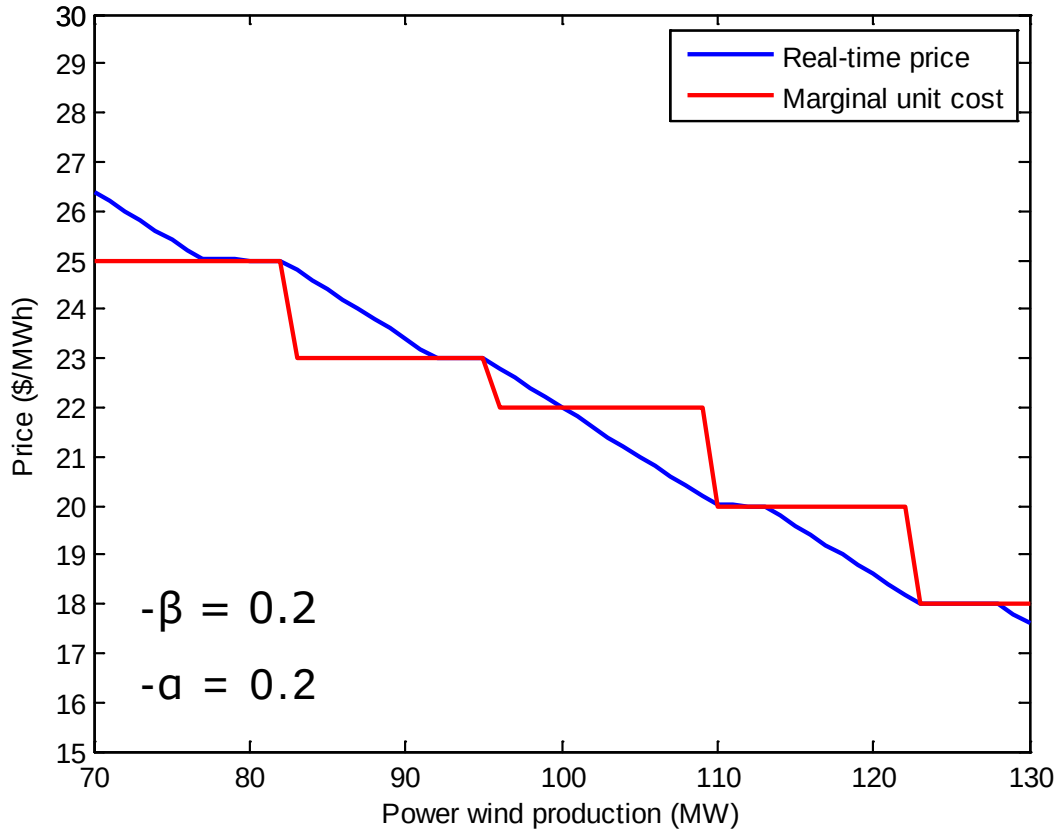
EcoGrid EU Market Concept

- Example (known wind production):



EcoGrid EU Market Concept

- Example (known wind production):



EcoGrid EU Market Concept

- Determining 5-minute prices (**uncertain** wind production):

Maximize $\lambda^{D} \cdot \Delta P^{L} - 0.5 \cdot \Delta P^{L} \cdot \alpha \cdot \Delta P^{L} - \lambda^{UP} \cdot P^{UP} + \lambda^{DO} \cdot P^{DO}$

Subject to $P^{UP} - P^{DO} + \Delta W = \Delta P^{L}$

$0 < P^{UP} < P^{UP,max}$ $\quad 0 < P^{DO} < P^{DO,max}$ $\quad$ RAMPS!!!!!

$\alpha \cdot \Delta P^{L} = \lambda^{D} - \lambda^{RT}$ $\quad P^{min} < P^{D} + \Delta P < P^{max}$

Scenario	t1	t2	t3	t4	t5
s1	100	80	90	60	70
s2	100	120	110	140	130

Probability s1 = $1 - \chi$

Probability s2 = χ

EcoGrid EU Market Concept

- Determining 5-minute prices (**uncertain** wind production):

Maximize $\quad \text{Expected}\ (\lambda^{D} \cdot \Delta P^{L} - 0.5 \cdot \Delta P^{L} \cdot \alpha \cdot \Delta P^{L} - \lambda^{UP} \cdot P^{UP} + \lambda^{DO} \cdot P^{DO})$

Subject to $\quad P^{UP} - P^{DO} + \Delta W = \Delta P^{L}$

$0 < P^{UP} < P^{UP,max} \qquad 0 < P^{DO} < P^{DO,max} \qquad$ RAMPS!!!!!

$\alpha \cdot \Delta P^{L} = \lambda^{D} - \lambda^{RT} \qquad P^{min} < P^{D} + \Delta P < P^{max}$

Scenario	t1	t2	t3	t4	t5
s1	100	80	90	60	70
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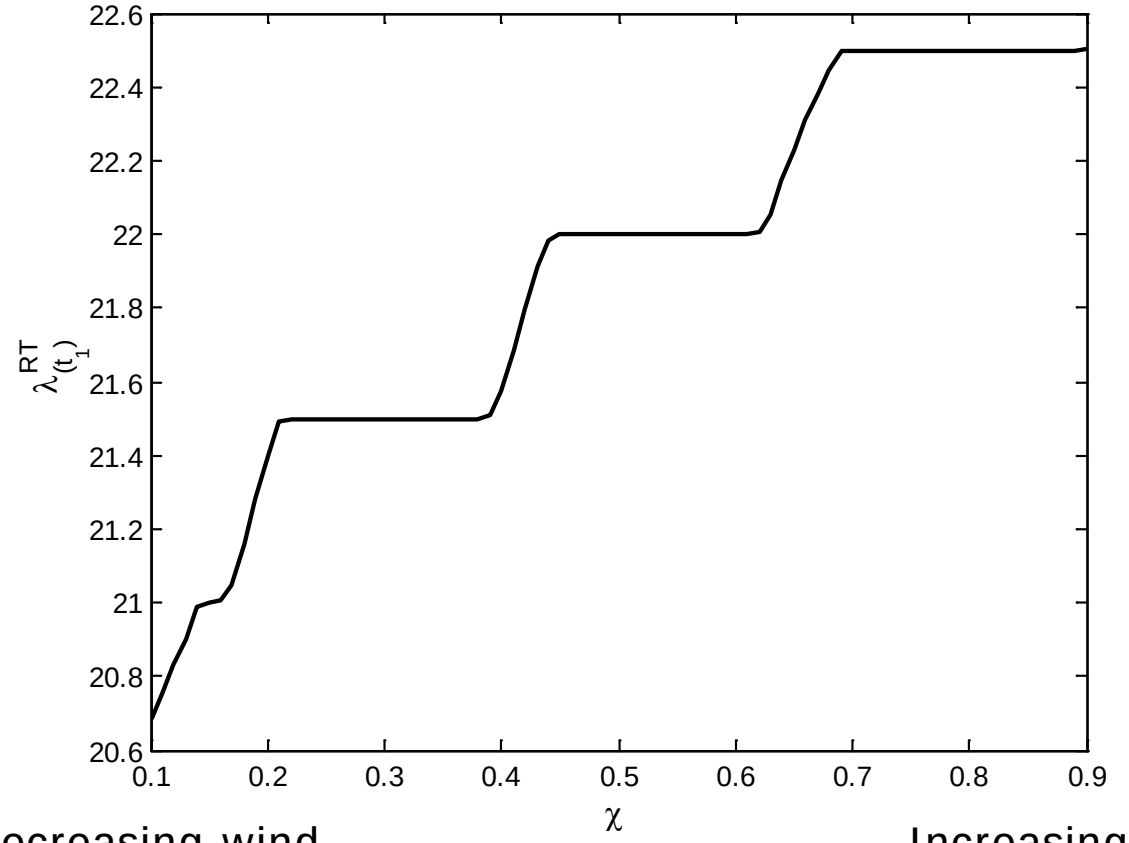
EcoGrid EU Market Concept

- Example (**uncertain** wind production):

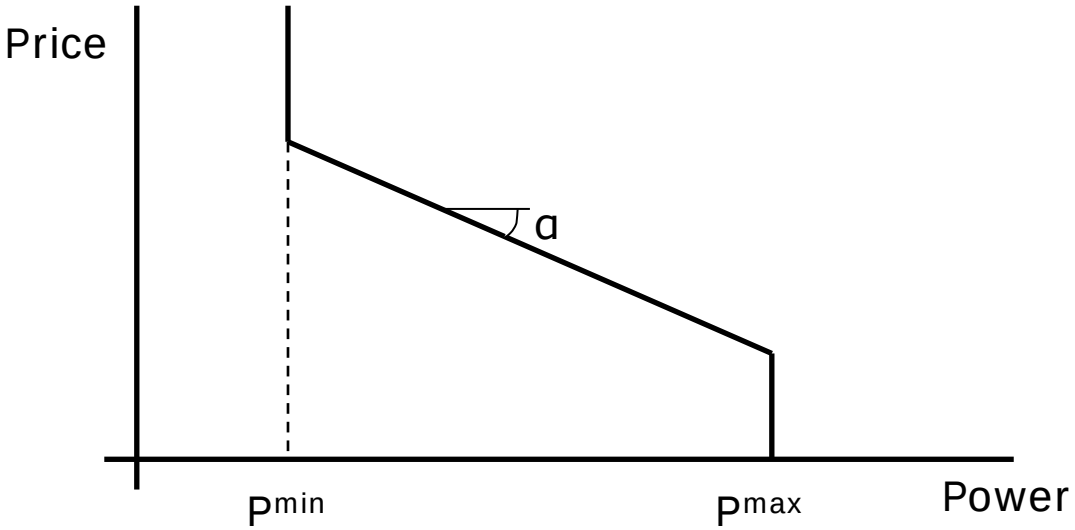


Decreasing wind

Increasing wind

EcoGrid EU Market Concept

- Theoretical issues: demand response modeling



It not so simple!!!!

- Demand response curve vary throughout time (one curve for each time period)

- Demand response curve is not totally known (scenarios characterizing uncertainty)

- Dynamic behavior of demand. Demand response curve for the next 5 minutes depends on the price we send right now to consumers. (suggestions???)

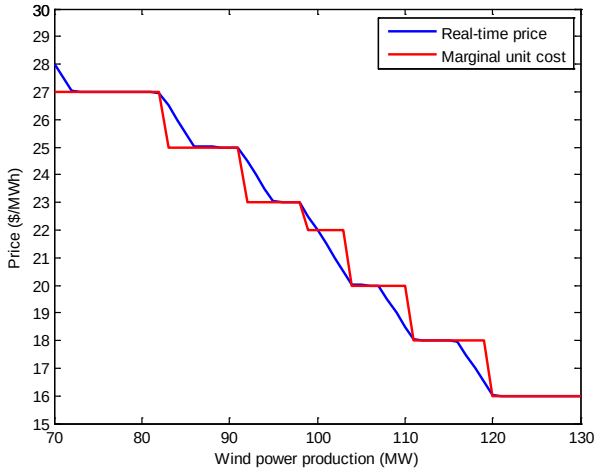
EcoGrid EU Market Concept

- Practical issues: regulating market is cleared by NordPool

- Both the regulating price and the corresponding accepted bids are decided by the NordPool.

- Therefore, in Bornholm, we cannot reduce the power output of a very expensive and contaminating unit even though we have enough demand response to balance the system.

- Moreover, regulating prices cannot be published…



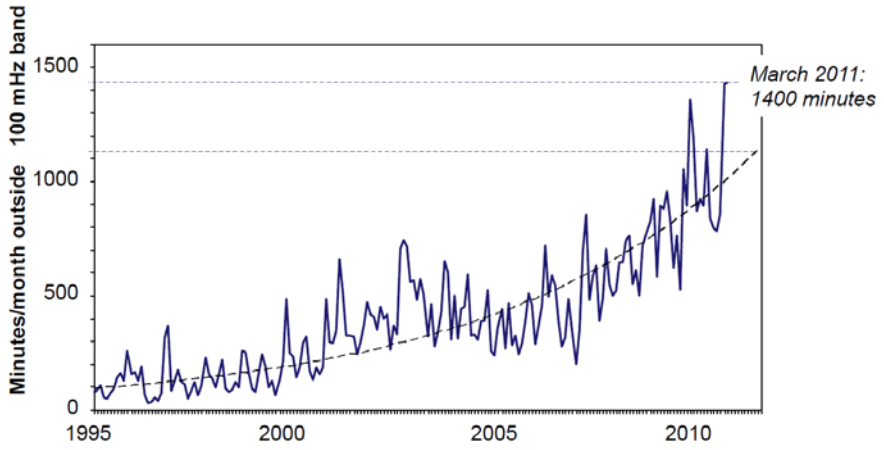
EcoGrid EU Market Concept

- Conclusions:

- EcoGrid EU proposes a new market concept that allows the participation of small distributed energy sources as well as small end-consumers.

- We will be able to balance the power variations caused by renewable (and clean) production with demand response.

- This may also improve the frequency quality in the Nordpool system.



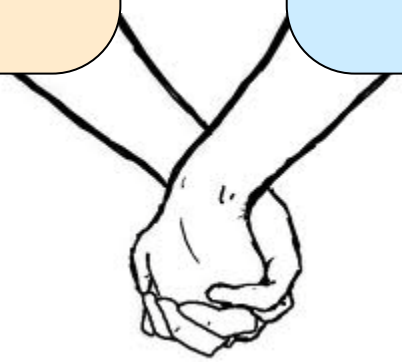
EcoGrid EU Market Concept

Network operation:

- Continuous balance between generation and consumption
- Voltage within limits
- Stability analysis
- etc.

Electricity markets:

- Determine accepted bids and offers to sell and buy electricity
- Determine electricity price
- etc.



Thanks for your attention

Questions, comments, suggestions, ideas?