Electricity markets and wind power integration

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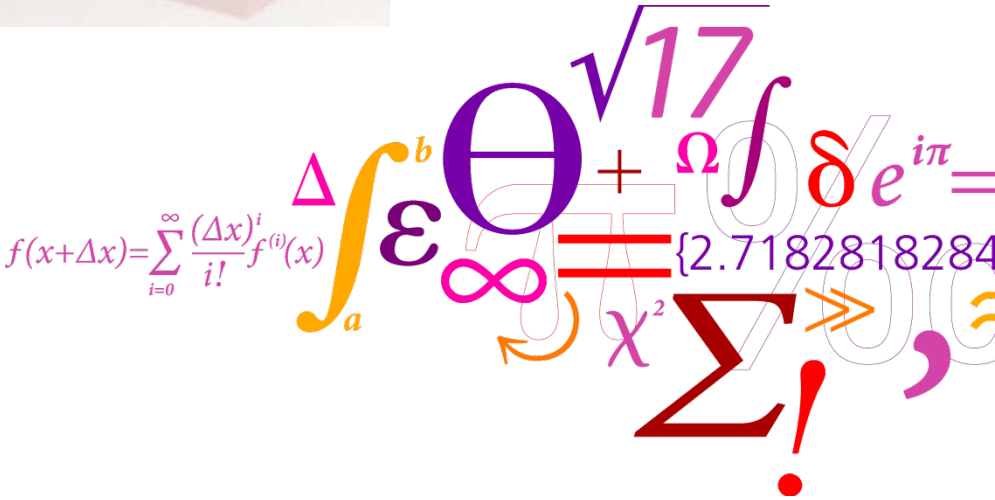
Centre for Electric Power and Energy (CEE)

16/11/2012
Integration of Wind Power in the Power System



DTU Electrical Engineering
Department of Electrical Engineering

Outline

- Introduction to markets
- Day-ahead electricity market
- Balancing electricity market
- New market solutions

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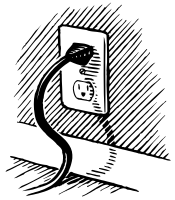
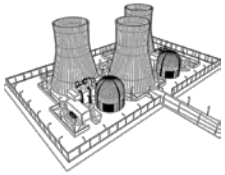
- Introduction to markets
- Day-ahead electricity market
- Balancing electricity market
- New market solutions

What is a market?

- People need certain products


- People can produce such products

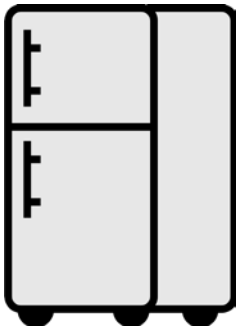
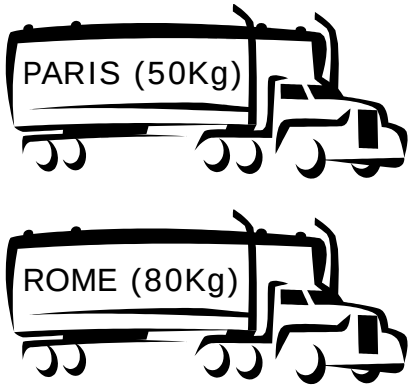
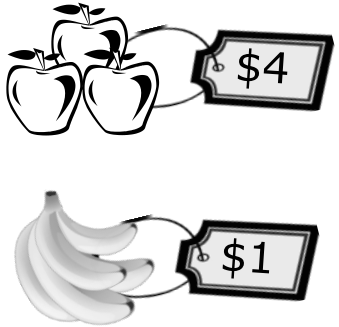
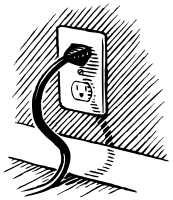
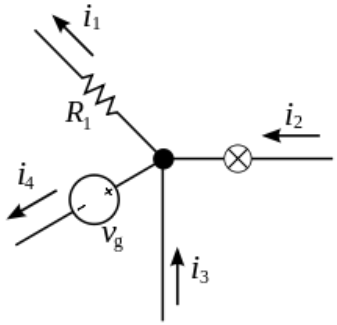
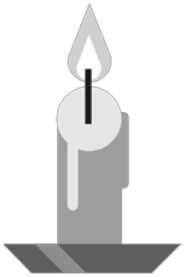
- Place to trade the products

nordpool spot

What is a market?

- A market is any structure that allows buyers and sellers to **exchange** any type of goods, services and information.
- Goods or services are exchange for **money**.
- Market participants consist of all the **buyers** and **sellers** of a good who influence its price.
- The market facilitates trade and enables the distribution and **allocation of resources** in a society.
- Markets allow any tradable item to be evaluated and **priced**.

WHY IS ELECTRICITY DIFFERENT?

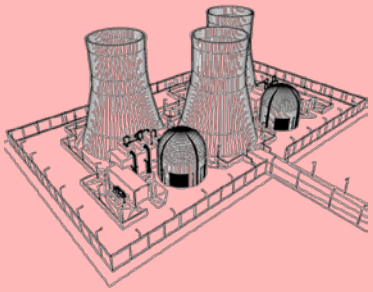
PRODUCT	STORED	TRANSPORTATION	DEMAND
			
			

Electricity market

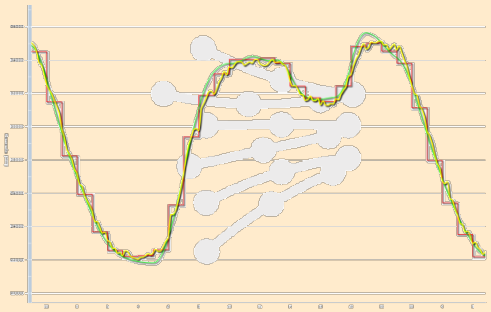
- We need to know the characteristics of the product:
  - Electricity **cannot be stored** (consumption and production equal at any time)
  - Electricity flows on the grid are governed by **Kirchhoff's Laws**
  - Electricity demand is highly **inelastic**

Electricity market

- We need to know the characteristics of the players:



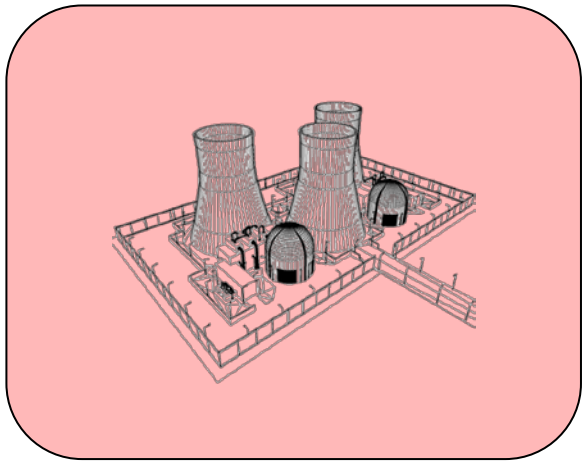
- Large fuel-based units (economy of scale)
- Technical constraints (required a schedule)
- Far from consumption centers (transmission)

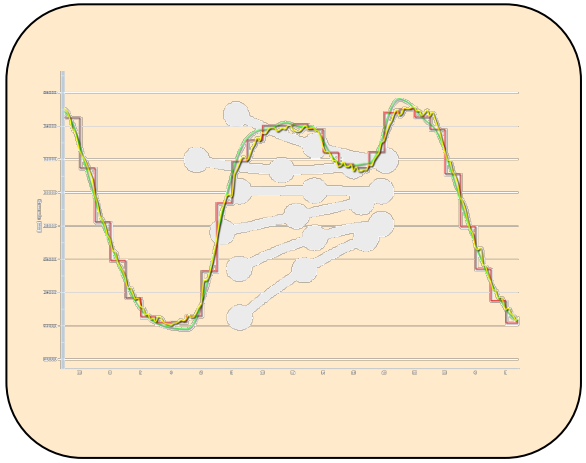


- Demand level easily forecast
- Known daily, weekly, and yearly patterns
- High inflexibility

Day-ahead electricity market

- We need to know the characteristics of the players:





Day-ahead market

- Power producers submit offers to sell electricity for the next 24 hours
- The demand for the next day is forecast
- The cheapest offers are accepted up to the forecast demand

Outline

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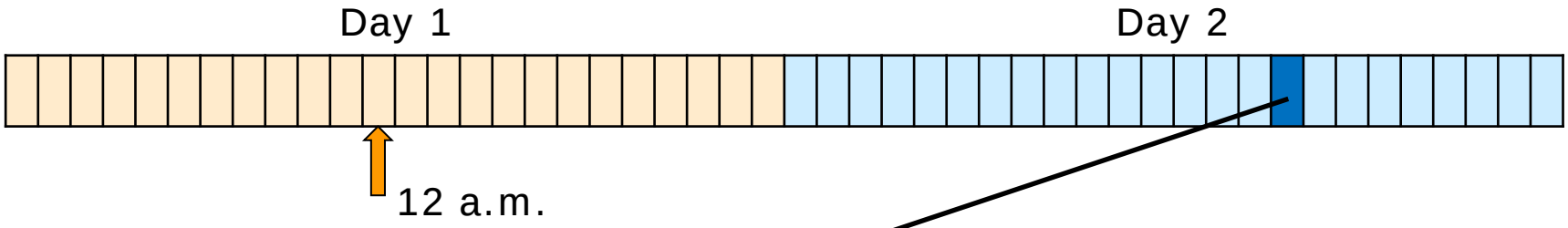
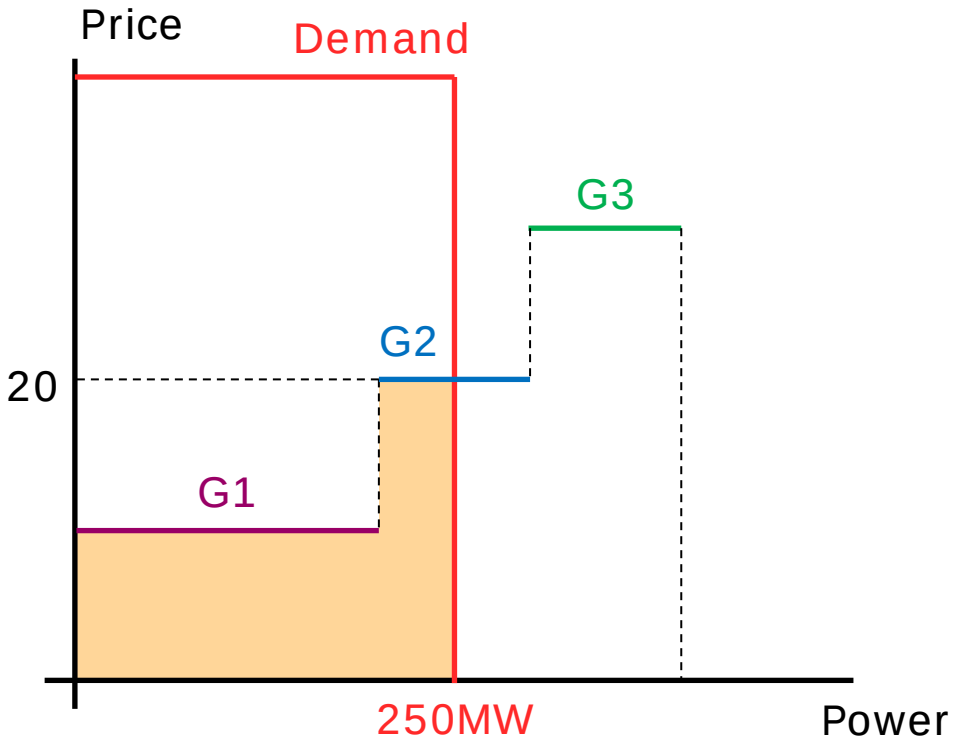
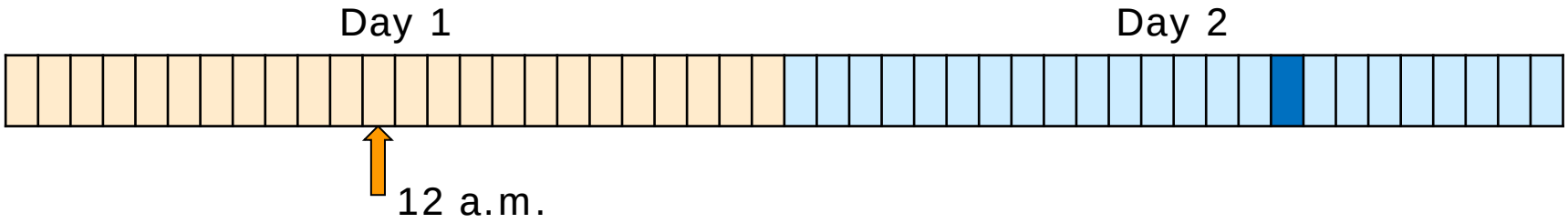
DAY-AHEAD ELECTRICITY MARKET



4-5 P.M.			
UNIT	COST	OFFERS	DEMAND
G1	5	200@10	250 MW
G2	15	100@20	
G3	25	100@30	



DAY-AHEAD ELECTRICITY MARKET



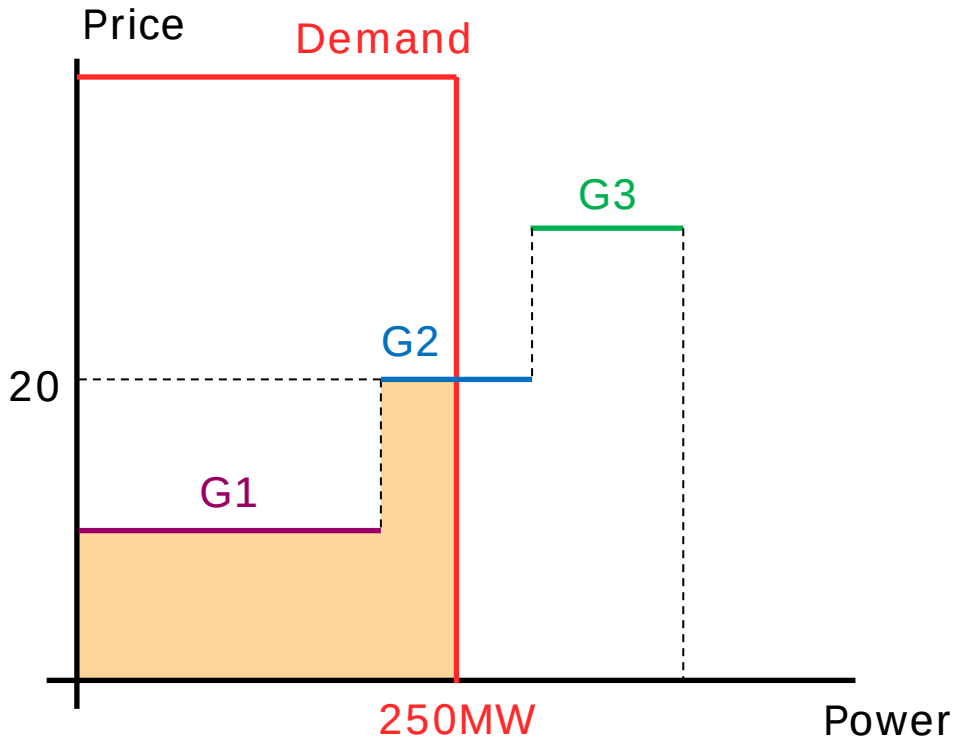
DEMAND = 250X20 = 5000

G1 = 20X200 = 4000

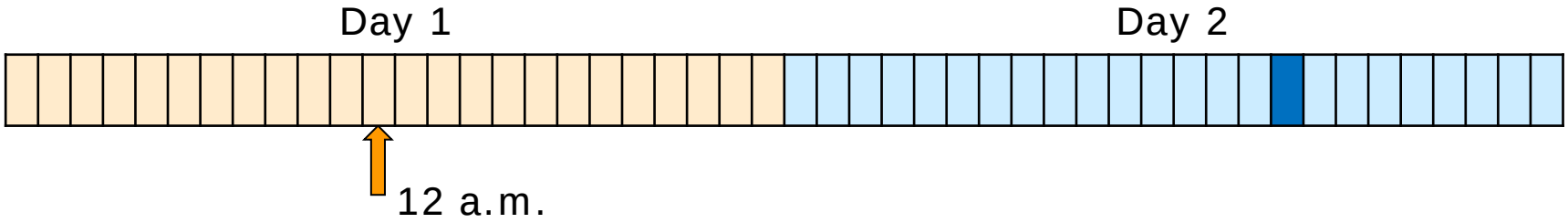
G2 = 20X50 = 1000

THIS IS CALLED MARGINAL PRICING

IS FAIR THAT G1 IS PAID AT THE MARGINAL PRICE?



Day-ahead electricity market



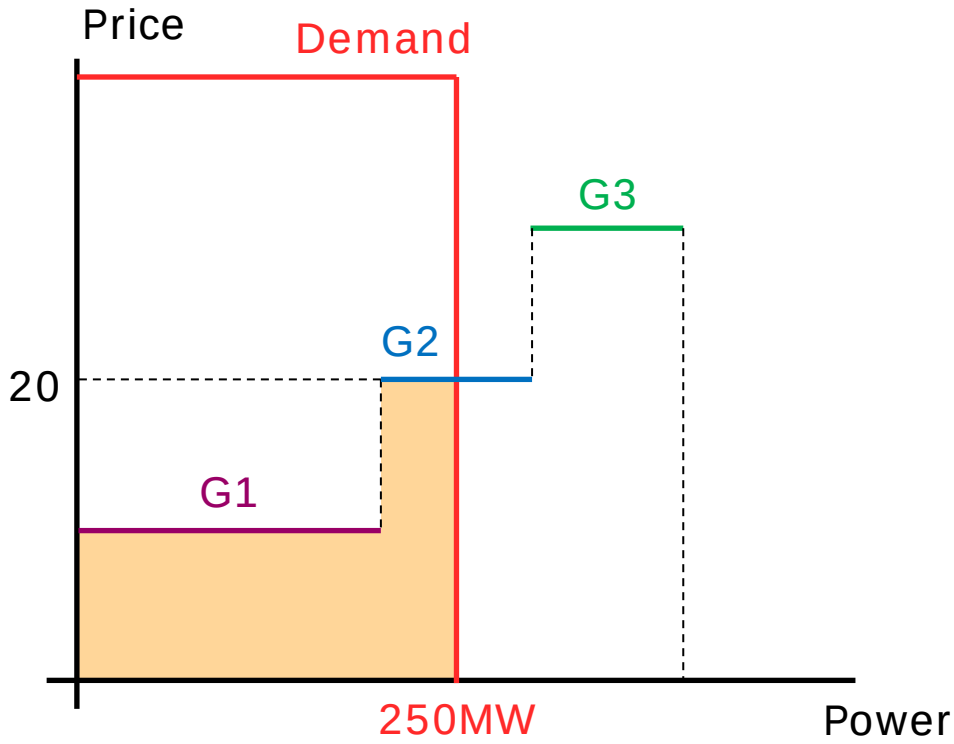
What if accepted offers are paid-as-bid?

Demand = 250x20 = 5000

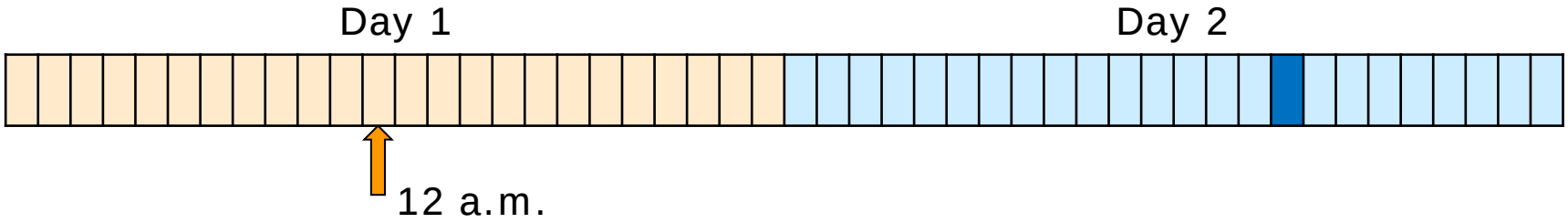
G1 = 10x200 = 3000

G2 = 20x50 = 1000

Missing money!!!!



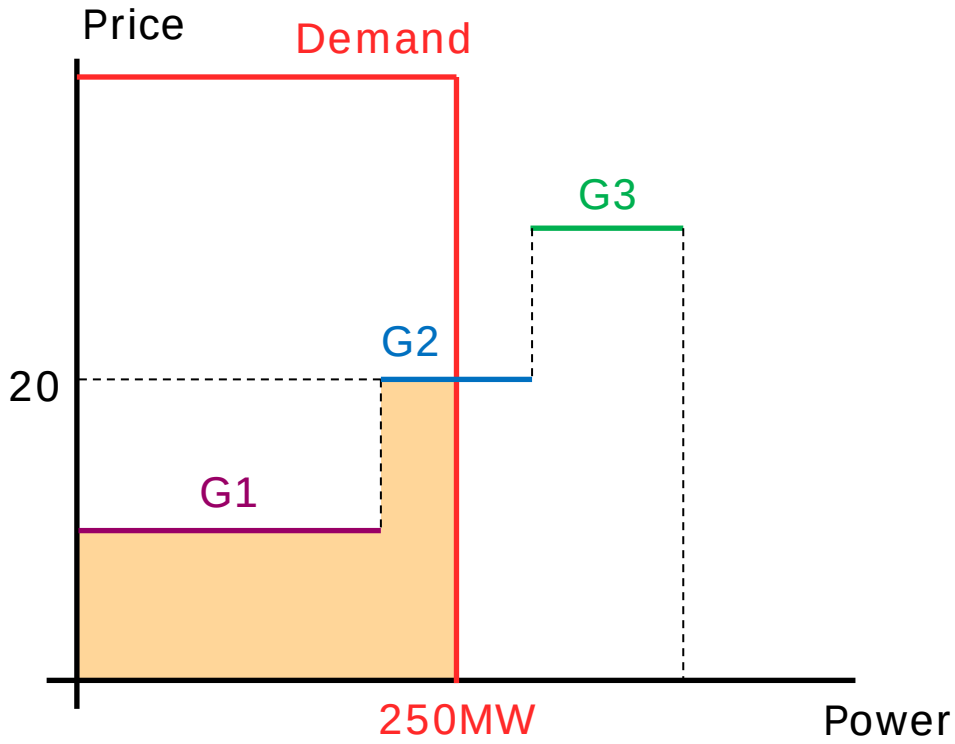
Day-ahead electricity market



What would G1 do?

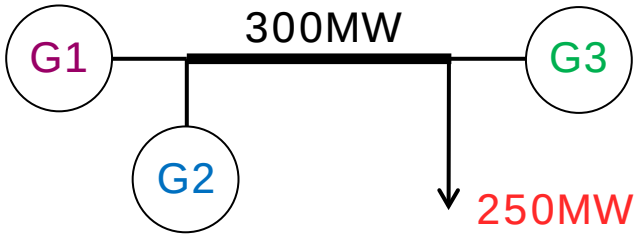
G1 would increase its bid to make more money

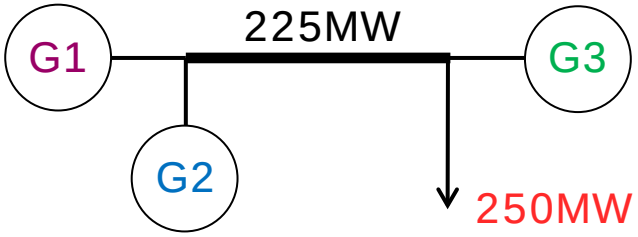
It can be proved that pay-as-bid market clearing increase electricity prices.

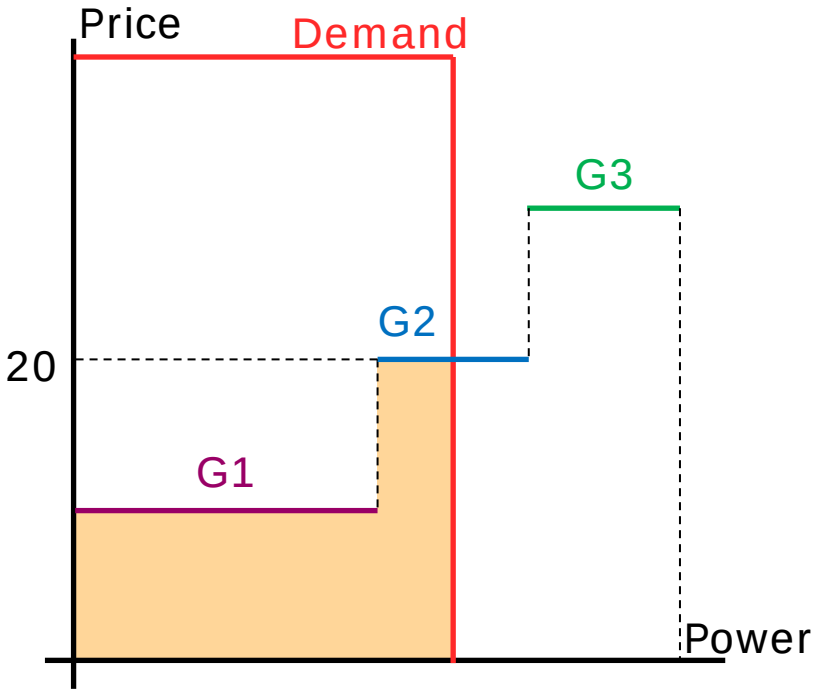


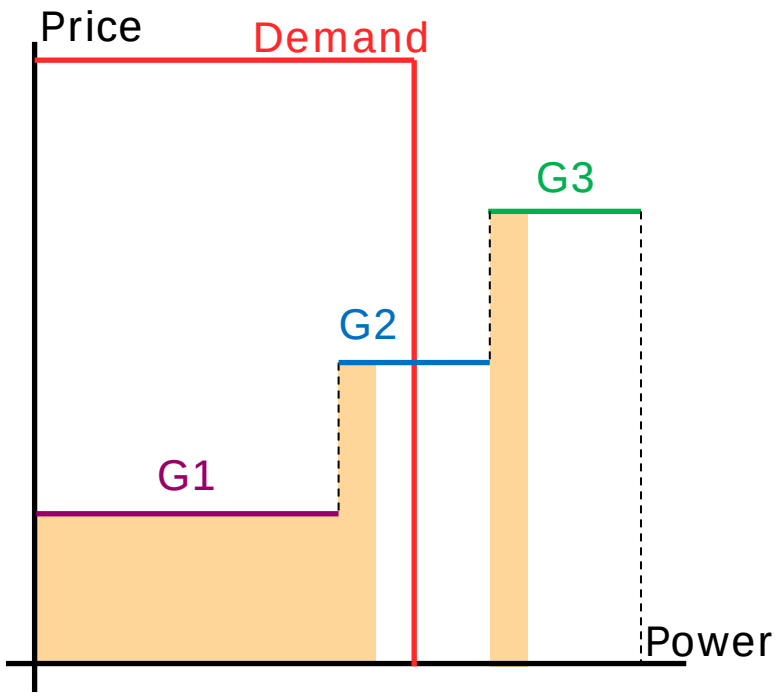
Day-ahead electricity market

- What about the network?









DAY-AHEAD ELECTRICITY MARKET

- WHAT ABOUT THE NETWORK?

WHAT SHOULD BE THE PRICE?

Price	G1	G2	G3
20			
30			
20/30			

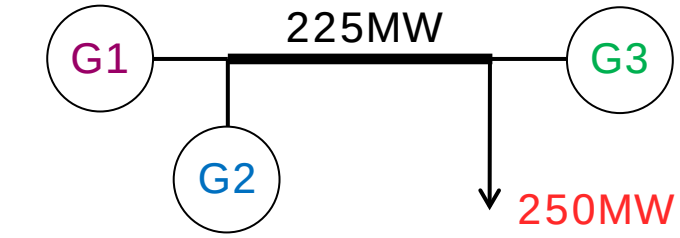
Demand = 250x30 = 7500

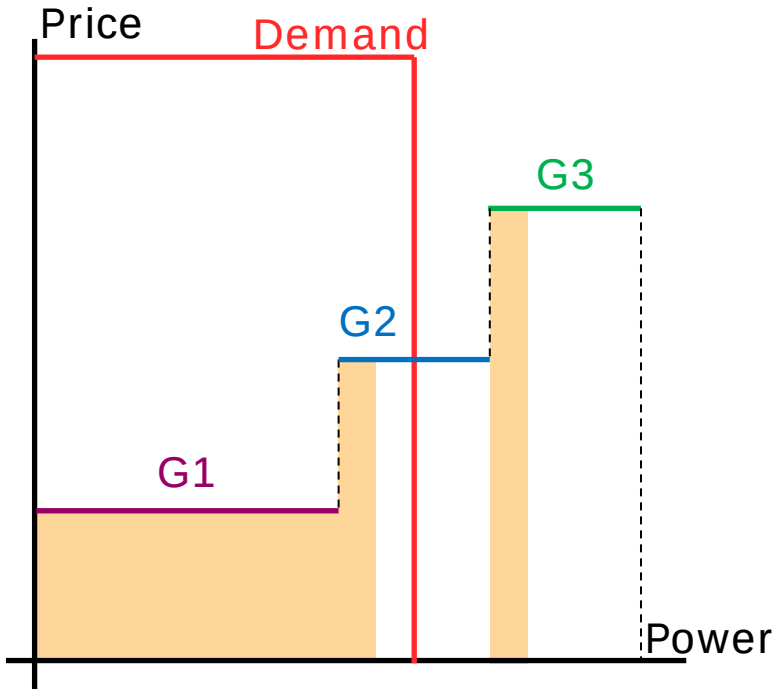
G1 = 20x200 = 4000

G2 = 20x25 = 500

G3 = 30x25 = 750

2250 extra!!

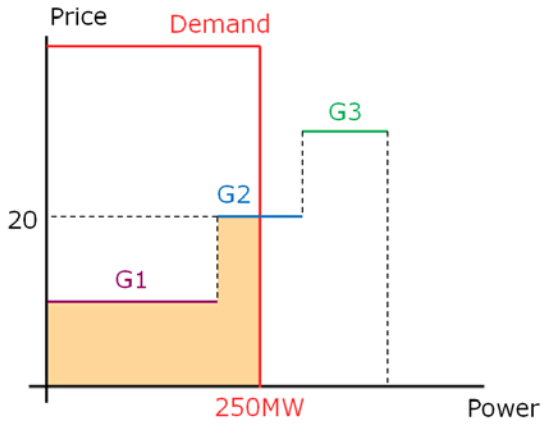


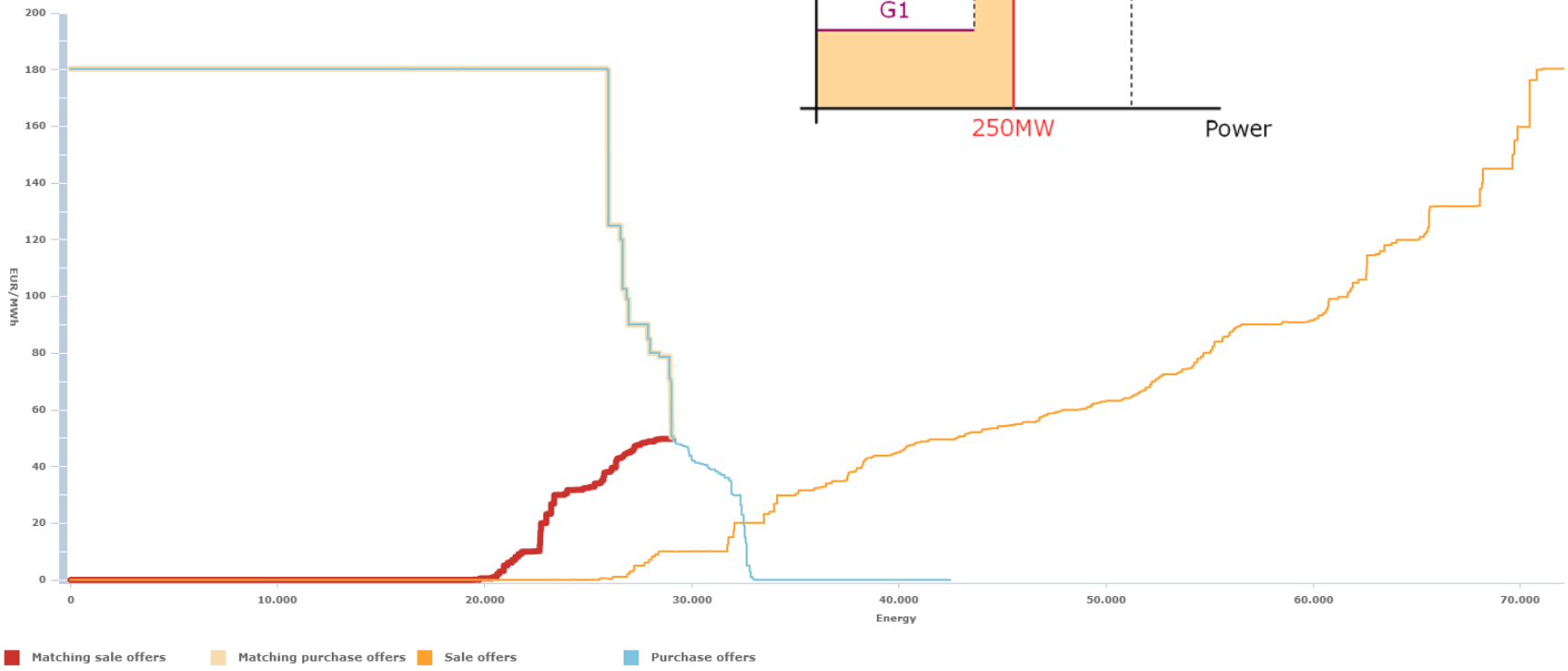


Day-ahead electricity market

- Large and inflexible units
- Predictable demand
- Day-ahead electricity market
- Generating unit schedules determined 24h ahead
- Electricity price equal to the marginal cost
- Locational marginal prices if the network is congested

DAY-AHEAD ELECTRICITY MARKET





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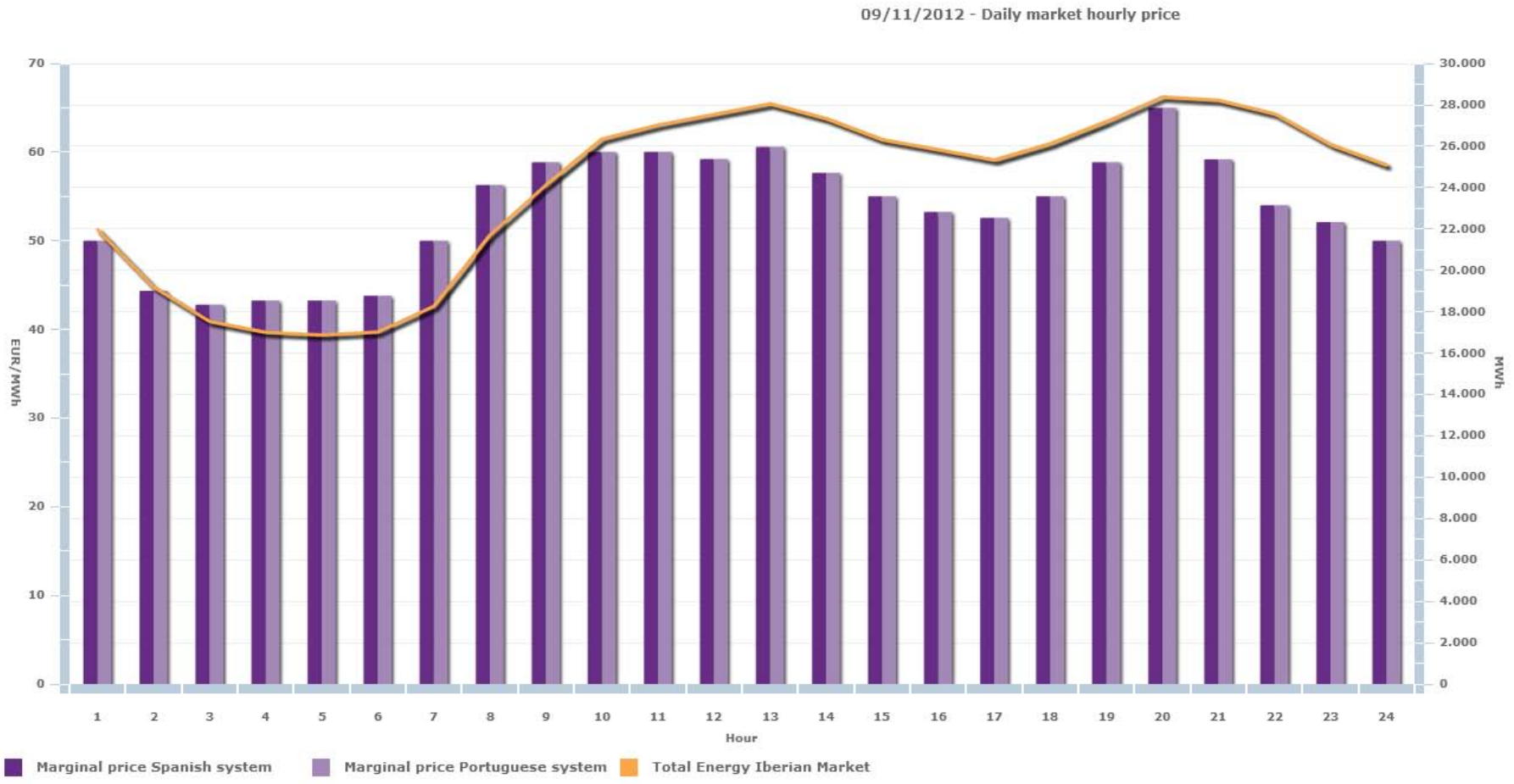

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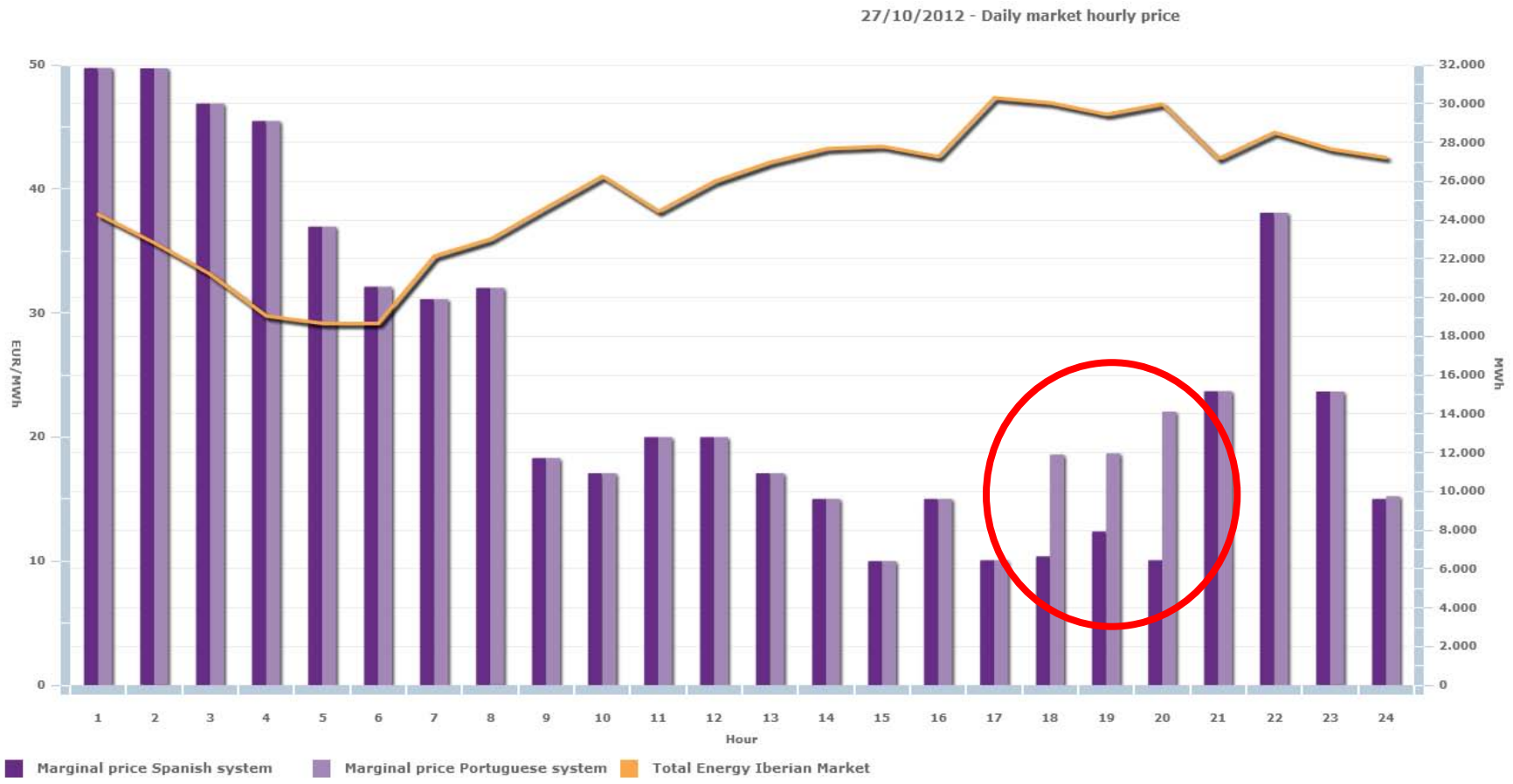


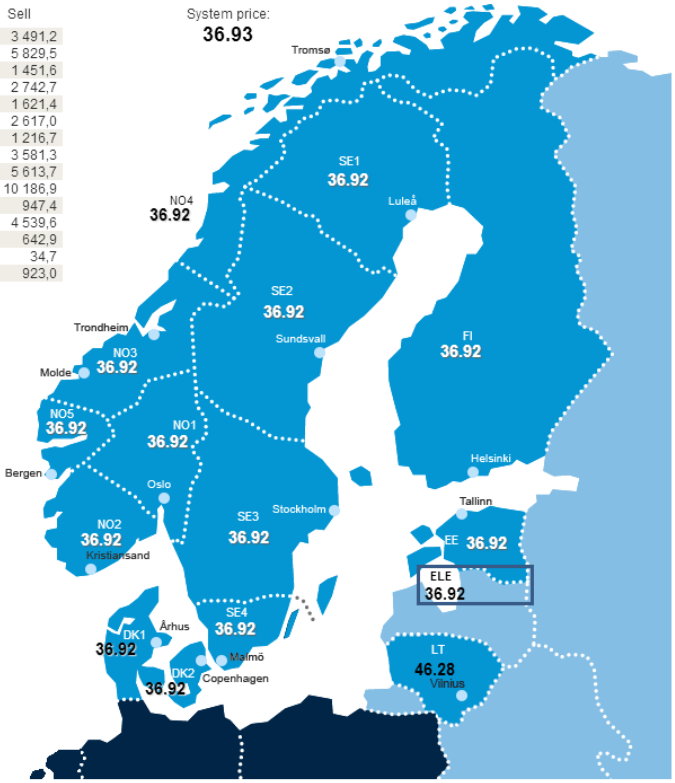
DAY-AHEAD ELECTRICITY MARKET

01-11-2012 Resolution 10 - 11 Currency EUR Capacities ITVC Flow ITVC Area Prices

Elspot volumes

	Buy	Sell
NO1	5 241,4	3 491,2
NO2	4 405,9	5 829,5
NO3	2 430,0	1 451,6
NO4	2 218,5	2 742,7
NO5	1 715,8	1 621,4
DK1	3 083,2	2 617,0
DK2	1 720,9	1 216,7
SE1	1 270,6	3 581,3
SE2	1 675,2	5 613,7
SE3	10 732,2	10 186,9
SE4	3 100,5	947,4
FI	6 112,6	4 539,6
EE	333,4	642,9
ELE	476,4	34,7
LT	923,0	923,0

System price: **36.93**

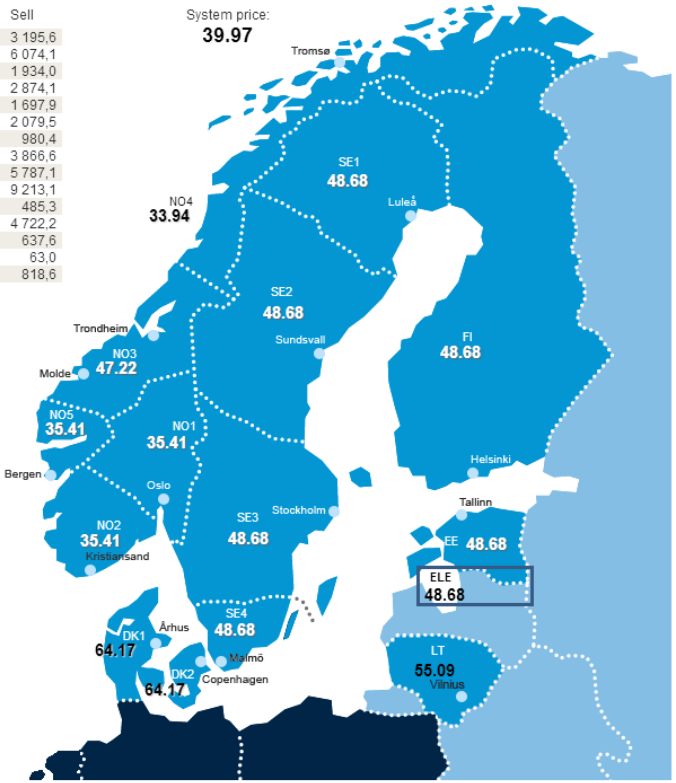


10-10-2012 Resolution 18 - 19 Currency EUR Capacities ITVC Flow ITVC Area Prices

Elspot volumes

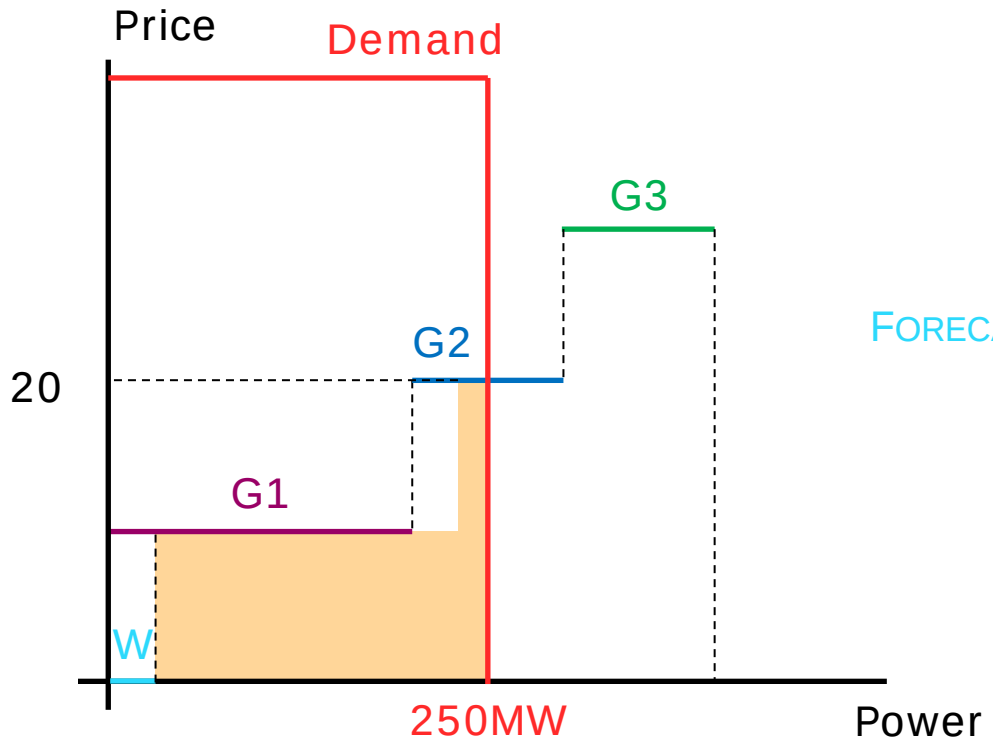
	Buy	Sell
NO1	4 141,1	3 195,6
NO2	3 876,6	6 074,1
NO3	2 134,0	1 934,0
NO4	1 824,1	2 874,1
NO5	1 419,9	1 697,9
DK1	3 439,5	2 079,5
DK2	2 280,4	980,4
SE1	1 206,4	3 866,6
SE2	1 709,4	5 787,1
SE3	10 524,0	9 213,1
SE4	3 968,4	485,3
FI	6 436,9	4 722,2
EE	315,7	637,6
ELE	334,1	63,0
LT	818,6	818,6

System price: **39.97**



Day-ahead electricity market

- What about the wind?

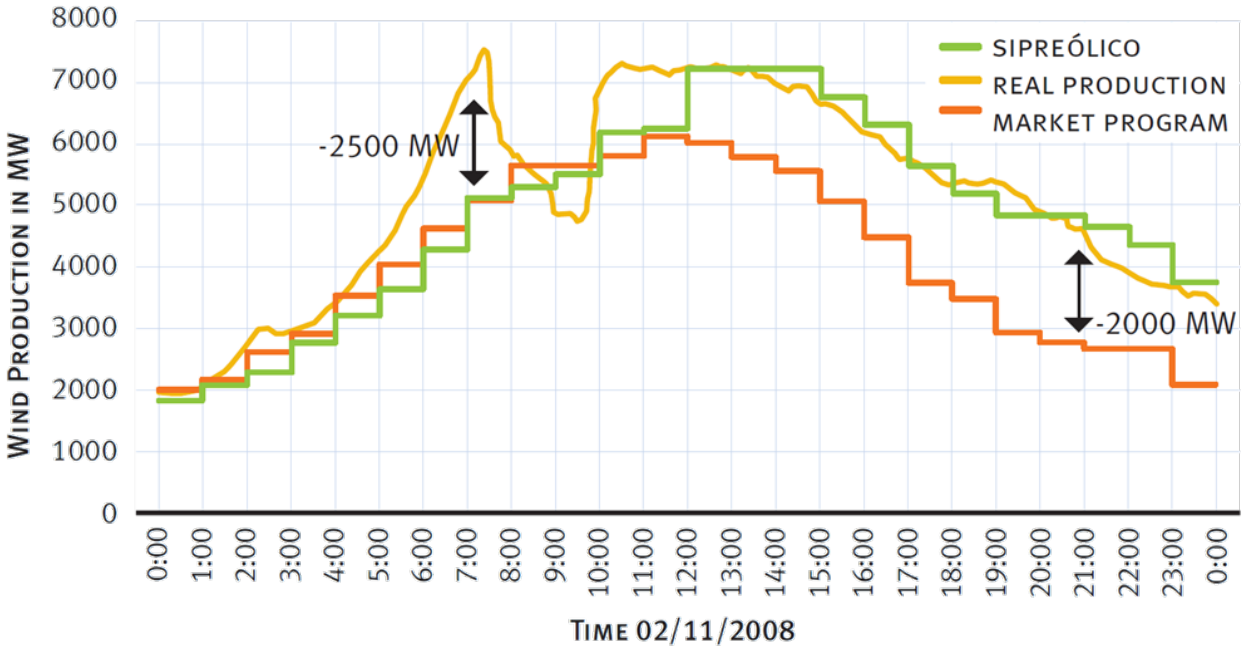


Forecast wind = 30 MW

Day-ahead electricity market

- So, what is the problem with wind?

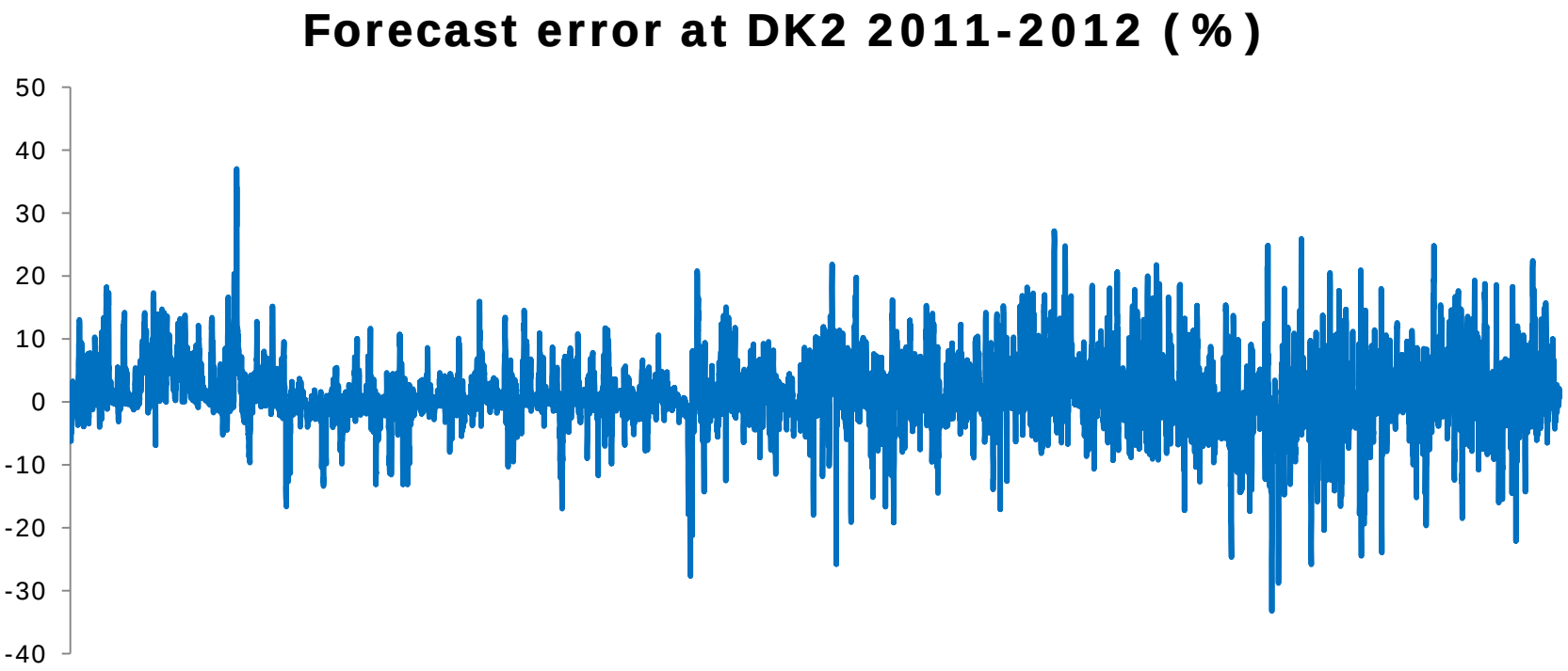
Figure 16: Wind forecast error in Spain



Wind cannot be predicted 24-36 hours ahead!!

DAY-AHEAD ELECTRICITY MARKET

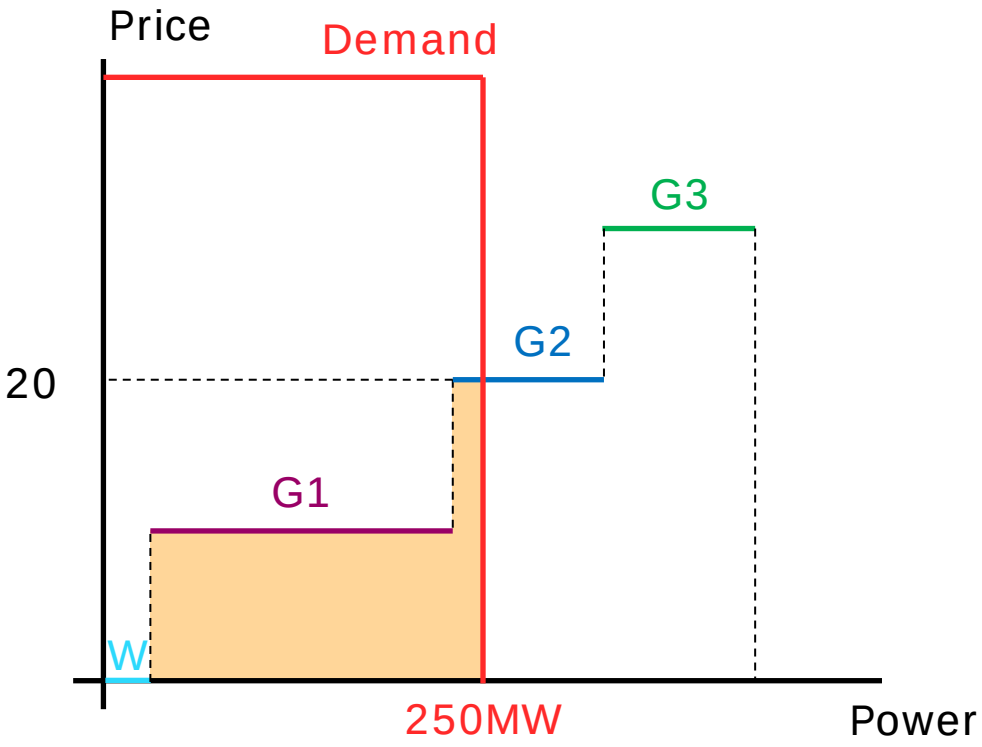
- SO, WHAT IS THE PROBLEM WITH WIND?



WIND CANNOT BE PREDICTED 24-36 HOURS AHEAD!!

Day-ahead electricity market

- How do we deal with wind forecast errors?



Nowadays:

Balancing market

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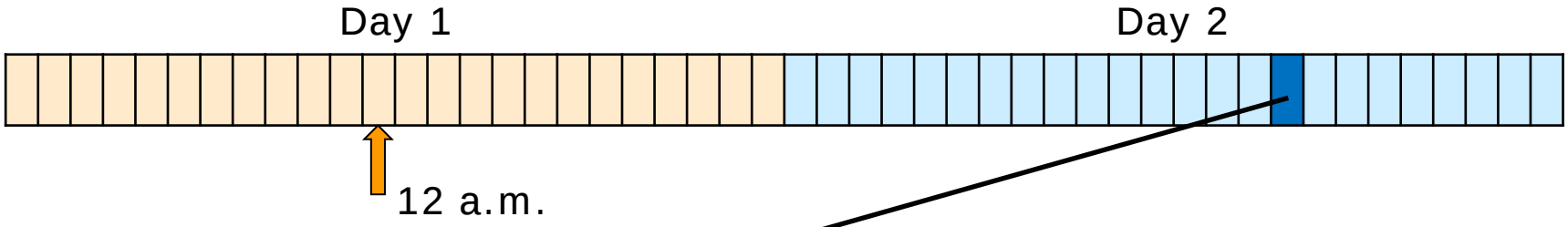
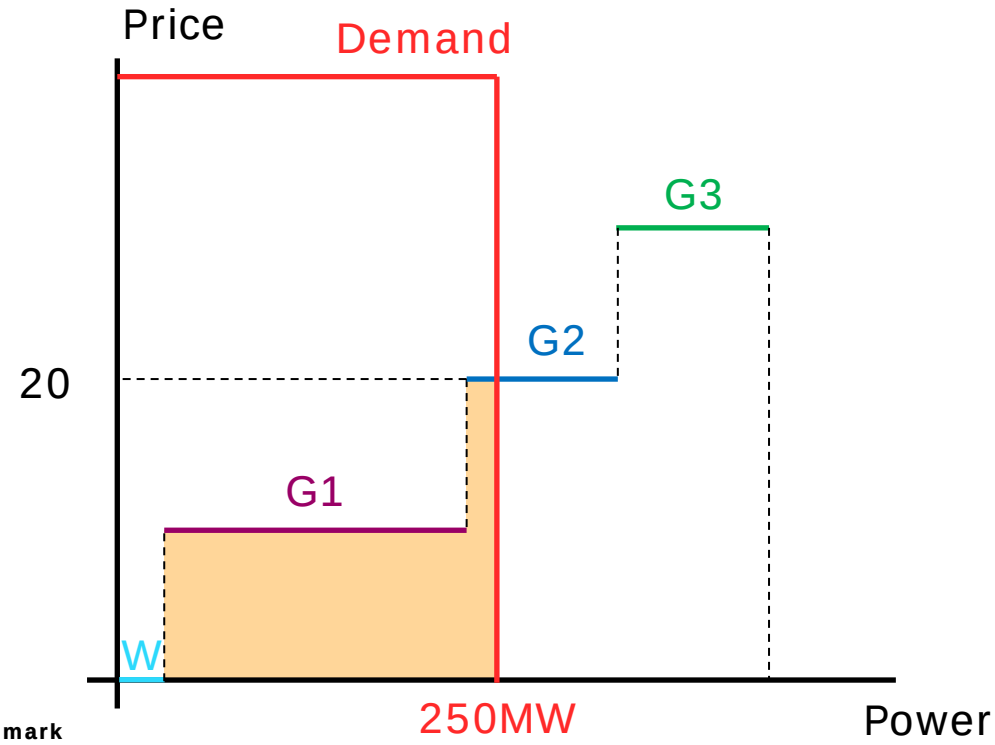
BALANCING ELECTRICITY MARKET

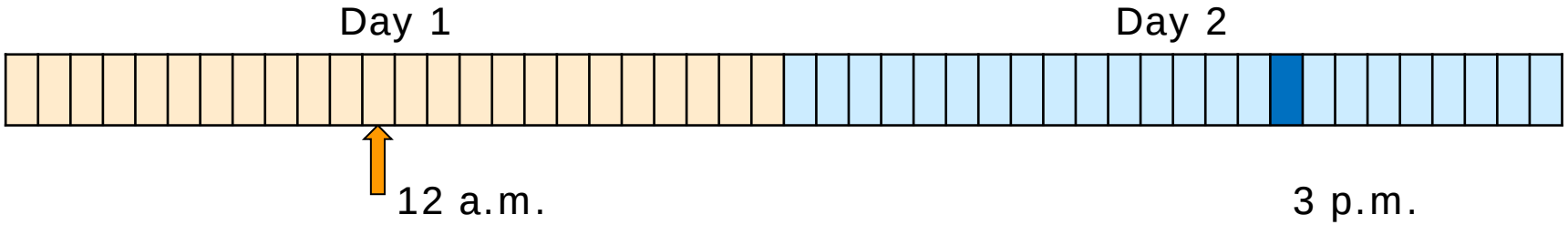


WIND FORECAST = 30 MW

4-5 P.M.			
UNIT	COST	OFFERS	DEMAND
W	0	30@0	250 MW
G1	5	200@10	
G2	15	100@20	
G3	25	100@30	

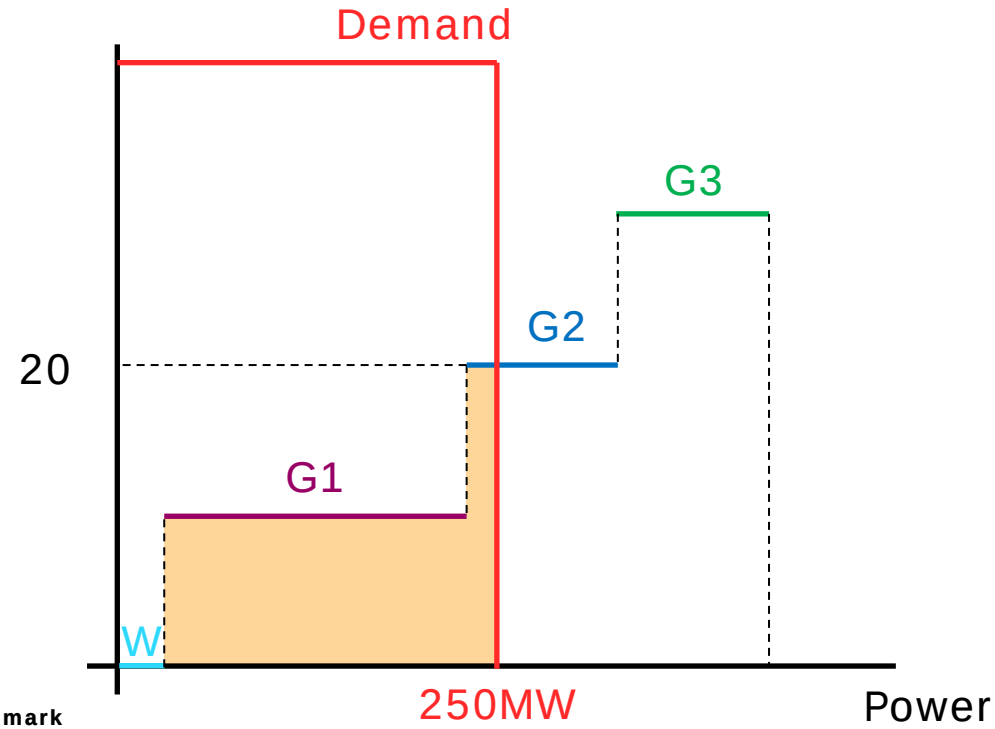


BALANCING ELECTRICITY MARKET

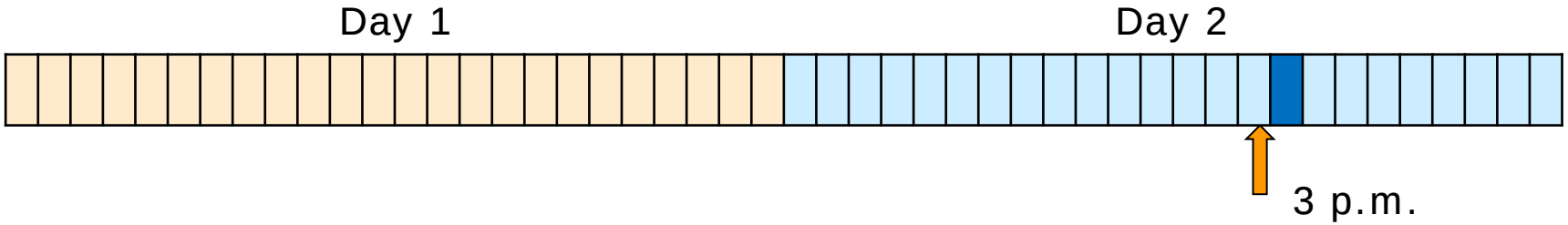


4-5 P.M.	
DA SCHEDULE	
UNIT	MW
W	30
G1	200
G2	20
G3	-

WIND FORECAST = 30 MW

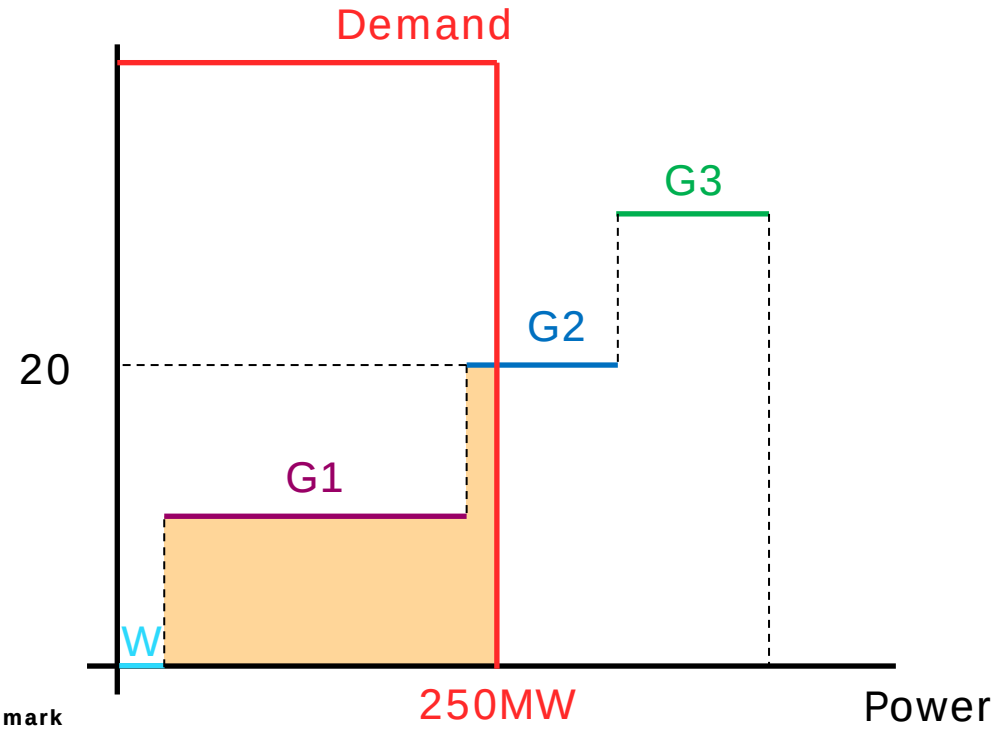


BALANCING ELECTRICITY MARKET



WIND POWER = 20 MW

4-5 P.M.			
DA SCHEDULE		REGULATING MARKET	
UNIT	MW	UP	DOWN
W	30	-	-
G1	200	-	
G2	20	10@25	
G3	-	20@35	



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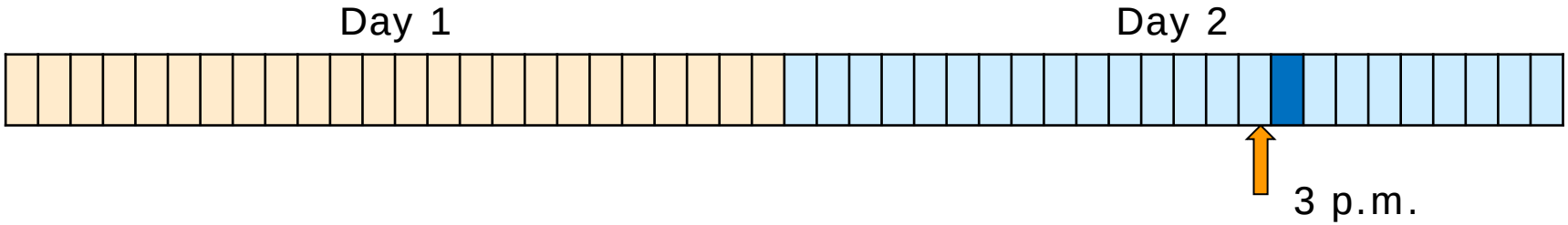
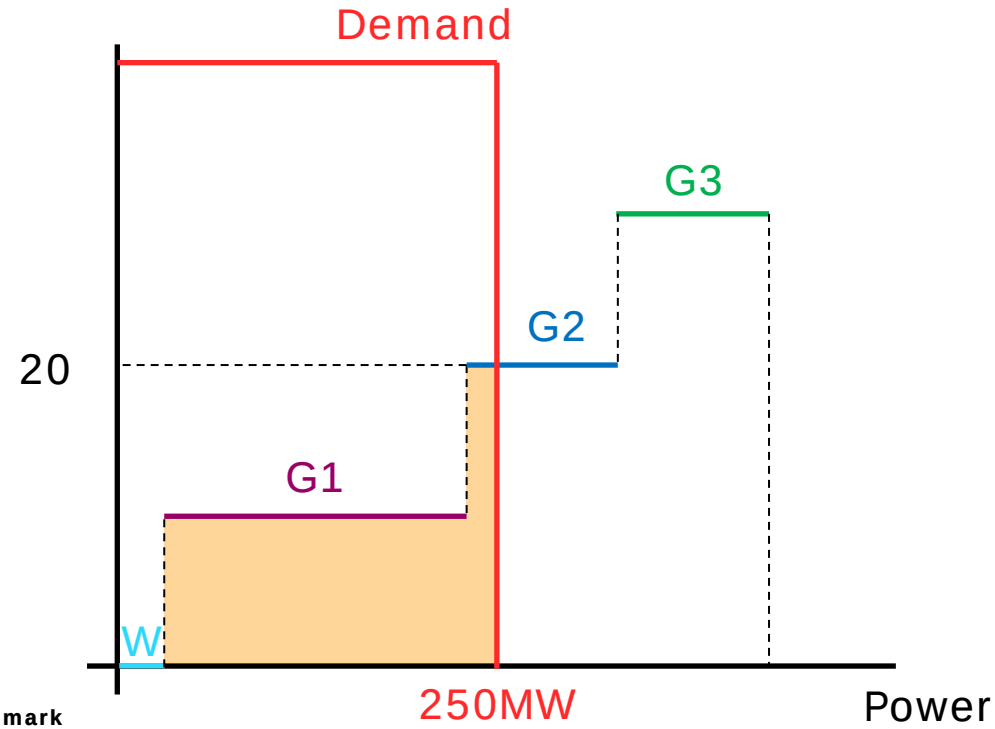
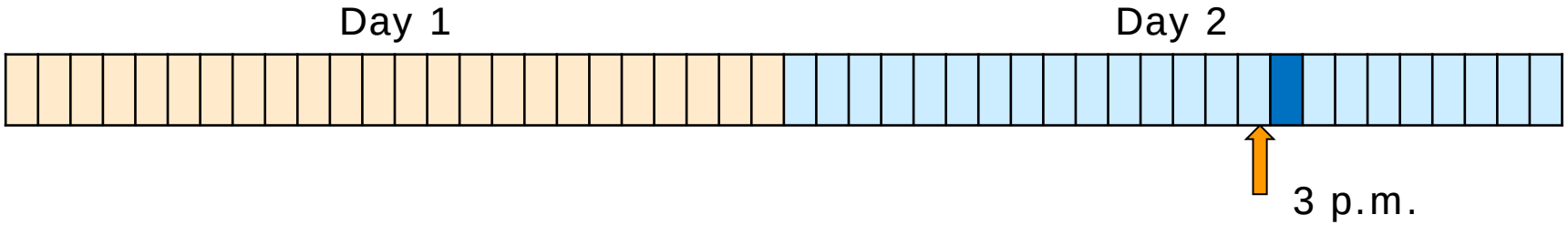


WIND POWER = 20 MW

4-5 P.M.			
DA SCHEDULE		REGULATING MARKET	
UNIT	MW	UP	DOWN
W	30	-	-
G1	200	-	
G2	20	10@25	
G3	-	20@35	

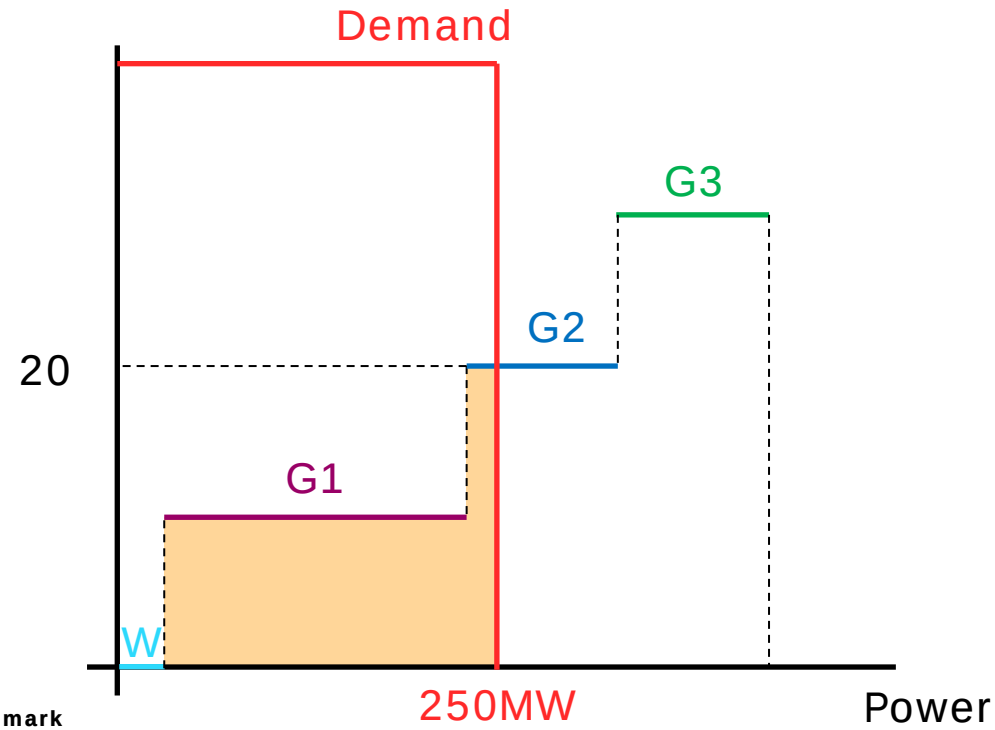


BALANCING ELECTRICITY MARKET



WIND POWER = 20 MW

4-5 P.M.	
DA SCHEDULE	
UNIT	MW
W	20
G1	200
G2	30
G3	-



BALANCING ELECTRICITY MARKET

- LET'S CHECK THE PROFITS

4-5 P.M.				
UNIT	DA MARKET	R MARKET	FUEL COST	TOTAL
W				
G1				
G2				
G3				

BALANCING ELECTRICITY MARKET

- LET'S CHECK THE PROFITS

4-5 P.M.				
UNIT	DA MARKET	R MARKET	FUEL COST	TOTAL
W	20x30=600			
G1	20x200=4000			
G2	20x20=400			
G3	0			

BALANCING ELECTRICITY MARKET

- LET'S CHECK THE PROFITS

4-5 P.M.				
UNIT	DA MARKET	R MARKET	FUEL COST	TOTAL
W	20x30=600	-25x10=-250		
G1	20x200=4000	0		
G2	20x20=400	25x10=250		
G3	0	0		

BALANCING ELECTRICITY MARKET

- LET'S CHECK THE PROFITS

4-5 P.M.				
UNIT	DA MARKET	R MARKET	FUEL COST	TOTAL
W	20x30=600	-25x10=-250	0	
G1	20x200=4000	0	5x200=1000	
G2	20x20=400	25x10=250	15x30=450	
G3	0	0	0	

BALANCING ELECTRICITY MARKET

- LET'S CHECK THE PROFITS

4-5 P.M.				
UNIT	DA MARKET	R MARKET	FUEL COST	TOTAL
W	20x30=600	-25x10=-250	0	350
G1	20x200=4000	0	5x200=1000	3000
G2	20x20=400	25x10=250	15x30=450	200
G3	0	0	0	0

BALANCING ELECTRICITY MARKET

- LET'S CHECK THE PROFITS

4-5 P.M.				
UNIT	DA MARKET	R MARKET	FUEL COST	TOTAL
W	20x30=600	-25x10=-250	0	350
G1	20x200=4000	0	5x200=1000	3000
G2	20x20=400	25x10=250	15x30=450	200
G3	0	0	0	0


(20-0)x20=400
(20-5)x200=3000
(20-15)x30=150
0

BALANCING ELECTRICITY MARKET

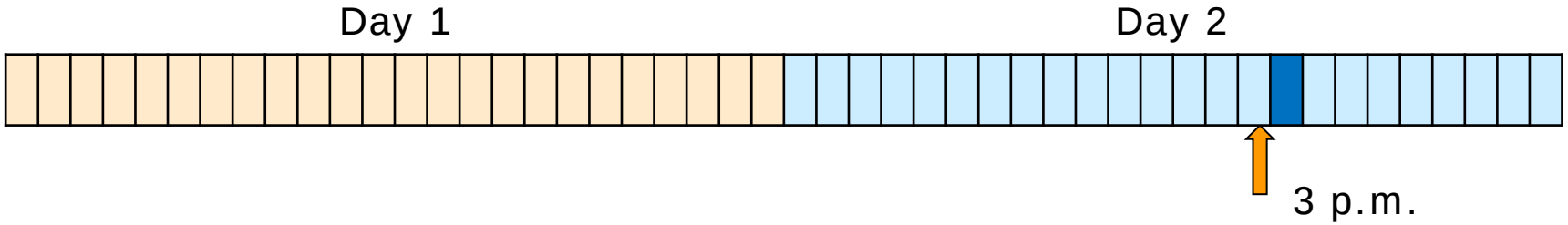
- LET'S CHECK THE PROFITS

4-5 P.M.				
UNIT	DA MARKET	R MARKET	FUEL COST	TOTAL
W	20x30=600	-25x10=-250	0	350
G1	20x200=4000	0	5x200=1000	3000
G2	20x20=400	25x10=250	15x30=450	200
G3	0	0	0	0

(20-0)x20=400
(20-5)x200=3000
(20-15)x30=150
0

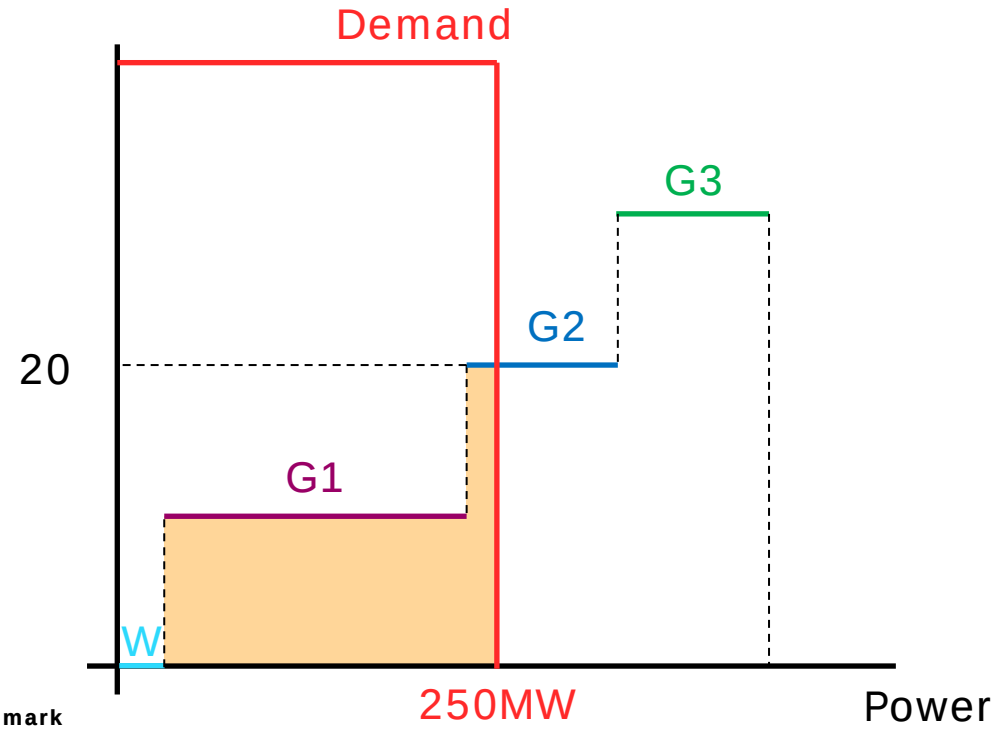
WIND PRODUCERS ARE PAYING FOR FORECAST ERRORS!!

BALANCING ELECTRICITY MARKET

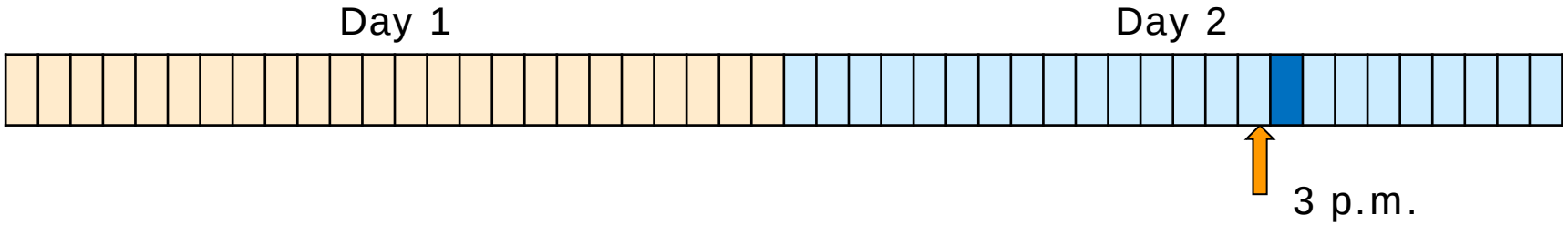


WIND POWER = 40 MW

4-5 P.M.			
DA SCHEDULE		REGULATING MARKET	
UNIT	MW	UP	DOWN
W	30	-	-
G1	200	-	-
G2	20	10@25	10@15
G3	-	20@35	-

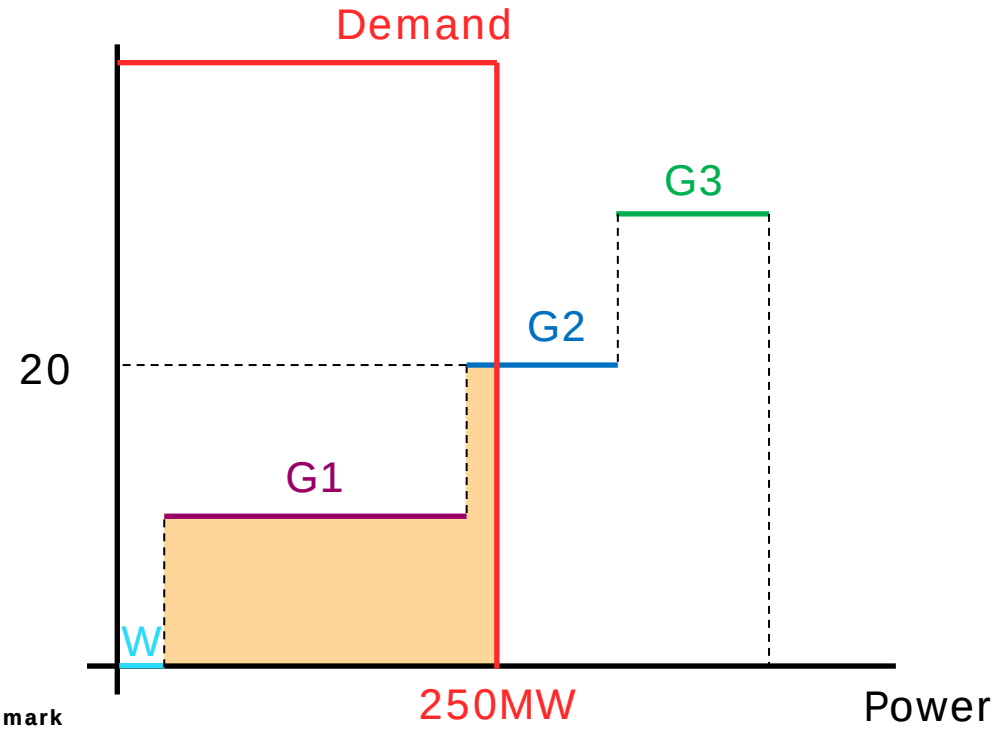


BALANCING ELECTRICITY MARKET



WIND POWER = 40 MW

4-5 P.M.			
DA SCHEDULE		REGULATING MARKET	
UNIT	MW	UP	DOWN
W	30	-	-
G1	200	-	-
G2	20	10@25	10@15
G3	-	20@35	-



BALANCING ELECTRICITY MARKET

- LET'S CHECK THE PROFITS

4-5 P.M.					
UNIT	DA MARKET	R MARKET	FUEL COST	TOTAL	
W	20x30=600	15x10=150	0	750	(20-0)x40=800
G1	20x200=4000	0	5x200=1000	3000	(20-5)x200=3000
G2	20x20=400	-15x10=150	15x10=150	100	(20-15)x10=50
G3	0	0	0	0	0
L	20x250=5000	0	-	5000	20x250=5000

BALANCING ELECTRICITY MARKET

- LET'S CHECK THE PROFITS

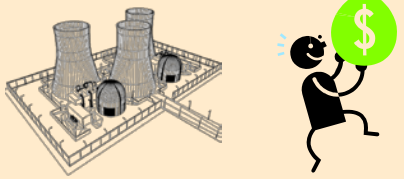
4-5 P.M.					
UNIT	DA MARKET	R MARKET	FUEL COST	TOTAL	
W	20x30=600	15x10=150	0	750	(20-0)x40=800
G1	20x200=4000	0	5x200=1000	3000	(20-5)x200=3000
G2	20x20=400	-15x10=150	15x10=150	100	(20-15)x10=50
G3	0	0	0	0	0
L	20x250=5000	0	-	5000	20x250=5000

WIND PRODUCERS ARE PAYING FOR FORECAST ERRORS!!

Balancing electricity market

- Is this fair?
- Is it necessary to clear the market 24-36h ahead?

Large units



TSO

Customers

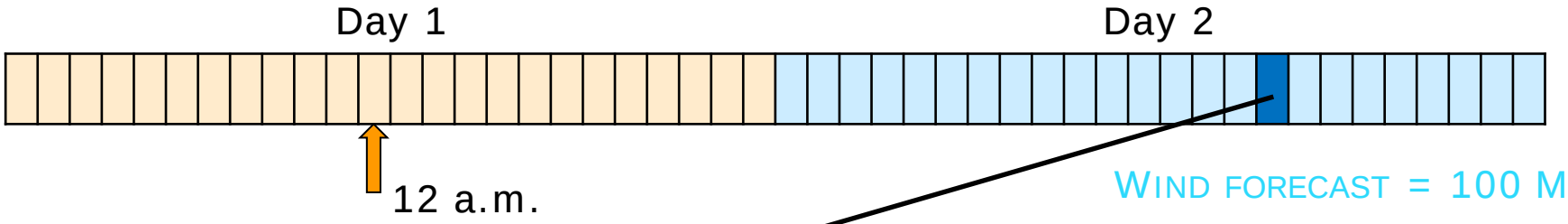
24-36h ahead — Shorter horizon

Wind producers

Low values of wind penetration!!

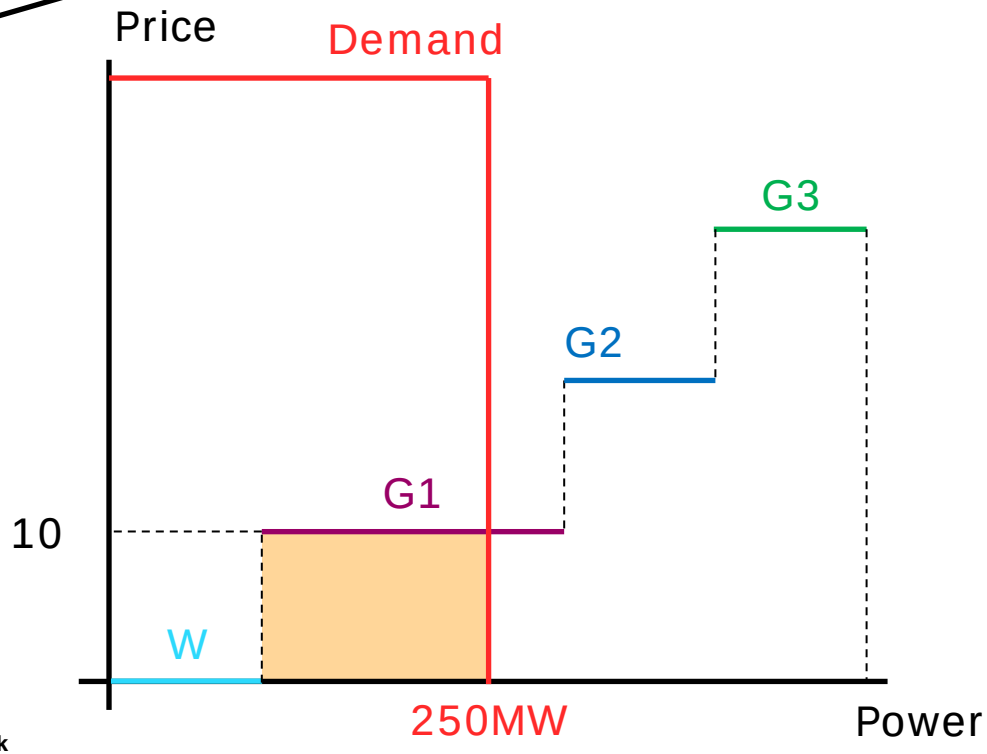
BALANCING ELECTRICITY MARKET

- WHAT WOULD HAPPEN IF WIND CAPACITY INCREASES?

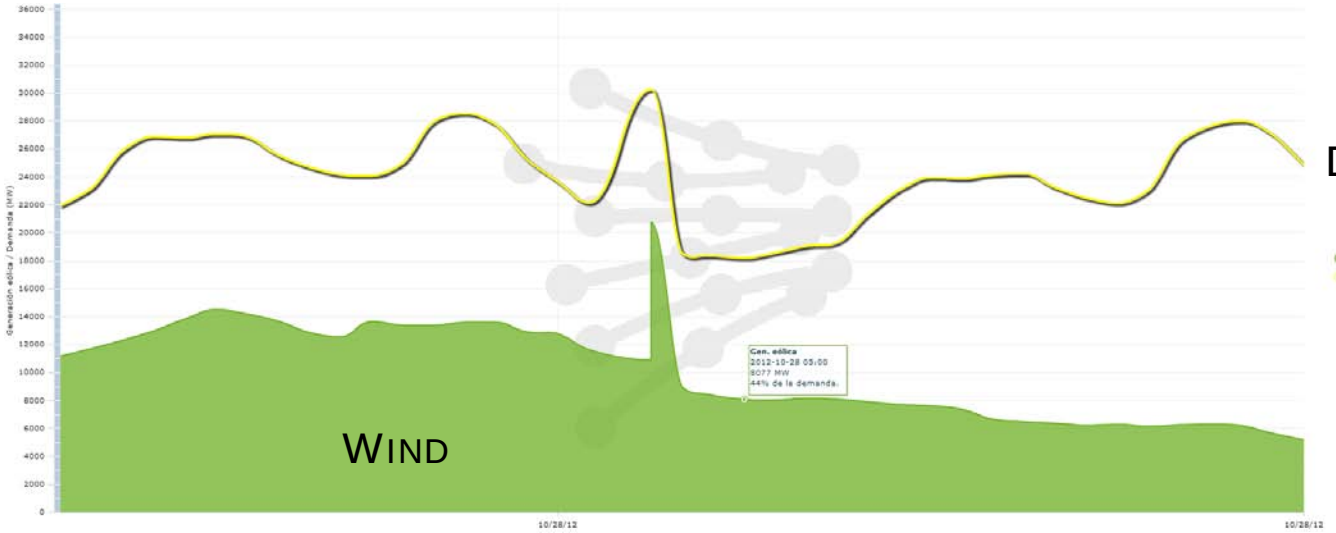


WIND FORECAST = 100 MW

4-5 P.M.			
UNIT	COST	OFFERS	DEMAND
W	0	100@0	250 MW
G1	5	200@10	
G2	15	100@20	
G3	25	100@30	



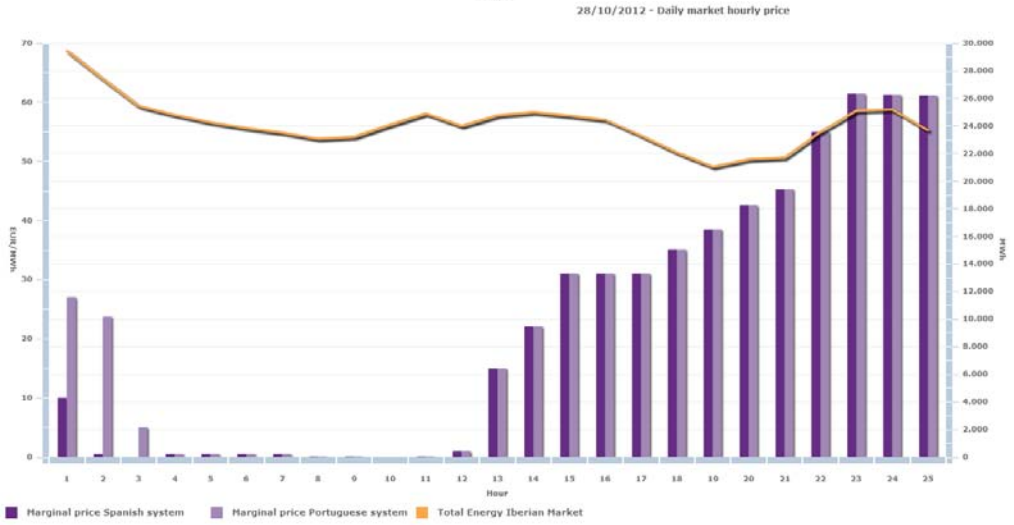
DAY-AHEAD ELECTRICITY MARKET



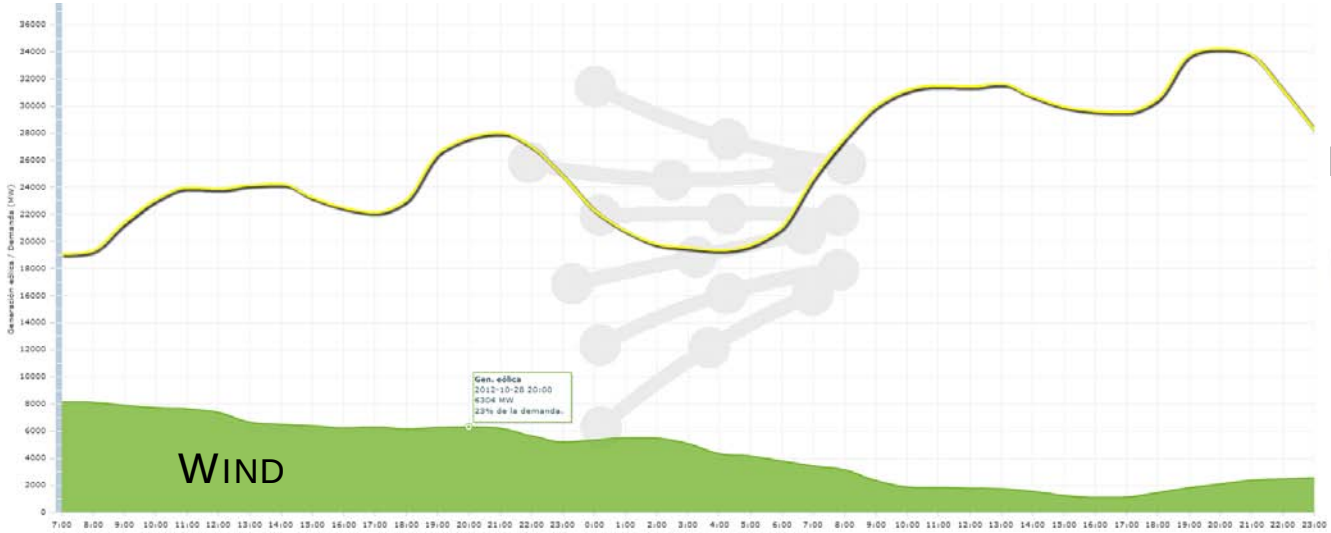
WIND

DEMAND

PRICES



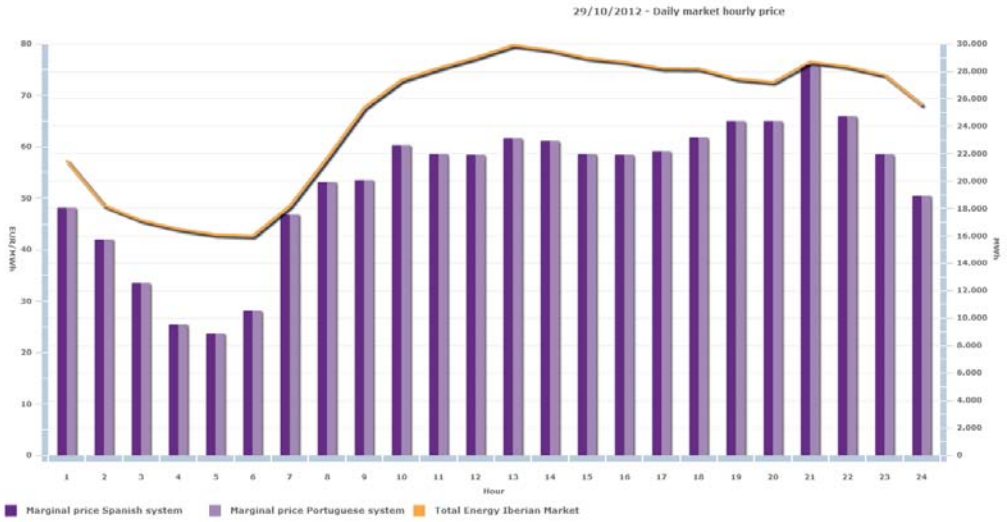
DAY-AHEAD ELECTRICITY MARKET



DEMAND

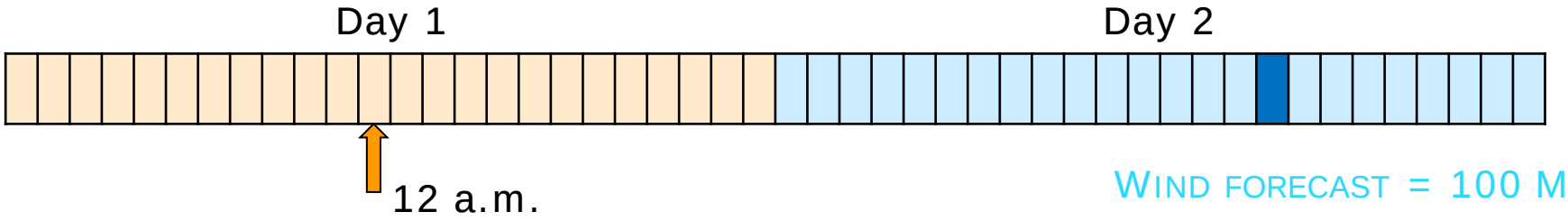
WIND

PRICES



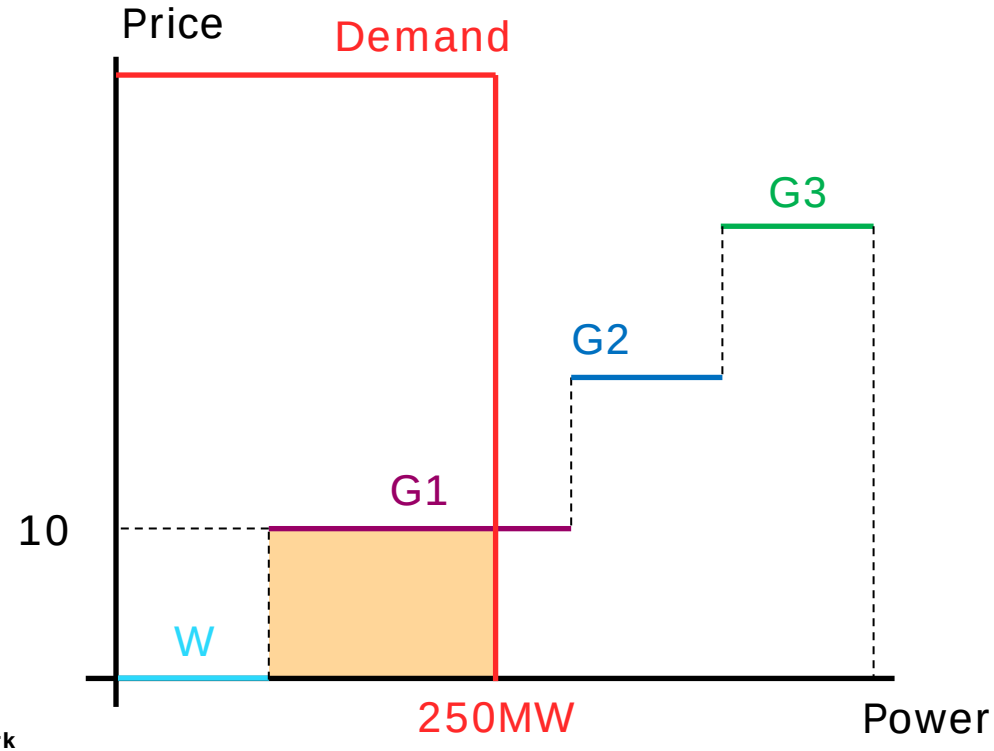
BALANCING ELECTRICITY MARKET

- WHAT WOULD HAPPEN IF WIND CAPACITY INCREASES?



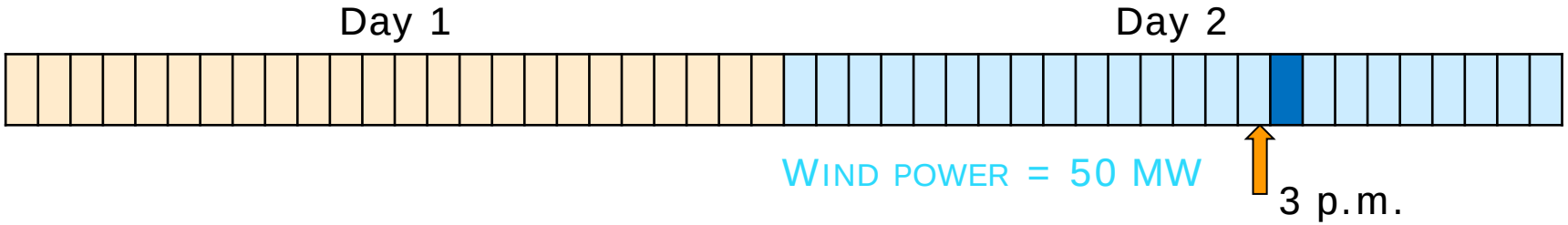
WIND FORECAST = 100 MW

4-5 P.M.	
DA SCHEDULE	
UNIT	MW
W	100
G1	150
G2	-
G3	-



BALANCING ELECTRICITY MARKET

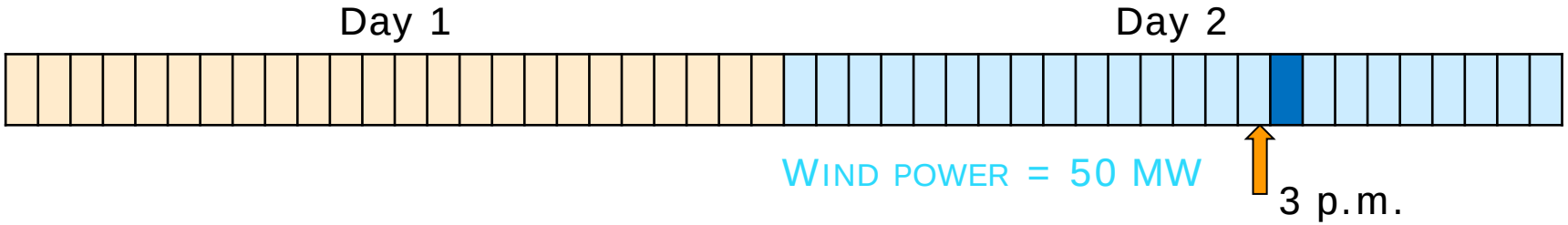
- WHAT WOULD HAPPEN IF WIND CAPACITY INCREASES?



4-5 P.M.			
DA SCHEDULE		REGULATING MARKET	
UNIT	MW	UP	DOWN
W	100	-	-
G1	150	-	
G2	-	10@25	
G3	-	20@35	

BALANCING ELECTRICITY MARKET

- WHAT WOULD HAPPEN IF WIND CAPACITY INCREASES?



4-5 P.M.			
DA SCHEDULE		REGULATING MARKET	
UNIT	MW	UP	DOWN
W	100	-	-
G1	150	-	
G2	-	10@25	
G3	-	20@35	

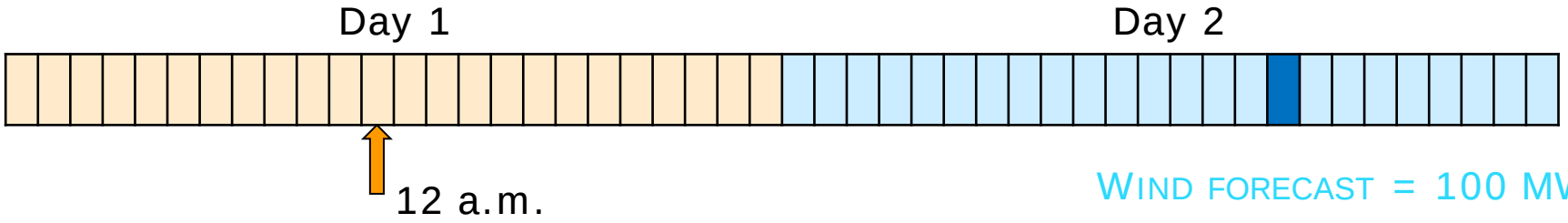
WIND 50MW LOWER THAN EXPECTED

ONLY 30MW OF UP REGULATING RESERVES

20MW OF LOAD SHEDDING

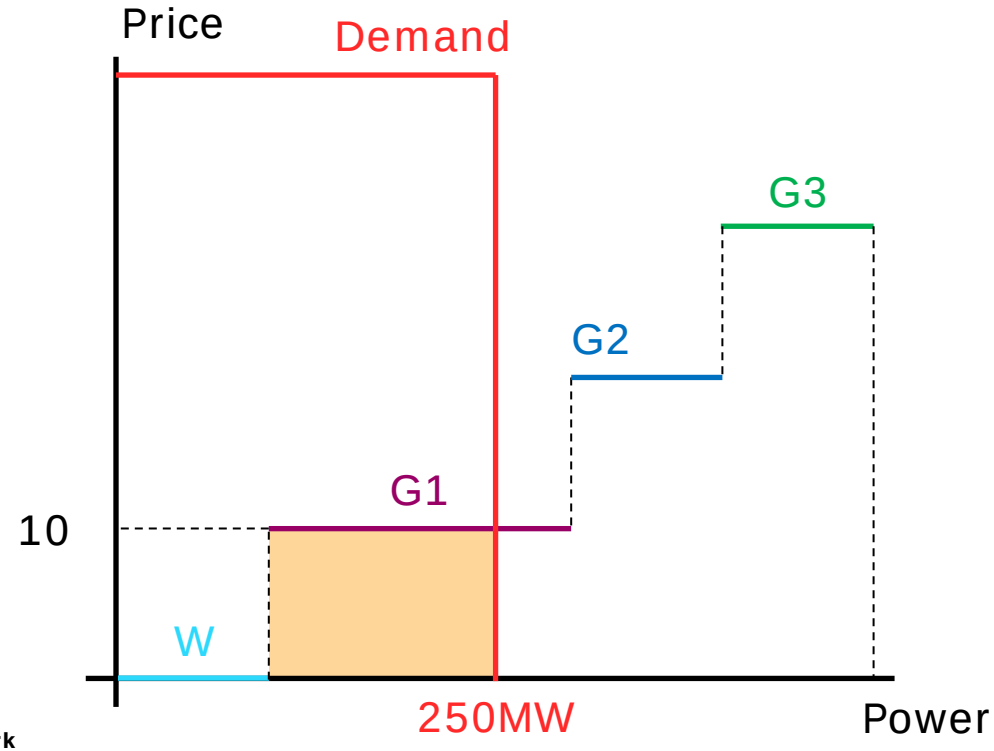
BALANCING ELECTRICITY MARKET

- WHAT WOULD HAPPEN IF WIND CAPACITY INCREASES?



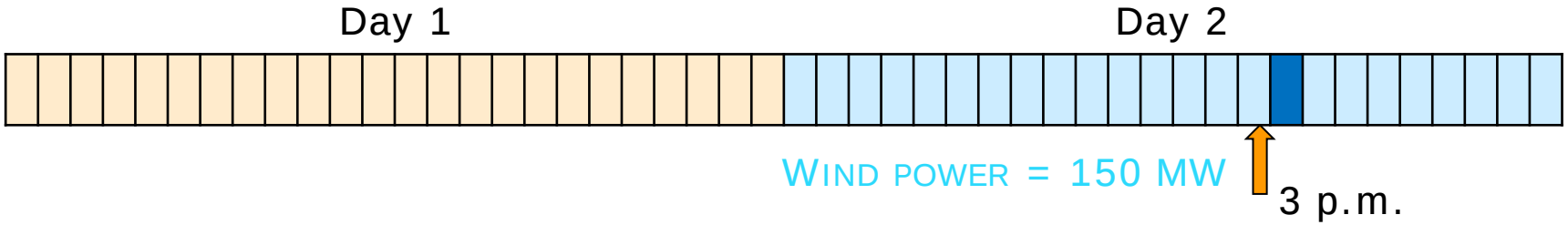
WIND FORECAST = 100 MW

4-5 P.M.	
DA SCHEDULE	
UNIT	MW
W	100
G1	150
G2	-
G3	-

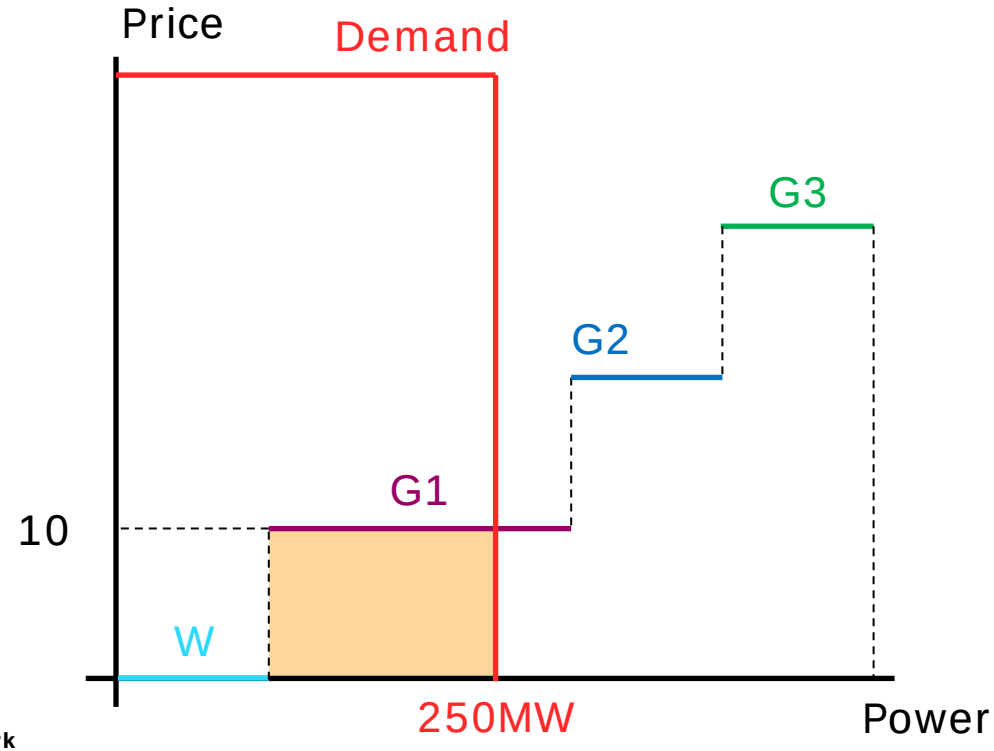


BALANCING ELECTRICITY MARKET

- WHAT WOULD HAPPEN IF WIND CAPACITY INCREASES?

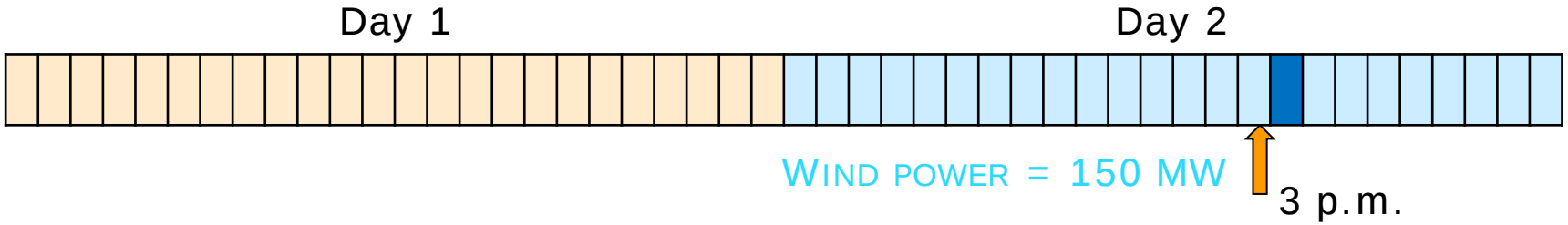


4-5 P.M.			
DA SCHEDULE		REGULATING MARKET	
UNIT	MW	UP	DOWN
W	100	-	-
G1	150	-	-
G2	-	10@25	10@15
G3	-	20@35	20@25



Balancing electricity market

- What would happen if wind capacity increases?



4-5 p.m.			
DA Schedule		Regulating market	
Unit	MW	UP	DOWN
W	100	-	-
G1	150	-	-
G2	-	10@25	10@15
G3	-	20@35	20@25

Wind 50MW higher than expected

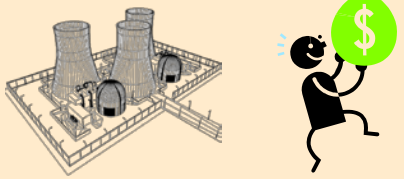
None down regulating reserves

50MW of wind spillage

Balancing electricity market

- Low wind power penetration

Large units



TSO

Customers

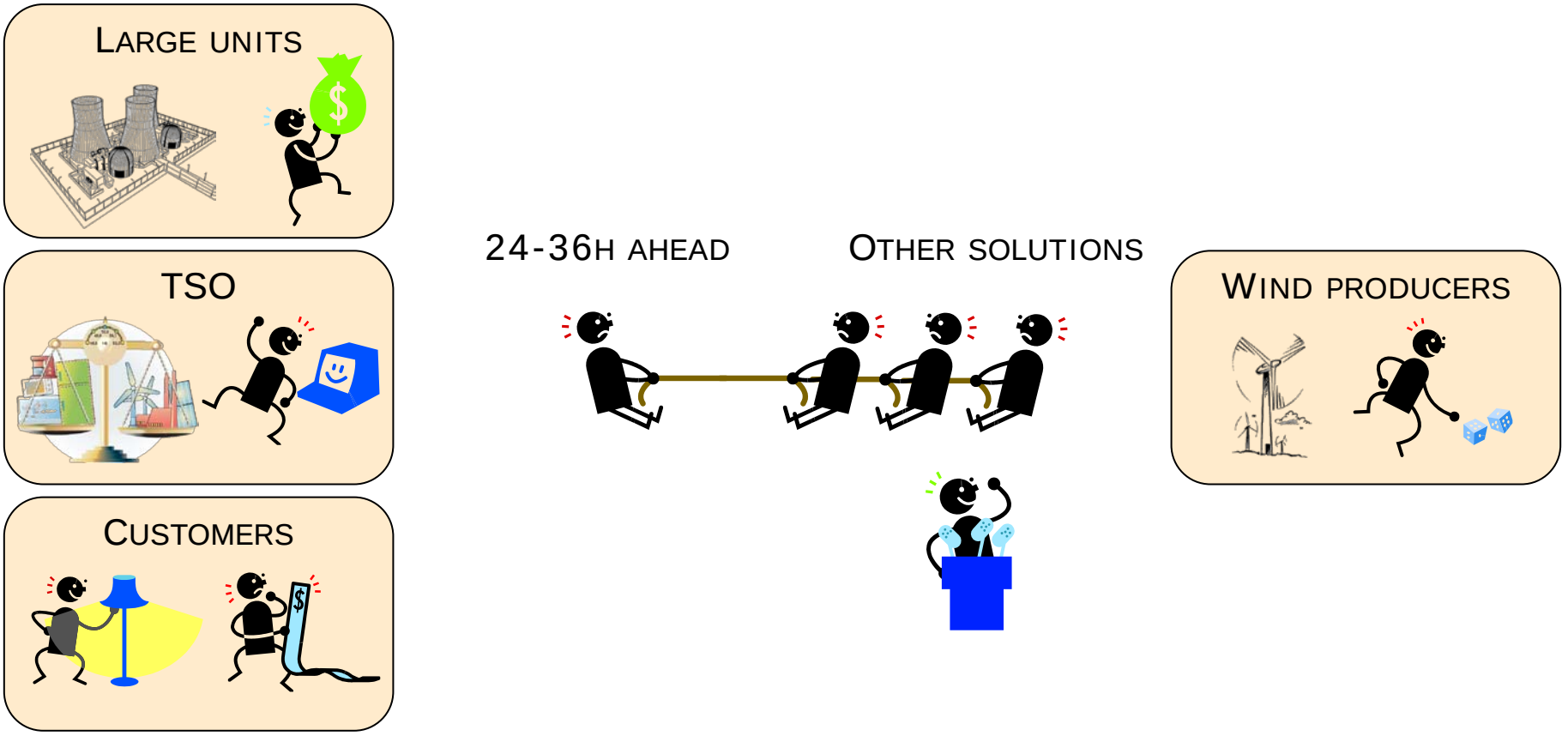
24-36h ahead

Shorter horizon

Wind producers

Balancing electricity market

- High wind power penetration



Outline

- Introduction to markets
- Day-ahead electricity market
- Balancing electricity market
- New market solutions

New solutions

Flexible generation

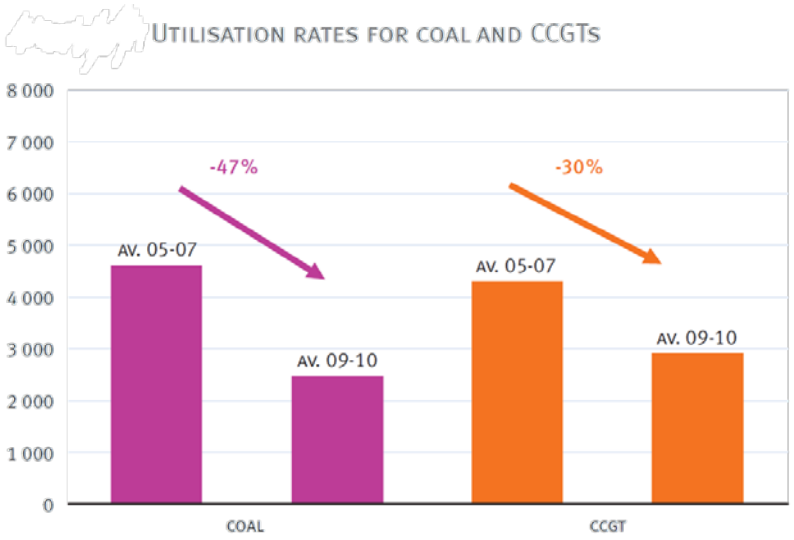
Transmission capacity

Smart Grids

New market designs

New solutions

Flexible generation



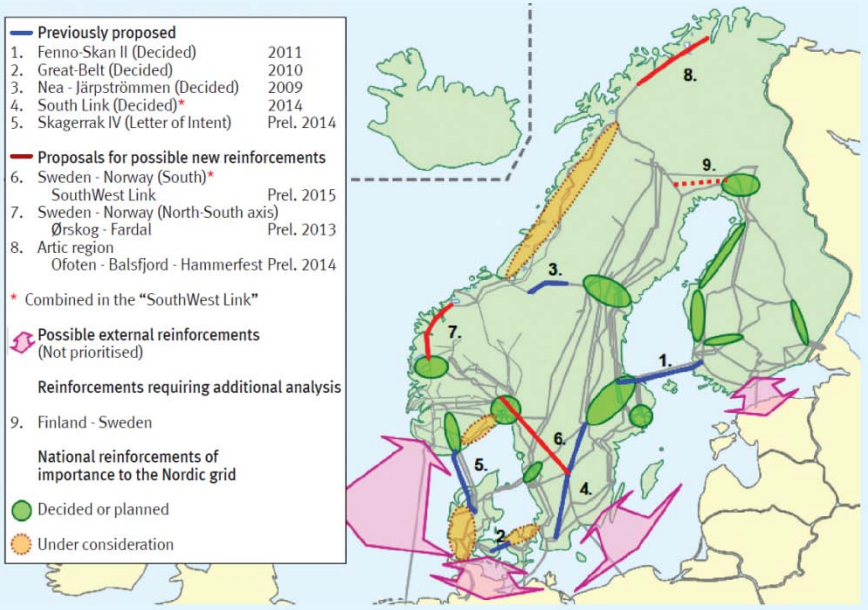
Source: Red Eléctrica de España, figure elaborated by Endesa

- Decreasing utilization rates as wind penetration increases
- Market revenues do not cover production costs
- Capacity market?

New solutions

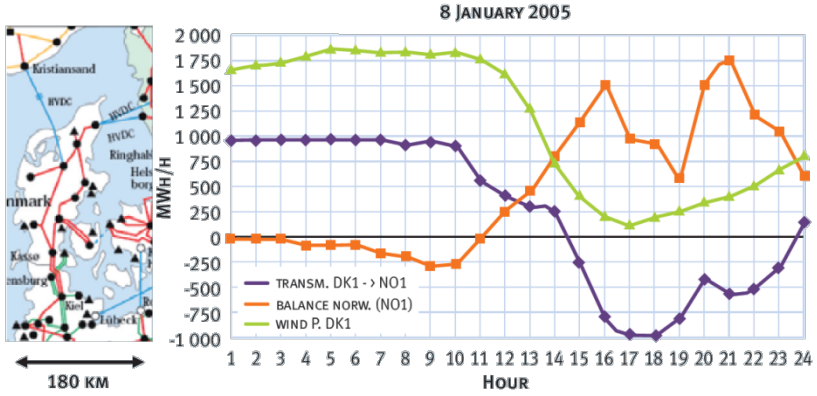
Transmission capacity

Figure 23: The Nordic Grid Master Plan

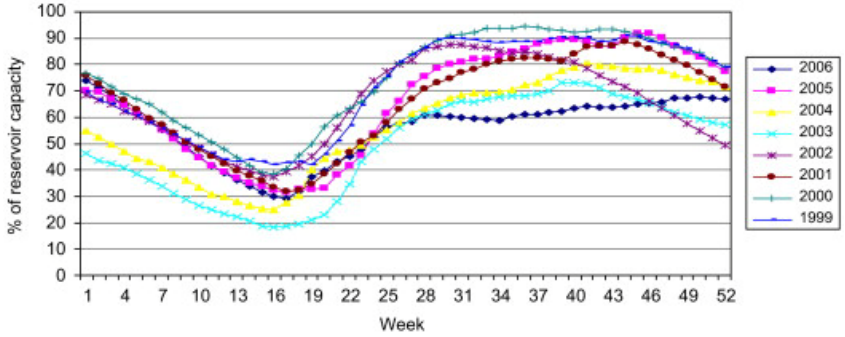


Source: NORDEL, Nordic Grid Master Plan, March 2008, in Svenska Kraftnät and Statnett, "Swedish-Norwegian grid development"

Figure 25: Correlation between a storm hitting the Danish western coast, Danish wind production and the balance of flows between Denmark and Norway



Source: North European Power Perspectives (http://www.nepp.se/organisation.htm)

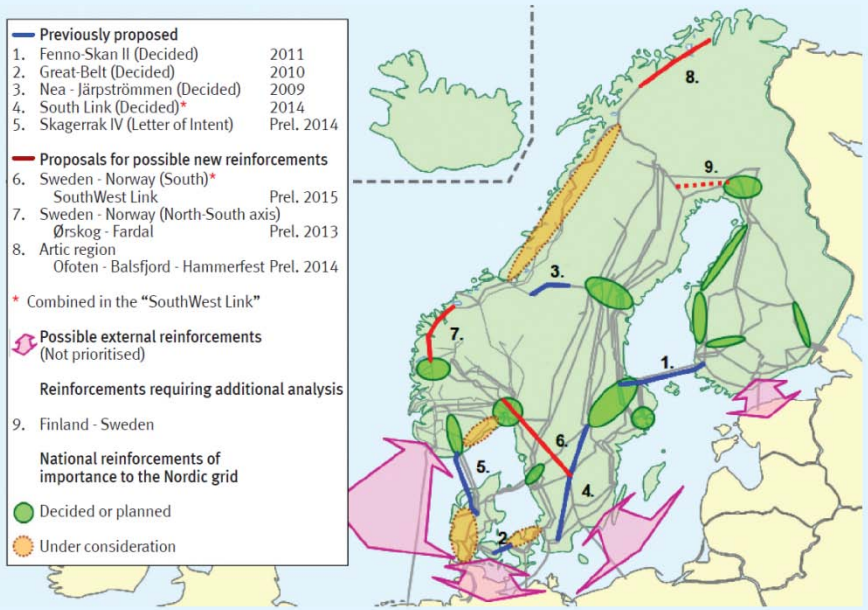


What would happens in dry years?

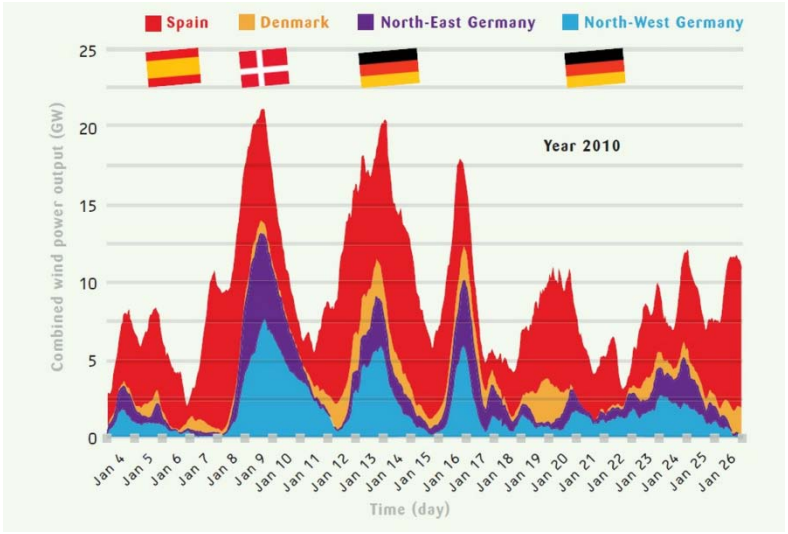
New solutions

Transmission capacity

Figure 23: The Nordic Grid Master Plan



Source: NORDEL, Nordic Grid Master Plan, March 2008, in Svenska Kraftnät and Statnett, "Swedish-Norwegian grid development"



- Dependence on other countries generation
- Failures

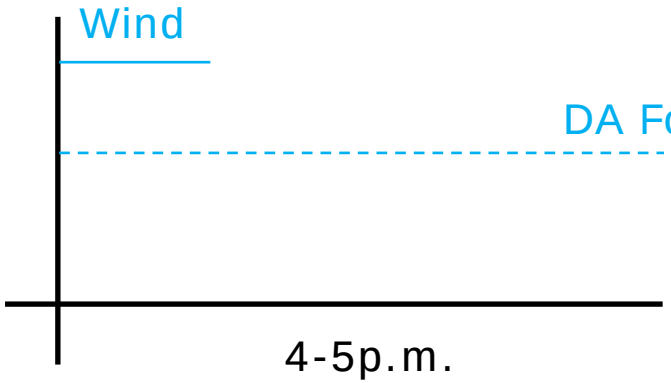
New solutions

Smart Grids

Electrical grid that uses information and communications technology to improve the efficiency, reliability, economics, and sustainability of the production and distribution of electricity.

New solutions

Smart Grids



TSO

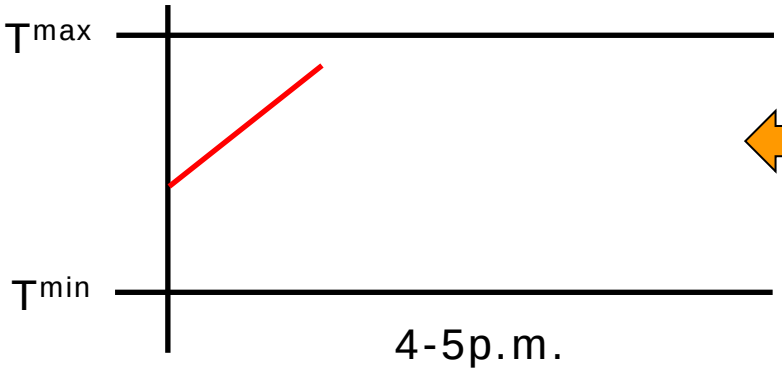
Balance the wind forecast error using flexible demand

Low price

$T^{max} = 22^oC$

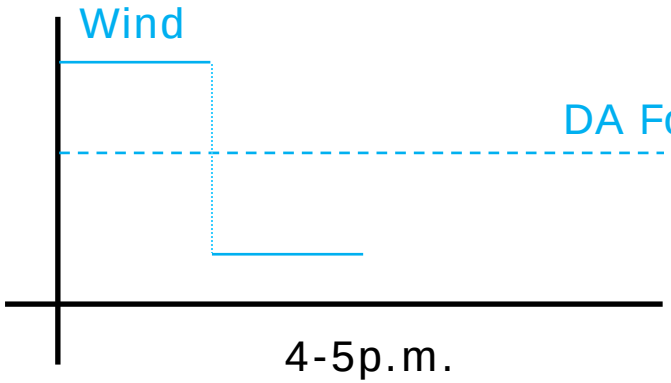
$T^{min} = 18^oC$

Turn on heating



New solutions

Smart Grids

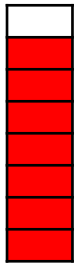


TSO

Balance the wind forecast error using flexible demand

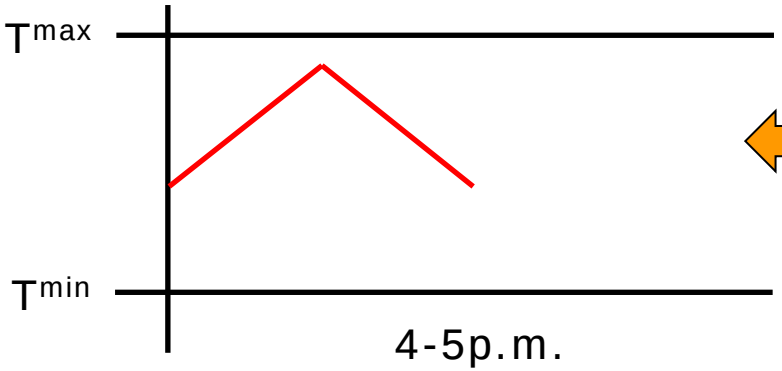
High price

$T^{max} = 22^oC$



$T^{min} = 18^oC$

Turn off heating



New solutions

Smart Grids

- Cheap balancing power
- Distributed resources
- High investment
- Customer acceptance
- Modeling of demand response

New solutions

Smart Grids

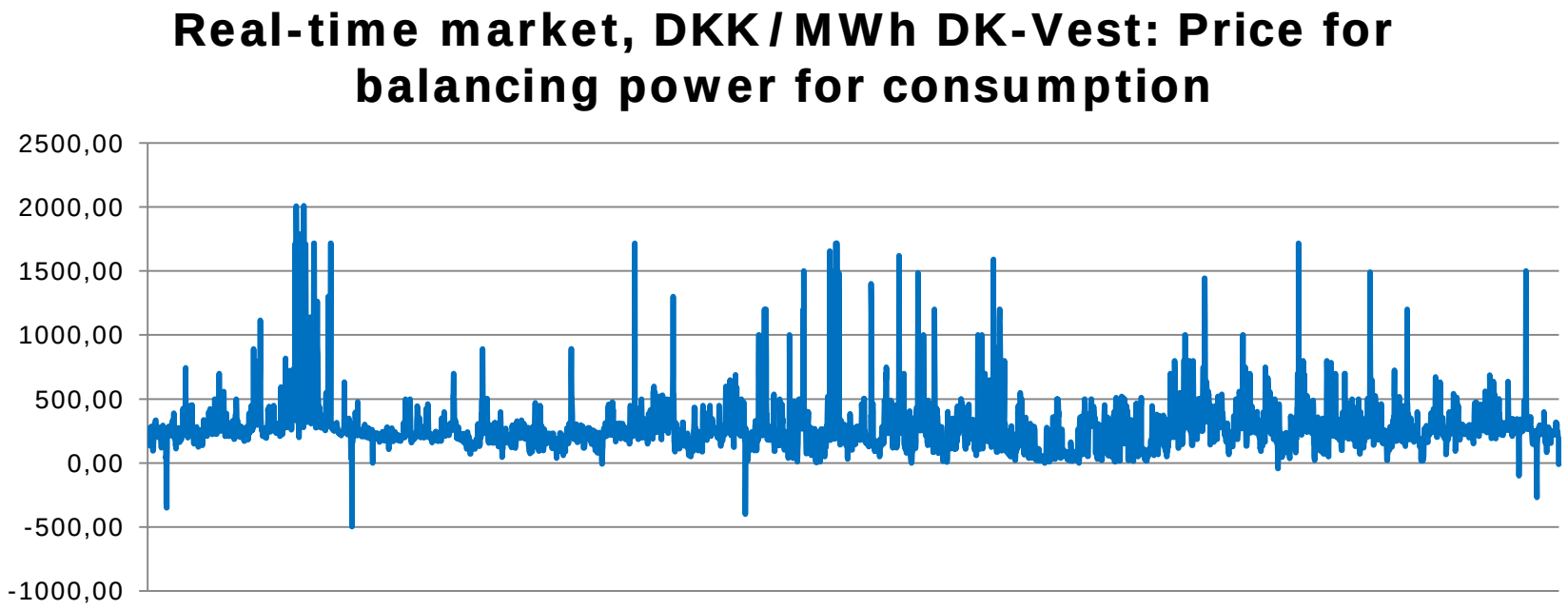
EcoGrid eu
www.eu-ecogrid.net

- 5 minutes real-time market
- 2000 households
- Starting 2013

New solutions

New market designs

- Negative prices



New solutions

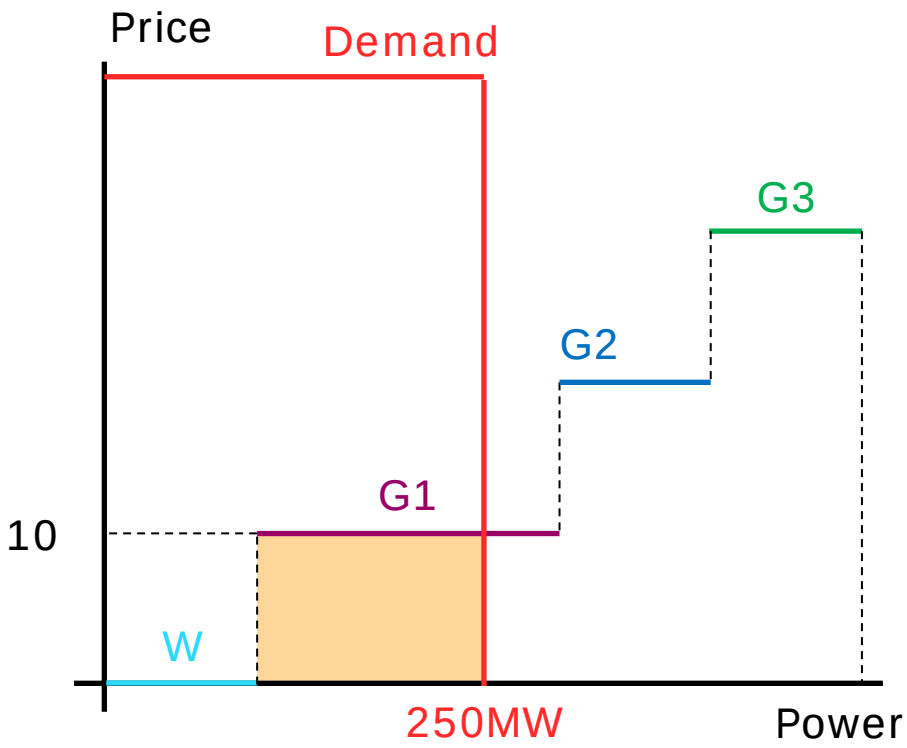
New market designs

- Coordination between day-ahead and balancing

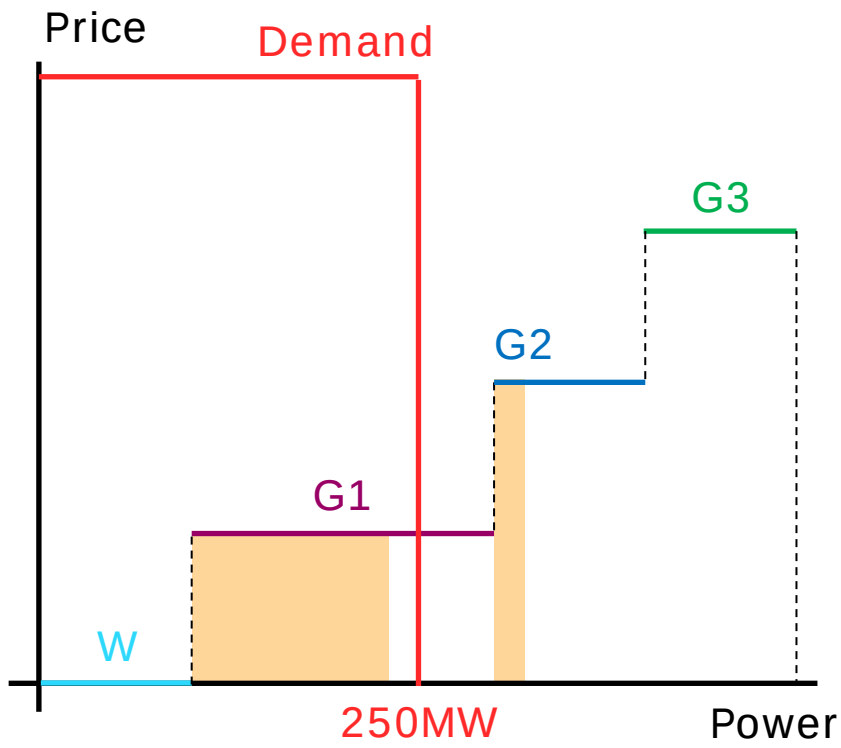
Forecast = 100 MW

Wind(30%) = 130 MW

Decoupled MC



Coupled MC



New solutions

Final solution to integrate renewable production into power systems

- Transmission capacity
- Flexible generation
- New market designs
- Smart Grids

Thanks for your attention!

Questions?