

Electricity Markets and Stochastic Producers



Salvador Pineda Morente

Lunch meeting 09/12/13



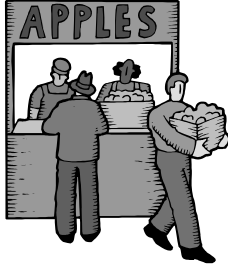

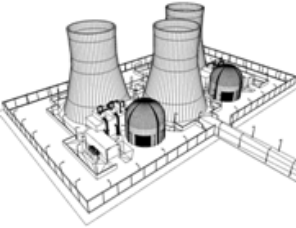

Outline

- Introduction
- Day-ahead market
- Balancing market
- Coordination day-ahead and balancing
- Generation expansion


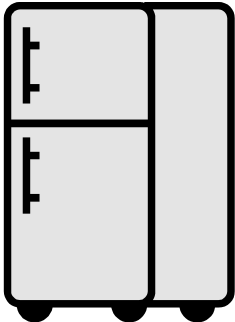
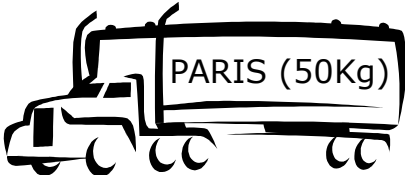


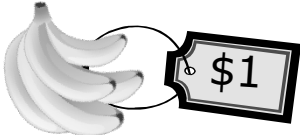


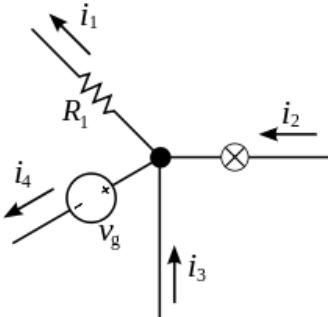
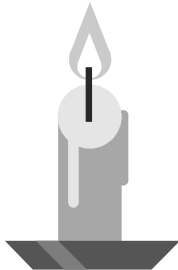
Outline

- Introduction
- Day-ahead market
- Balancing market
- Coordination day-ahead and balancing
- Generation expansion

What is the same?

People who needs products	People who produces those products	Place to trade the products
		
		

What is different?

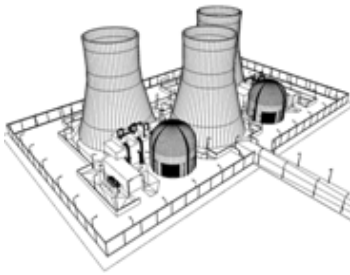
Product	Stored	Transportation	Demand
		 	 
			

Outline

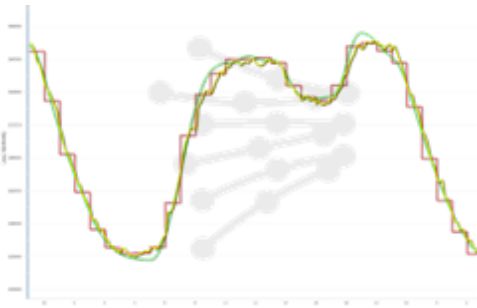
- Introduction
- Day-ahead market
- Balancing market
- Coordination day-ahead and balancing
- Generation expansion

Day-ahead electricity market

- Characteristics of the players:



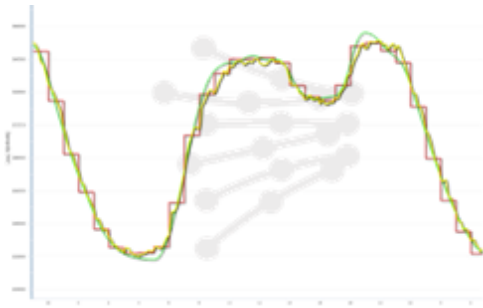
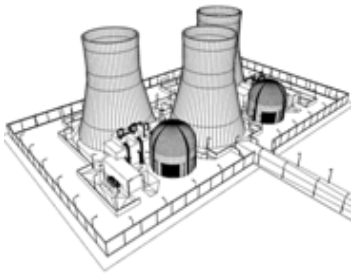
- Large fuel-based units (economy of scale)
- Technical constraints (required a schedule)
- Far from consumption centers (transmission)



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

Day-ahead electricity market

- Characteristics of the players:

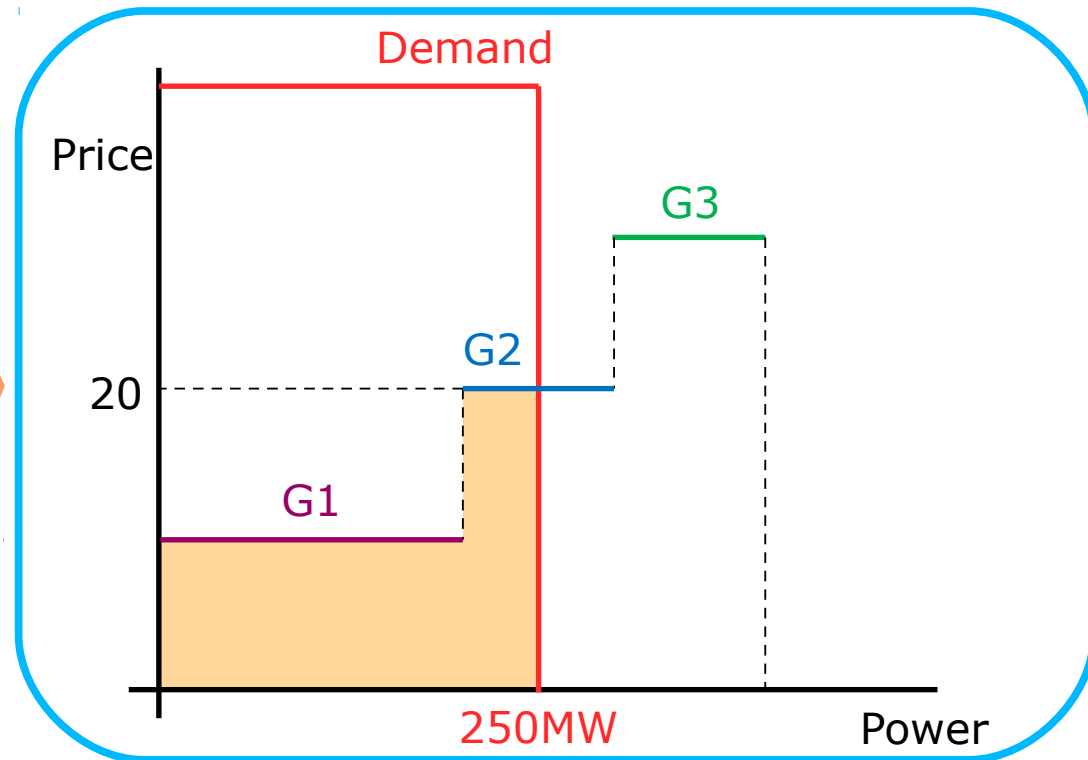
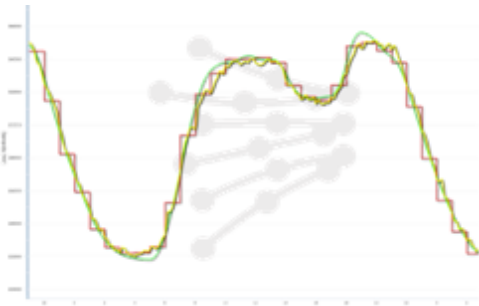
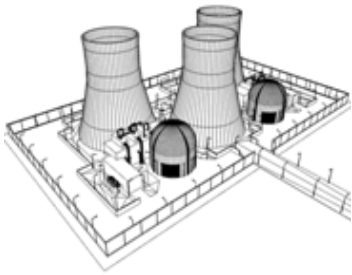


Day-ahead market

- 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

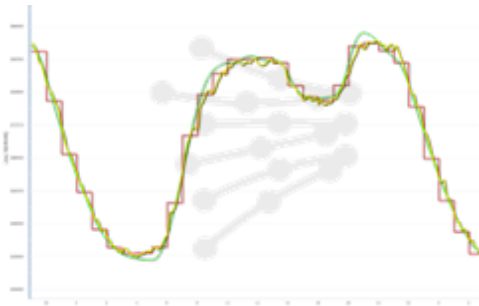
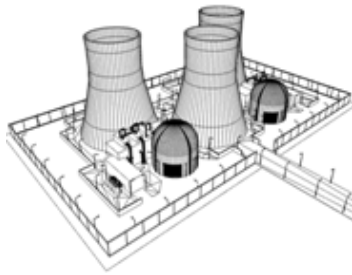
Day-ahead electricity market

- Characteristics of the players:



Day-ahead electricity market

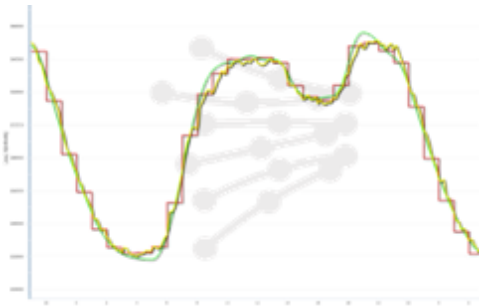
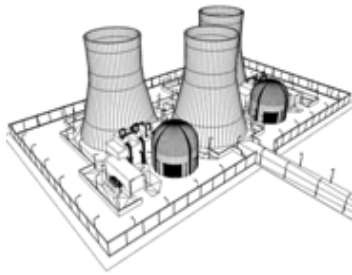
- Characteristics of the players:



$$\begin{aligned} & \underset{p_G}{\text{Minimize}} \quad \mathcal{C}^D(p_G) \\ & \text{s.t.} \quad h^D(p_G) - l = 0 : \lambda^D \\ & \quad \quad g^D(p_G) \leq 0 \end{aligned}$$

Day-ahead electricity market

- Characteristics of the players:



Minimize \mathcal{C}^D p_G

s.t. $h^D(p_G) - l = 0 : \lambda^D$

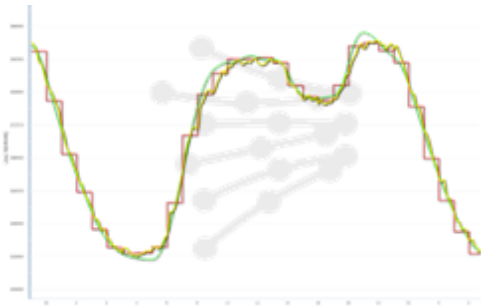
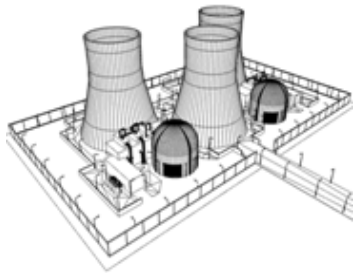
$g^D(p_G) \leq 0$

power dispatch

price

Day-ahead electricity market

- Characteristics of the players:



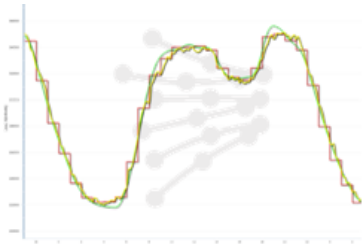
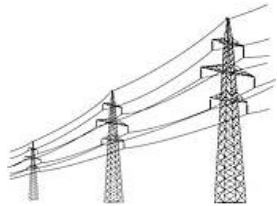
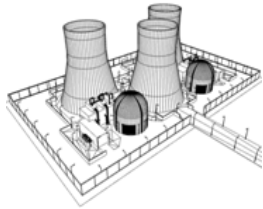
Minimize $\mathcal{C}^D(p_G)$ \longrightarrow cost

s.t. $h^D(p_G) - l = 0 : \lambda^D$ \longrightarrow balance

$g^D(p_G) \leq 0$ \longrightarrow limits

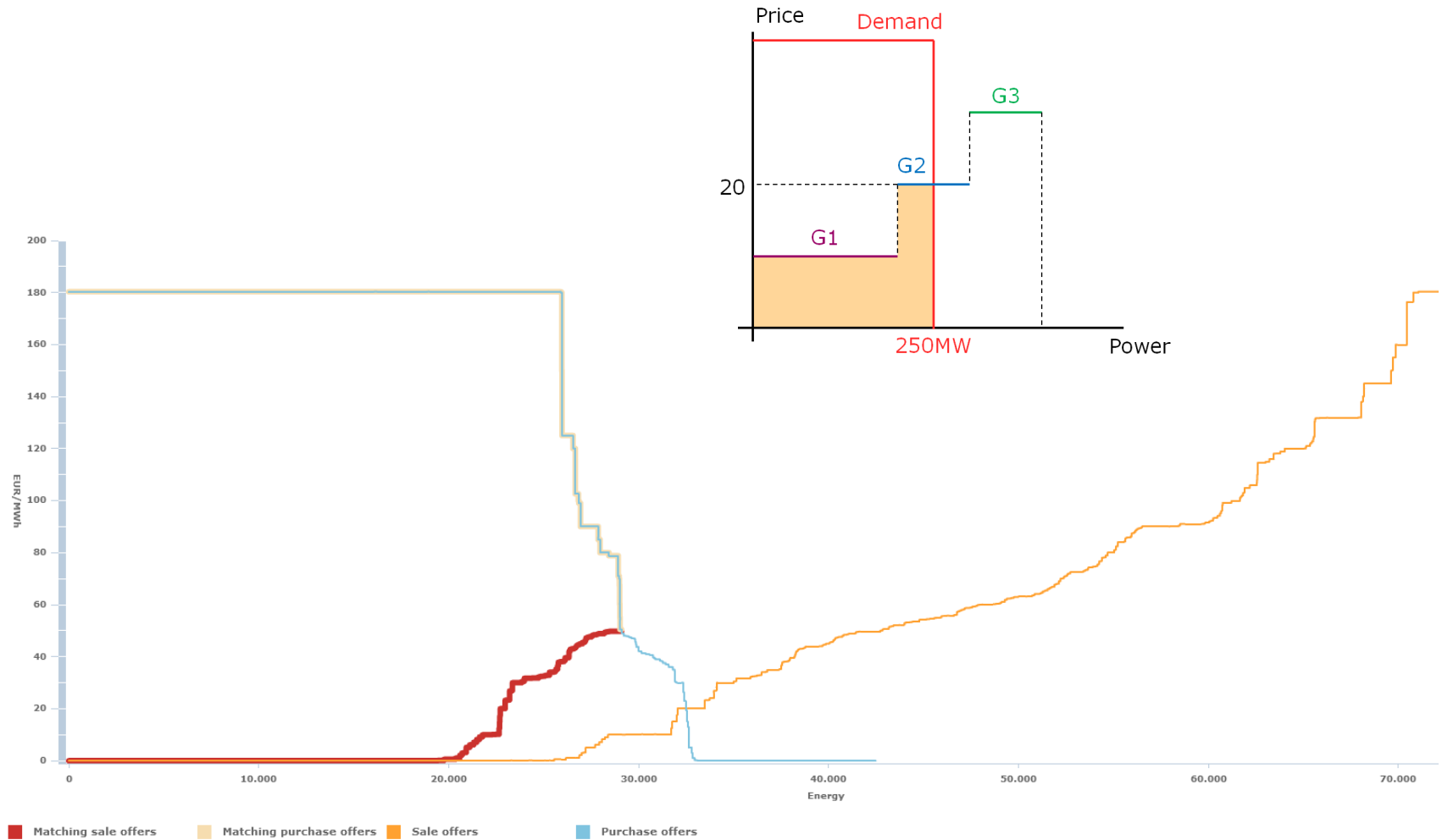
Day-ahead electricity market

- Characteristics of the players:



$$\begin{aligned} & \underset{p_G, \delta^0}{\text{Minimize}} \quad \mathcal{C}^D(p_G) & \longrightarrow & \text{cost} \\ & \text{s.t.} \quad h^D(p_G, \delta^0) - l = 0 : \lambda^D & \longrightarrow & \text{balance} \\ & \quad \quad g^D(p_G, \delta^0) \leq 0 & \longrightarrow & \text{limits} \end{aligned}$$

Day-ahead electricity market



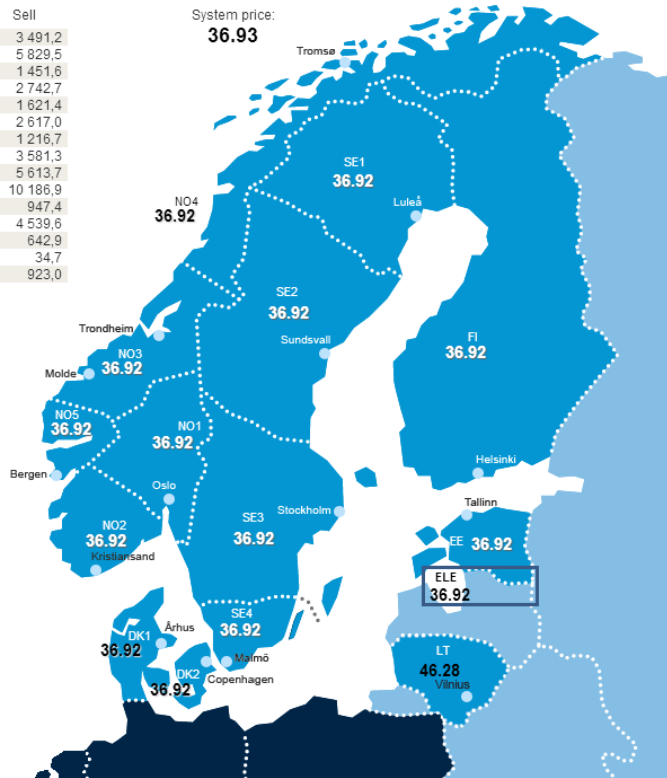
Day-ahead electricity market

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

Eislot 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

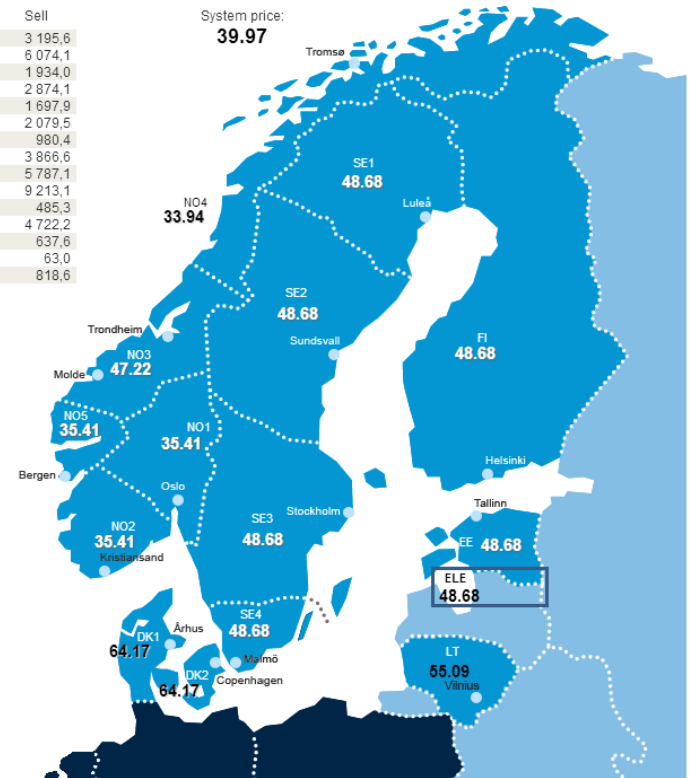


10-10-2012 Resolution 18 - 19 Currency EUR Capacities Flow Area Prices
ITVC ITVC

Eislot 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



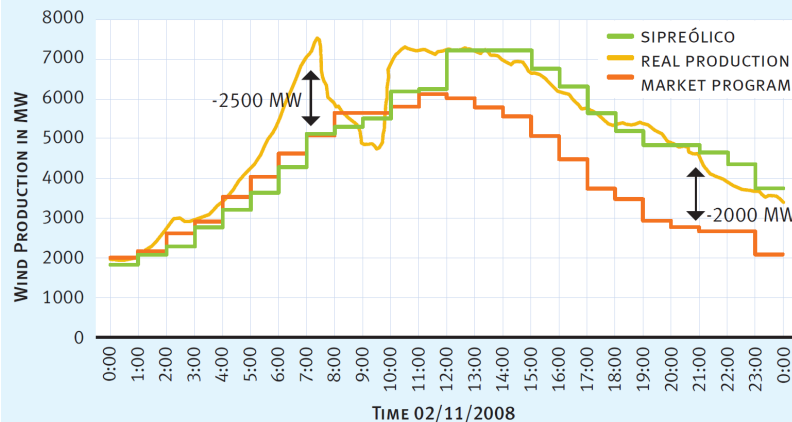
Outline

- Introduction
- Day-ahead market
- **Balancing market**
- Coordination day-ahead and balancing
- Generation expansion

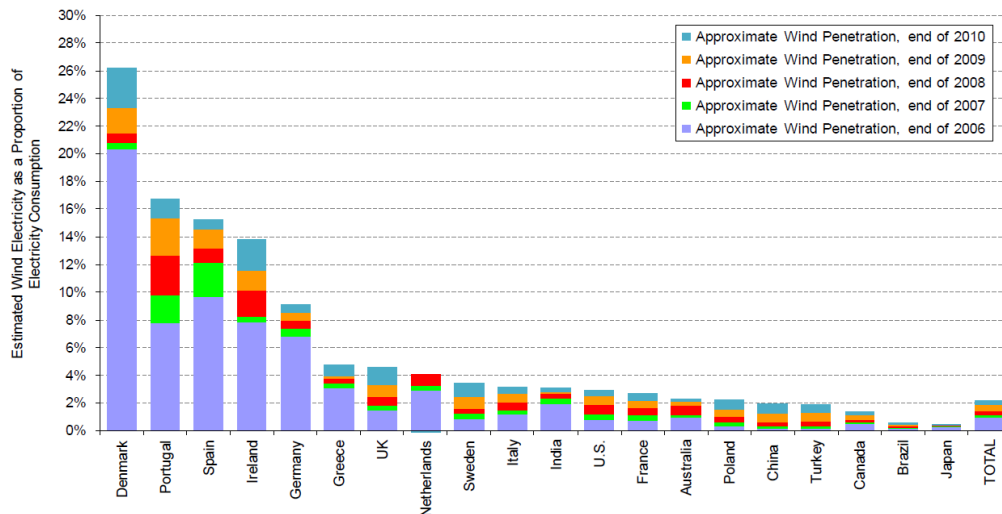
Balancing electricity market

- What about the wind?

FIGURE 16: WIND FORECAST ERROR IN SPAIN



We need to deal with forecast errors
Nowadays: balancing market



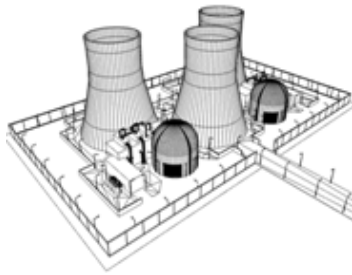
2020 target: 20% renewable

Week 43:

- 56% (one week)
- 89% (one day)
- 122% (one hour)

Balancing electricity market

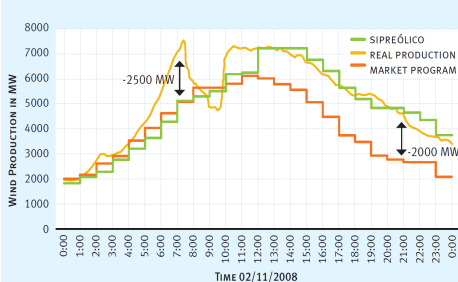
- Characteristics of the players:



Balancing market

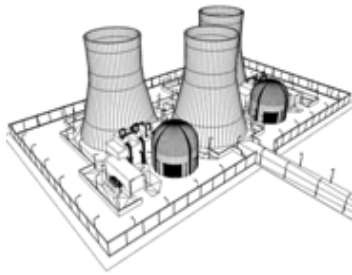
- Power producers submit offers to deviate from schedule
- The demand and wind is known
- The cheapest offers are accepted until deviations are balanced out

FIGURE 16: WIND FORECAST ERROR IN SPAIN



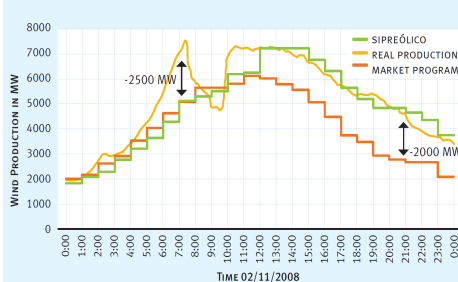
Balancing electricity market

- Characteristics of the players:

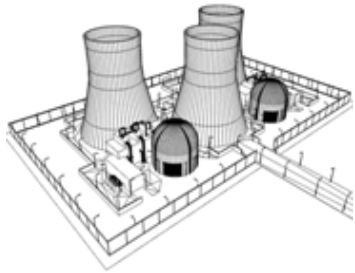


$$\begin{aligned} & \underset{y_{\omega'}, \delta_{\omega'}}{\text{Minimize}} \quad C^B(y_{\omega'}) \\ & \text{s.t.} \quad h^B(y_{\omega'}, \delta_{\omega'}, \delta^{0*}) + W_{\omega'} - p_W^* = 0 : \lambda_{\omega'}^B, \\ & \quad \quad g^B(y_{\omega'}, \delta_{\omega'}, p_G^*; W_{\omega'}) \leq 0 \end{aligned}$$

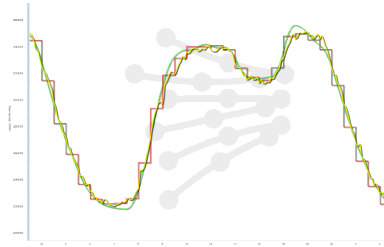
FIGURE 16: WIND FORECAST ERROR IN SPAIN



Balancing electricity market



+



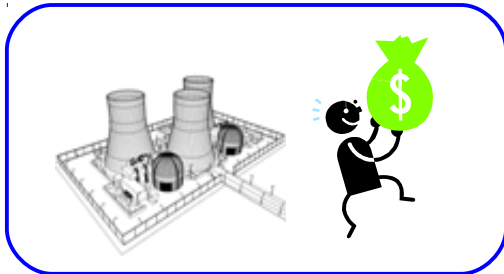
=

Day-ahead
market

Balancing

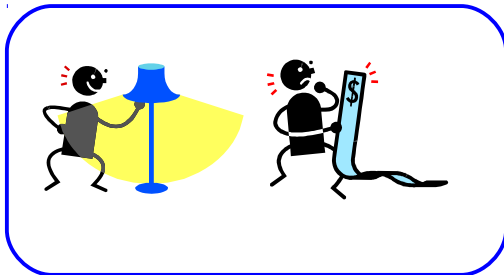
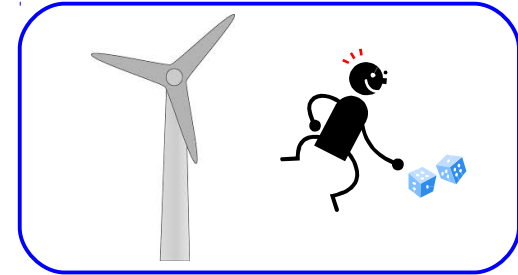
Balancing electricity market

- Low wind power penetration

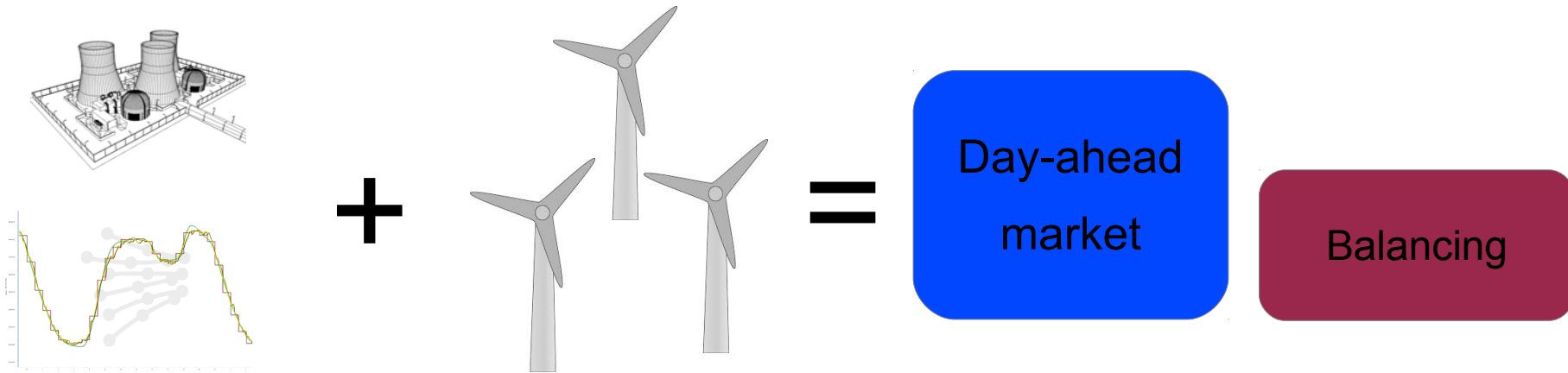
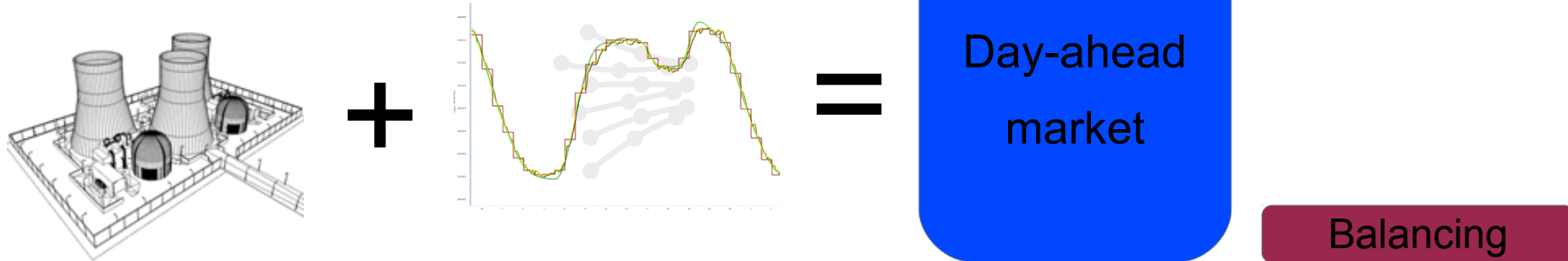


24-36h ahead

Shorter horizon

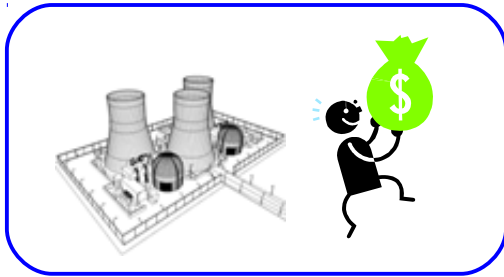


Balancing electricity market



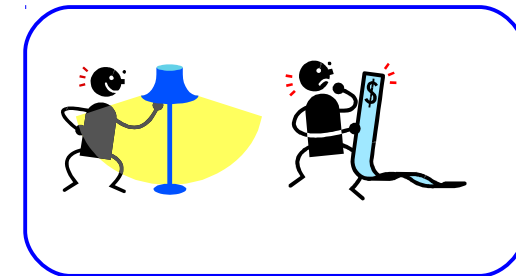
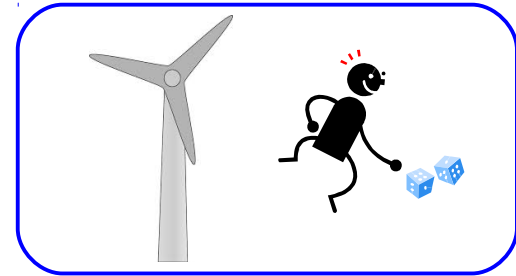
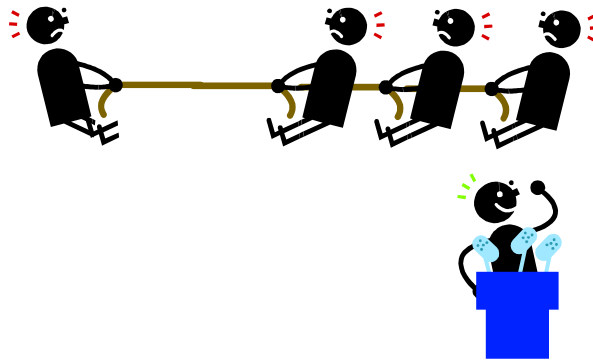
Balancing electricity market

- High wind power penetration



24-36h ahead

Shorter horizon



Outline

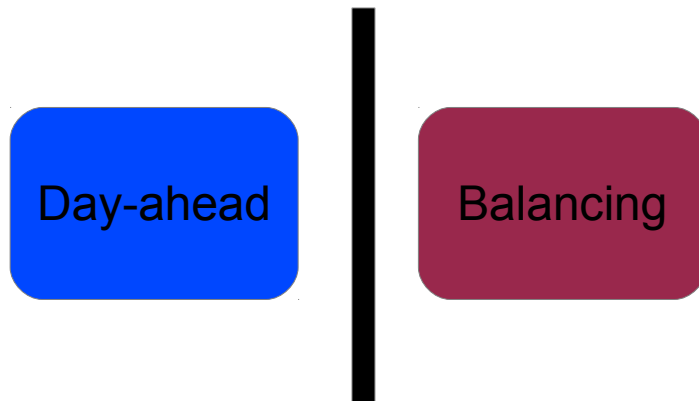
- Introduction
- Day-ahead market
- Balancing market
- Coordination day-ahead and balancing
- Generation expansion

Market design solutions

- Coordination between day-ahead and balancing

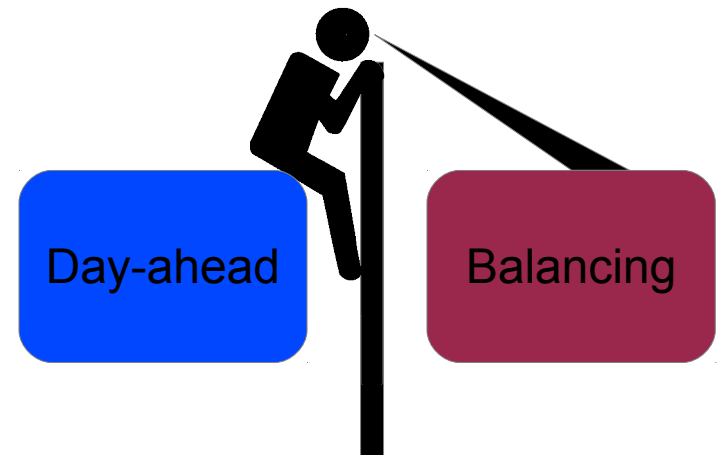
Conventional MC

Day-ahead dispatch
compute disregarding
balancing operation



Stochastic MC

Day-ahead dispatch
takes into account
balancing operation



Market design solutions

- Coordination between day-ahead and balancing

Conv MC

$$\begin{aligned}
 & \text{Minimize}_{p_G, p_W, \delta^0} \mathcal{C}^D(p_G, p_W) \\
 & \text{s.t.} \quad h^D(p_G, p_W, \delta^0) - l = 0 : \lambda^D \\
 & \quad \quad g^D(p_G, \delta^0) \leq 0 \\
 & \quad \quad p_W \leq \widehat{W}
 \end{aligned}$$



$$\begin{aligned}
 & \text{Minimize}_{y_{\omega'}, \delta_{\omega'}} \mathcal{C}^B(y_{\omega'}) \\
 & \text{s.t.} \quad h^B(y_{\omega'}, \delta_{\omega'}, \delta^{0*}) + W_{\omega'} - p_W^* = 0 : \lambda_{\omega'}^B \\
 & \quad \quad g^B(y_{\omega'}, \delta_{\omega'}, p_G^*; W_{\omega'}) \leq 0
 \end{aligned}$$

Stoc MC

$$\begin{aligned}
 & \text{Minimize}_{p_G, p_W, \delta^0; y_{\omega}, \delta_{\omega}, \forall \omega} \mathcal{C}^D(p_G, p_W) + \mathbb{E}_{\omega} [\mathcal{C}^B(y_{\omega})] \\
 & \text{s.t.} \quad h^D(p_G, p_W, \delta^0) - l = 0 : \lambda^D \\
 & \quad \quad g^D(p_G, \delta^0) \leq 0 \\
 & \quad \quad p_W \leq \overline{W} \\
 & \quad \quad h^B(y_{\omega}, \delta_{\omega}, \delta^0) + W_{\omega} - p_W = 0, \quad \forall \omega \in \Omega \\
 & \quad \quad g^B(y_{\omega}, \delta_{\omega}, p_G; W_{\omega}) \leq 0, \quad \forall \omega \in \Omega
 \end{aligned}$$



$$\begin{aligned}
 & \text{Minimize}_{y_{\omega'}, \delta_{\omega'}} \mathcal{C}^B(y_{\omega'}) \\
 & \text{s.t.} \quad h^B(y_{\omega'}, \delta_{\omega'}, \delta^{0*}) + W_{\omega'} - p_W^* = 0 : \lambda_{\omega'}^B \\
 & \quad \quad g^B(y_{\omega'}, \delta_{\omega'}, p_G^*; W_{\omega'}) \leq 0
 \end{aligned}$$

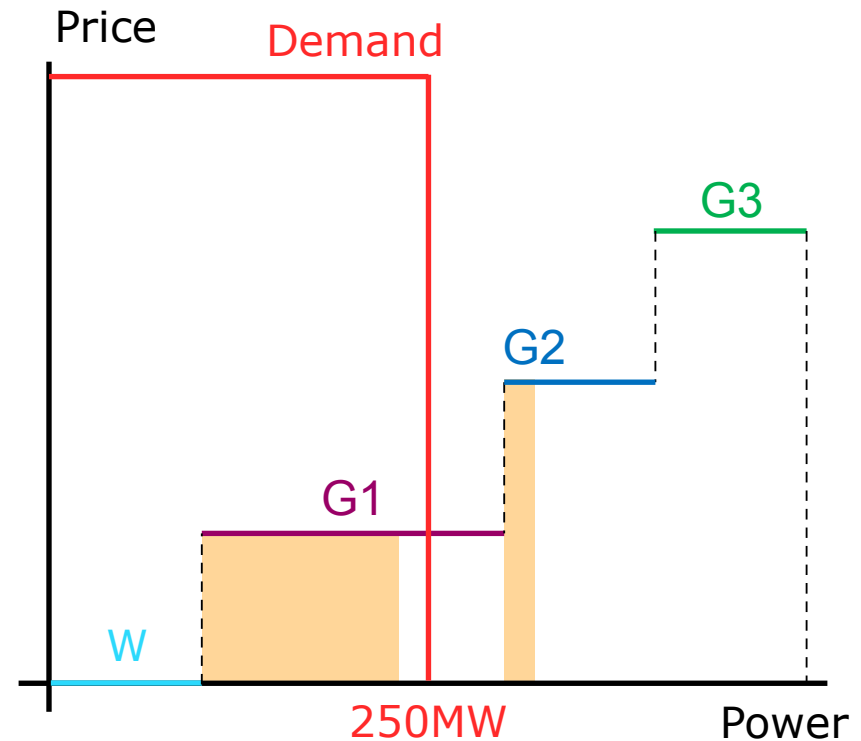
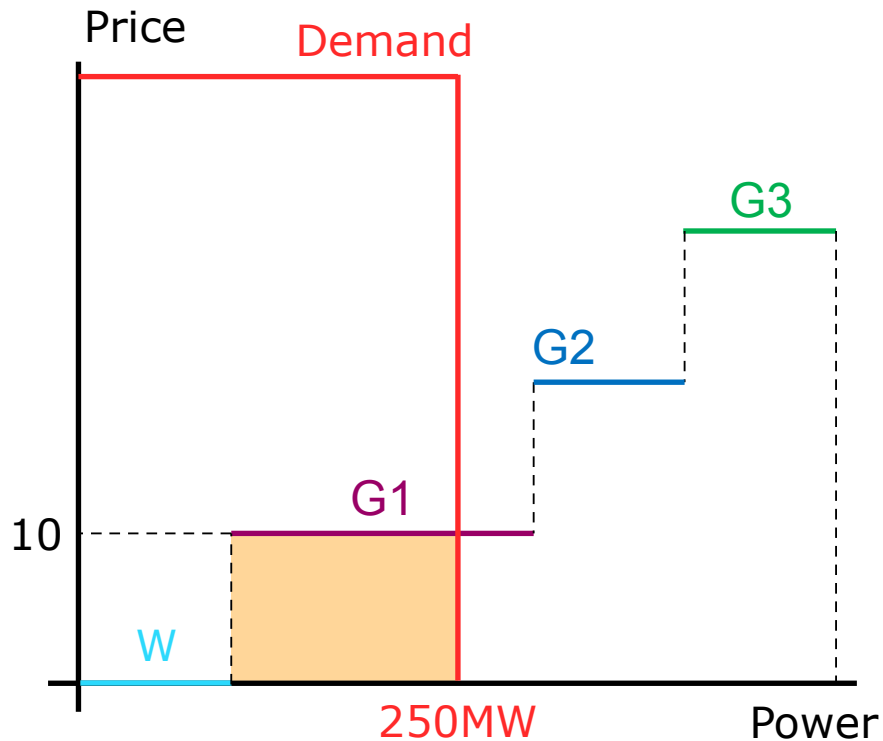
Market design solutions

- Coordination between day-ahead and balancing

Conv MC

Forecast=100 MW
Wind(30%)=130 MW

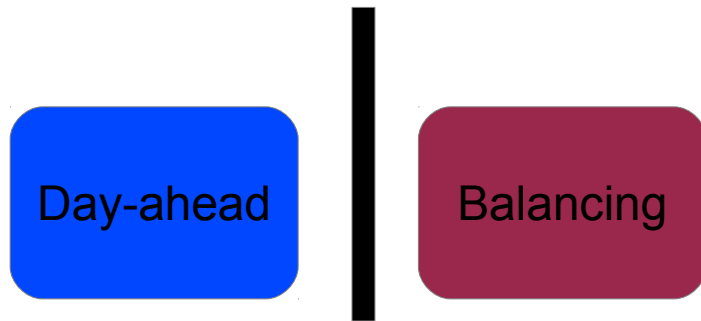
Stoc MC



Market design solutions

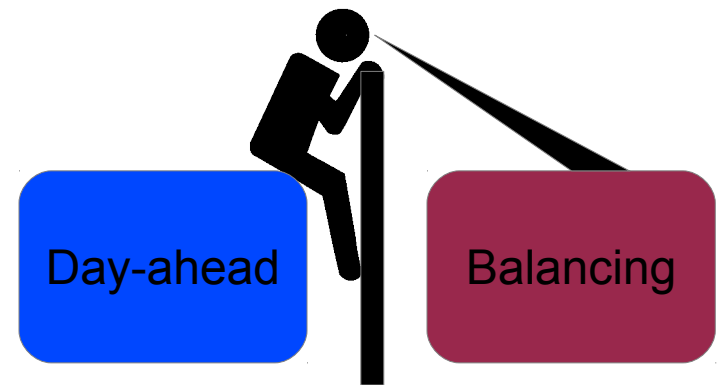
- Coordination between day-ahead and balancing

Conv MC



- DA dispatch: cheaper go first
- Balancing operation not included
- Minimizes day-ahead cost
- Higher imbalance cost
- All units obtain profits

Stoc MC

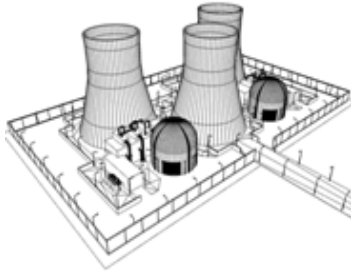


- DA dispatch: out of merit-order
- Balancing operation included
- Minimizes total cost
- Reduces imbalance cost
- Flexible units may incur losses

Outline

- Introduction
- Day-ahead market
- Balancing market
- Coordination day-ahead and balancing
- Generation expansion

Expansion of stochastic units

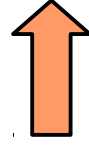


Power producer

Decide new units

Maximize profit

Capacities
& location



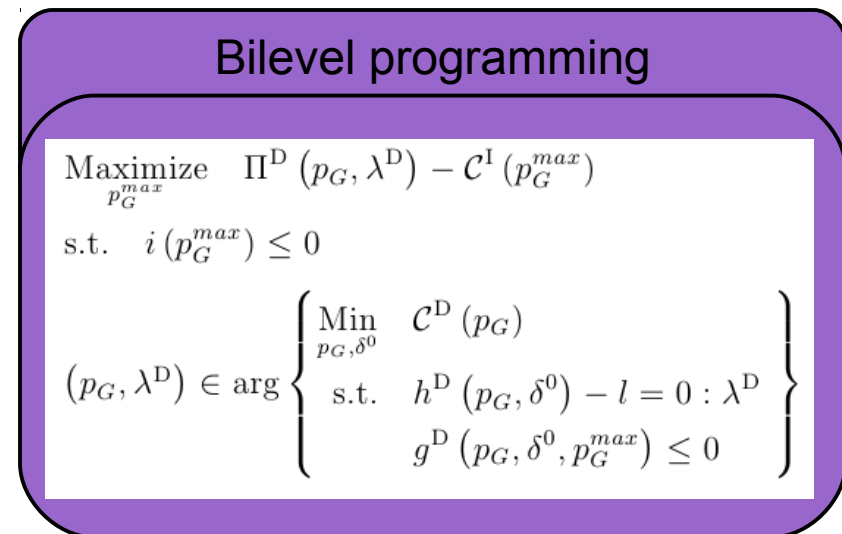
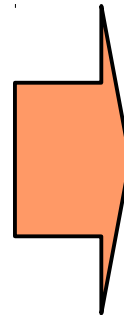
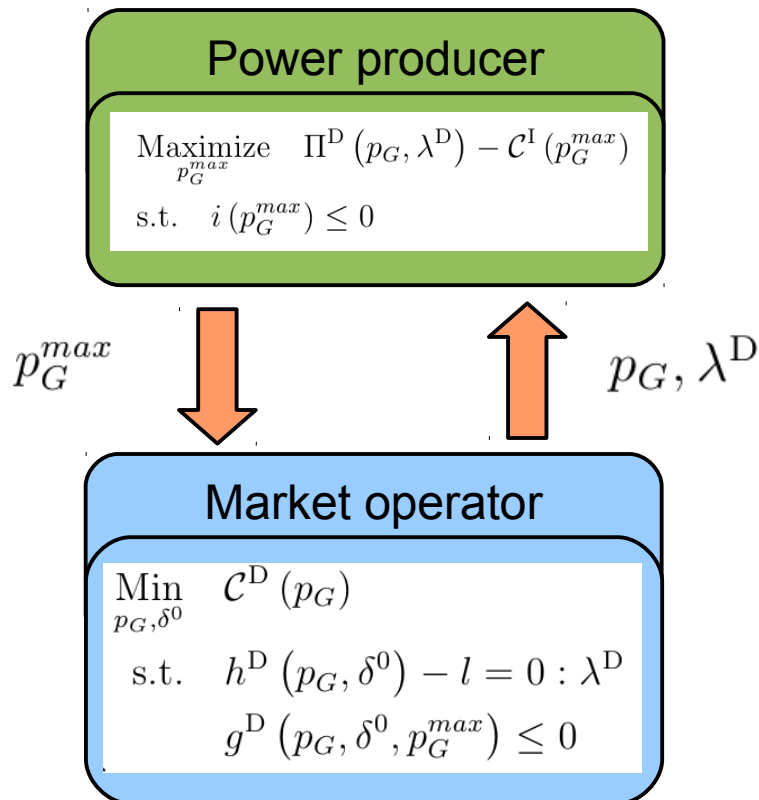
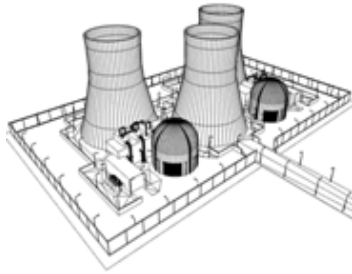
Dispatch
& prices

Market operator

Decide dispatch

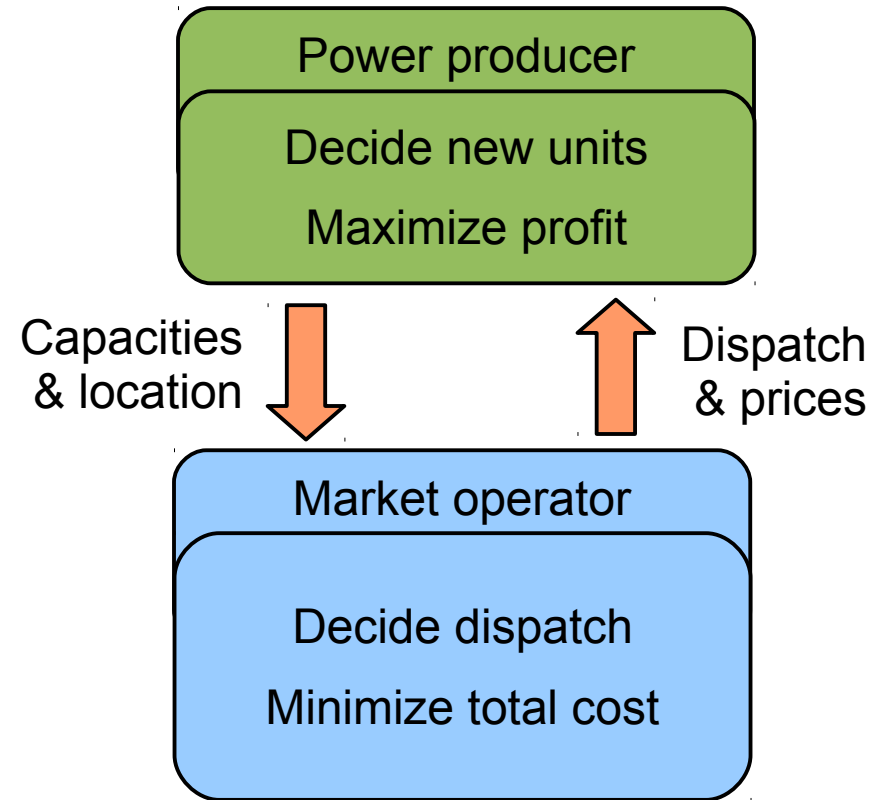
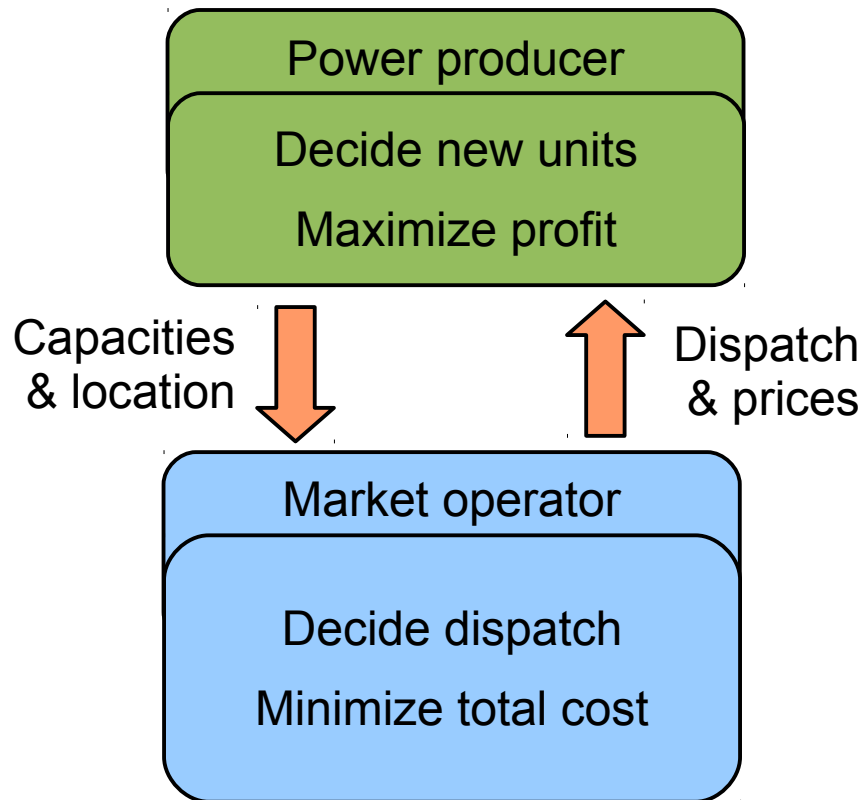
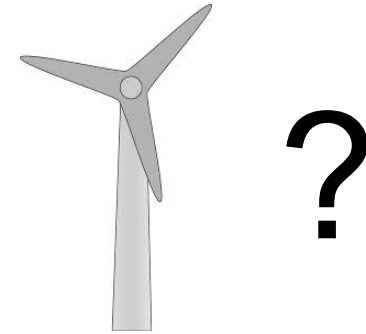
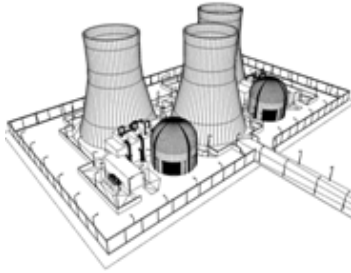
Minimize total cost

Expansion of stochastic units

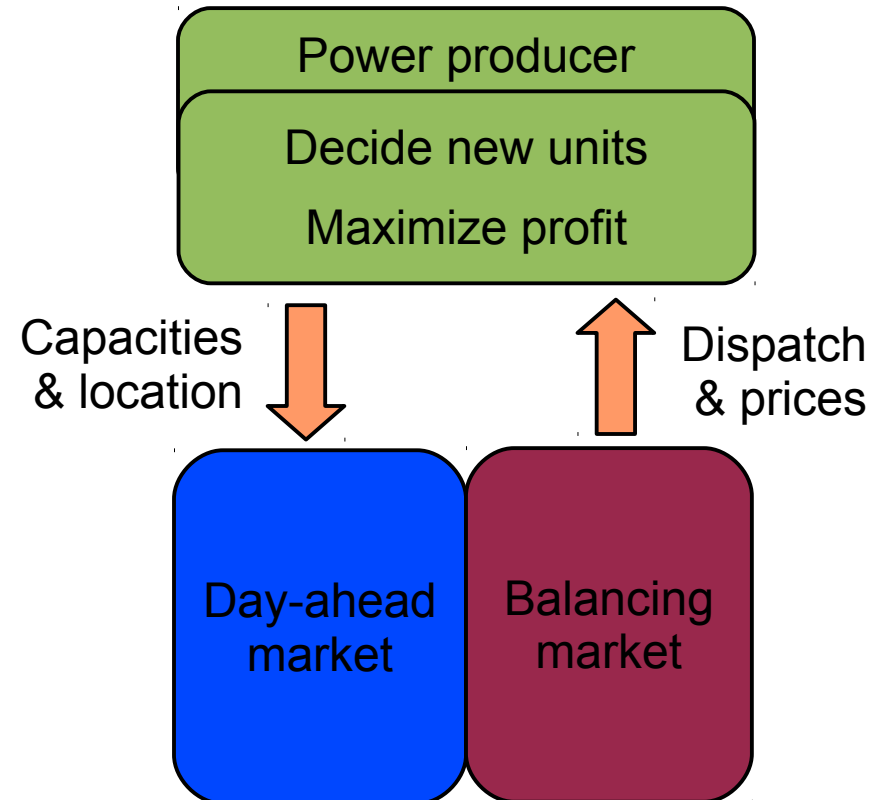
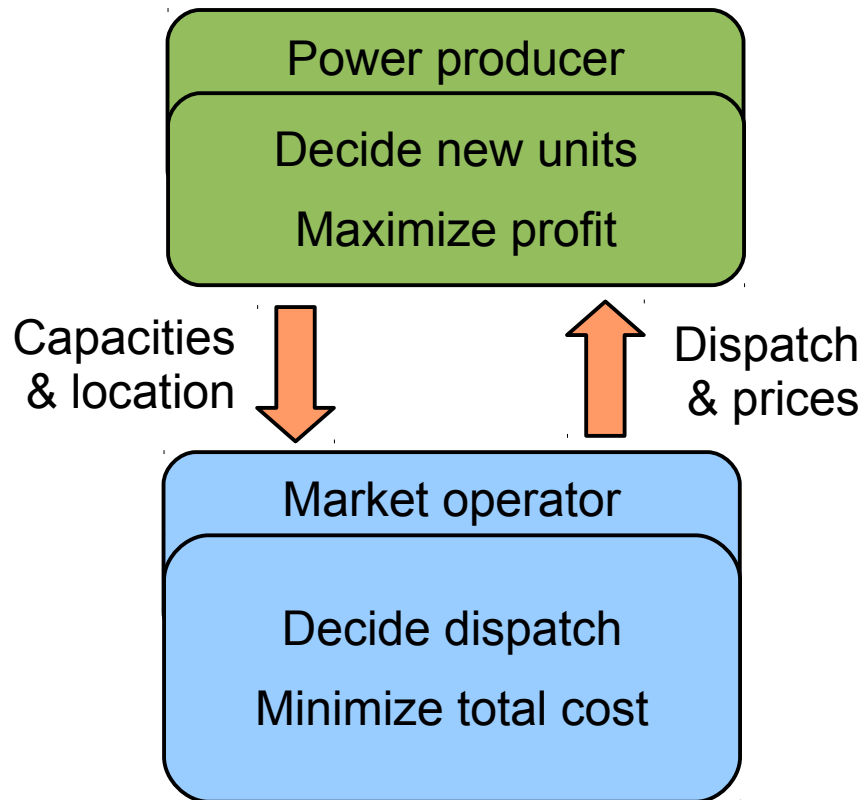
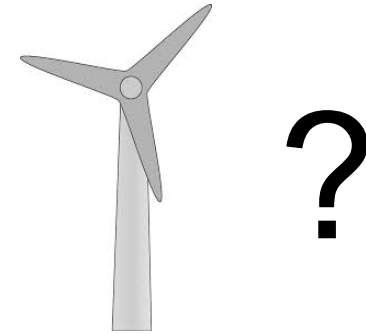
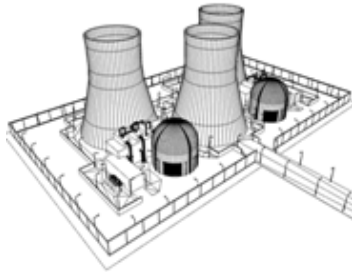


Solve replacing lower-level problem by its KKT conditions

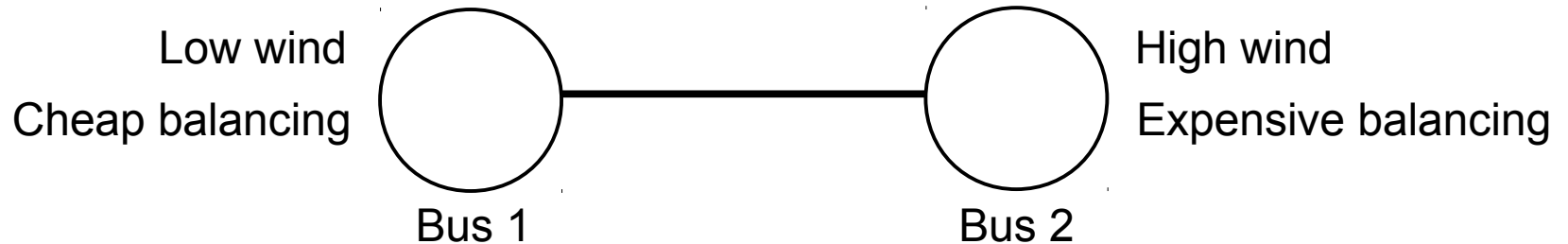
Expansion of stochastic units



Expansion of stochastic units



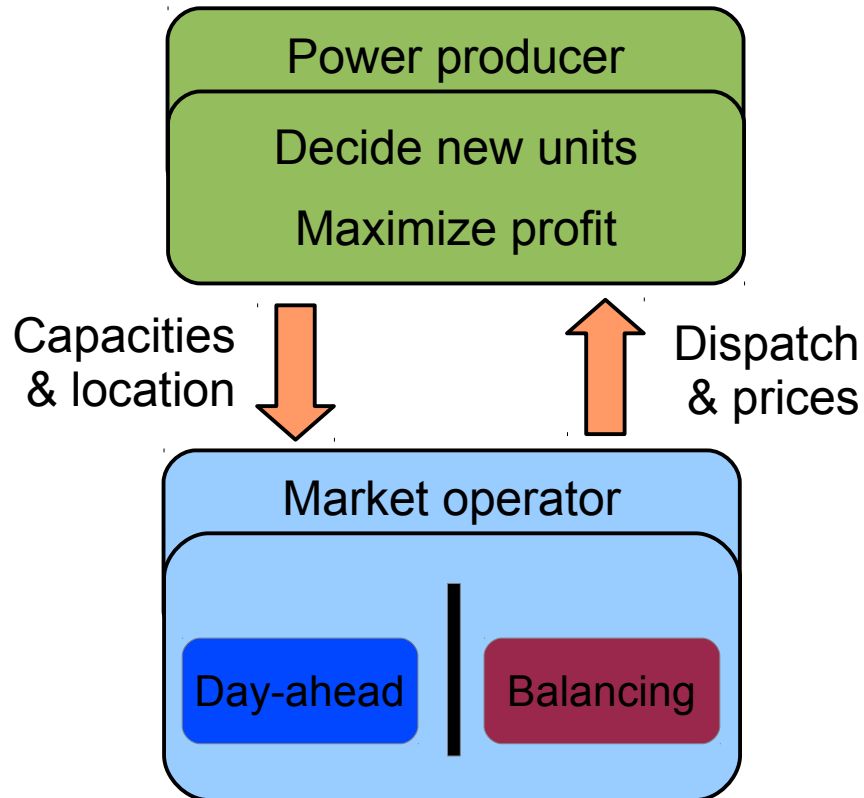
Expansion of stochastic units



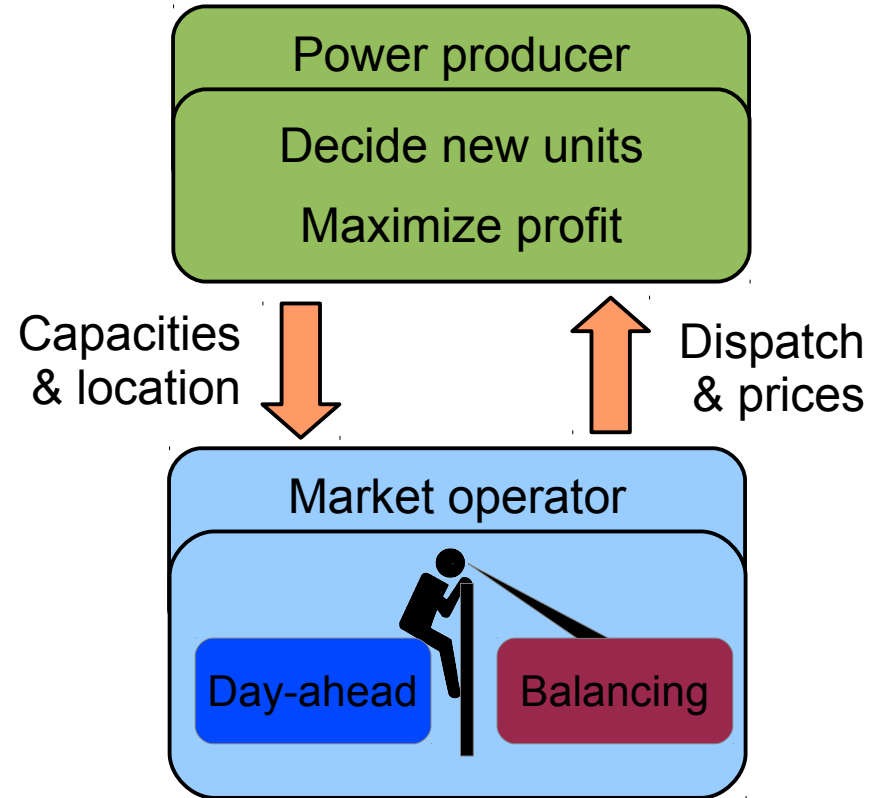
- Where would you locate new wind generating units?
- What about wind forecast errors?
- We need to model both day-ahead and balancing markets
- Will the coordination between DA-B affect investment?

Expansion of stochastic units

Investment under Conv MC

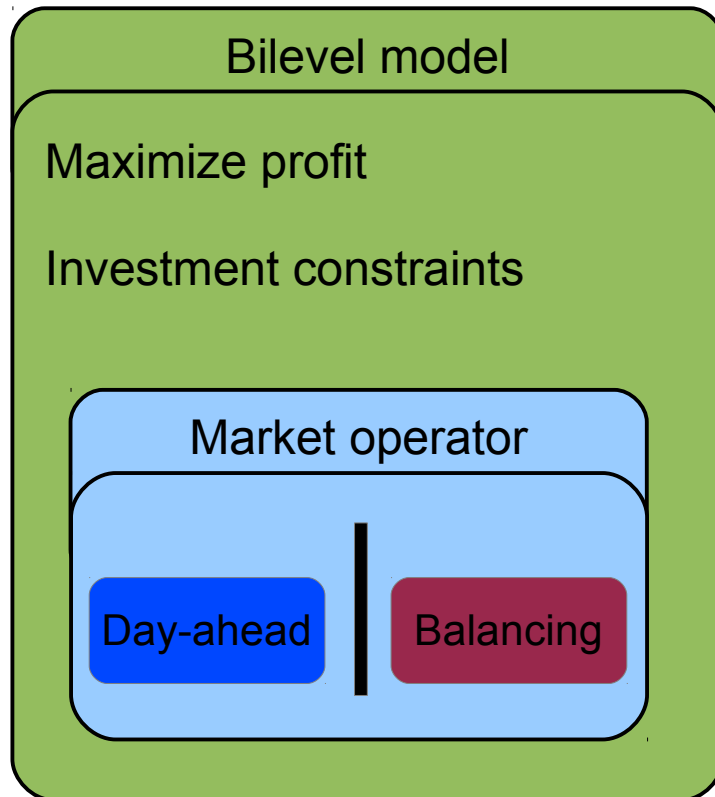


Investment under Stoc MC

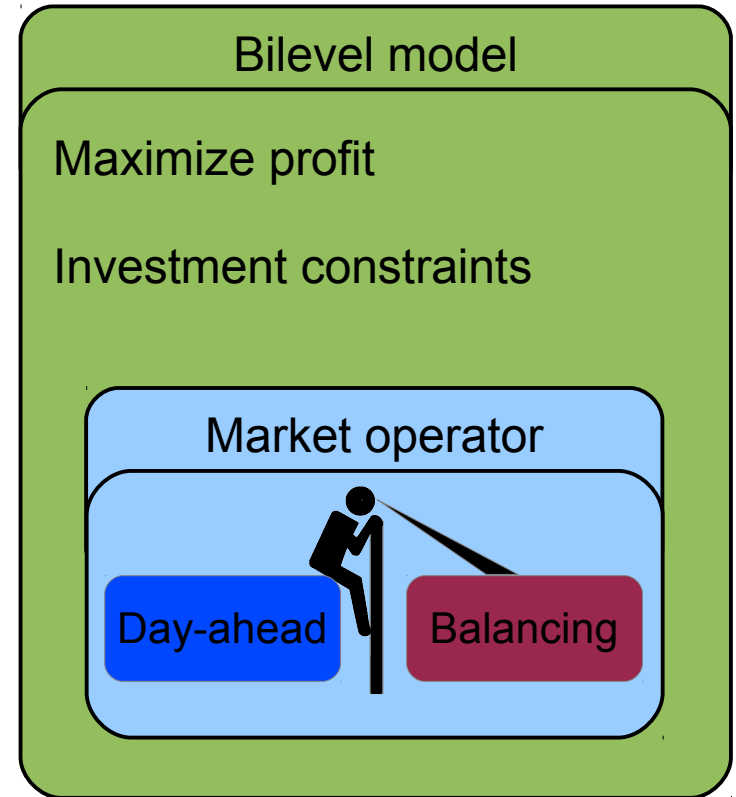


Expansion of stochastic units

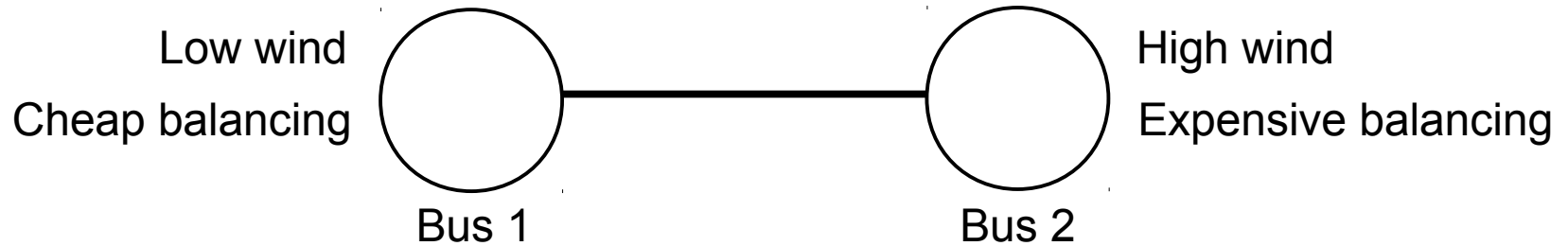
Investment under Conv MC



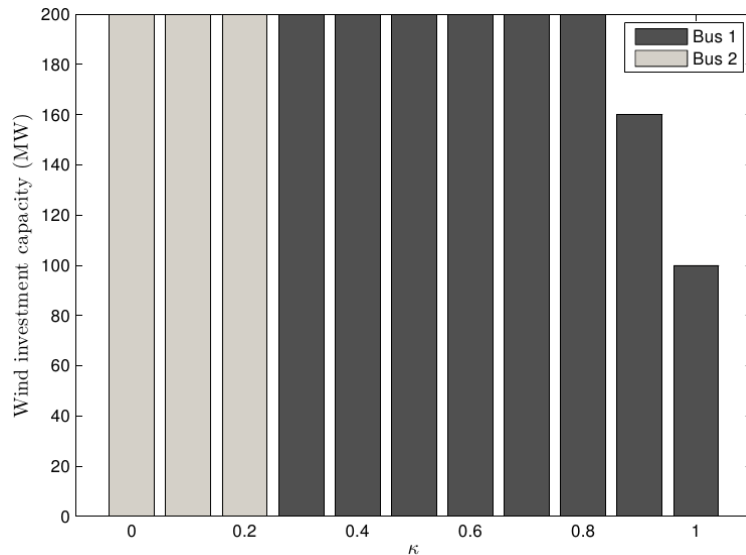
Investment under Stoc MC



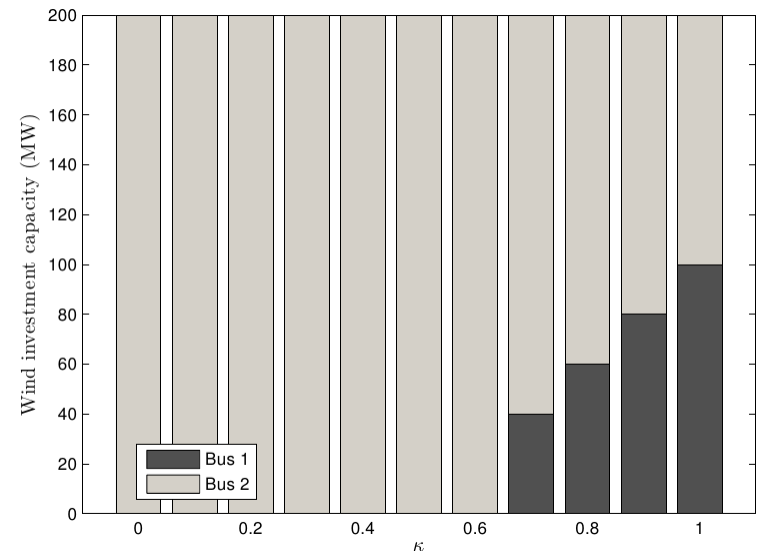
Expansion of stochastic units



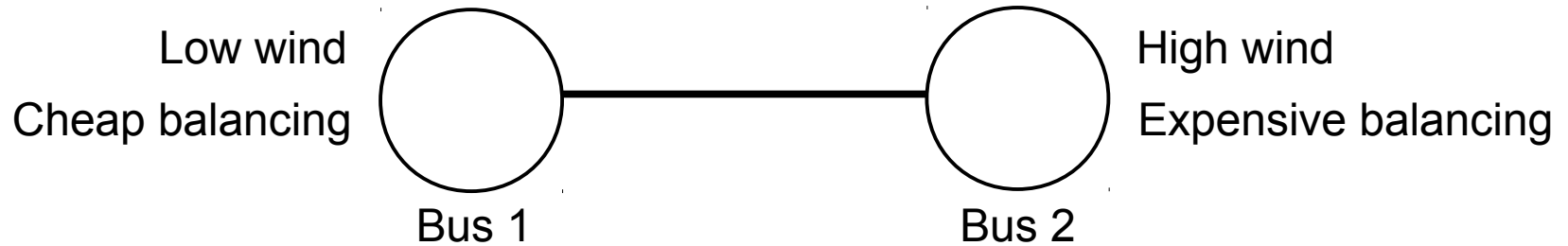
Conv MC



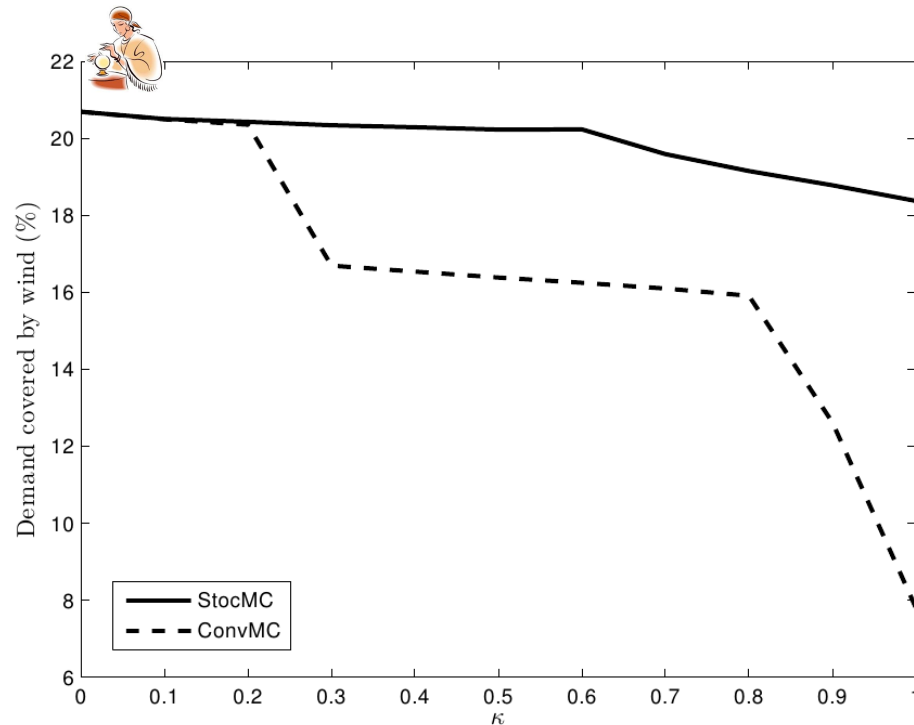
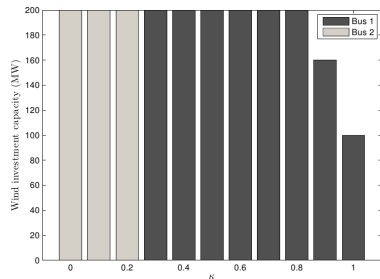
Stoc MC



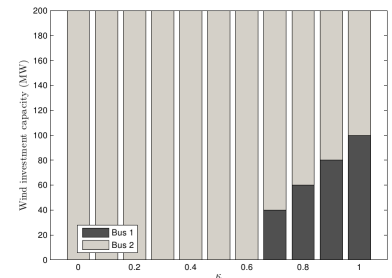
Expansion of stochastic units



Conv MC



Stoc MC

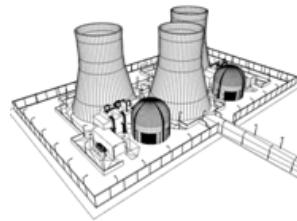


Expansion of stochastic units

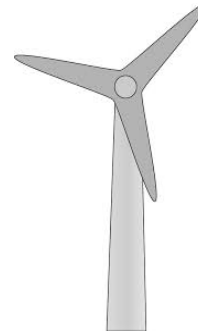
Investment model

Maximize profit

Day-ahead



\neq



Investment model

Maximize profit

Day-ahead

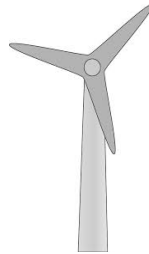
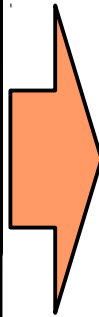
Balancing

Investment (Conv MC)

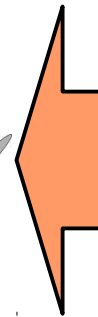
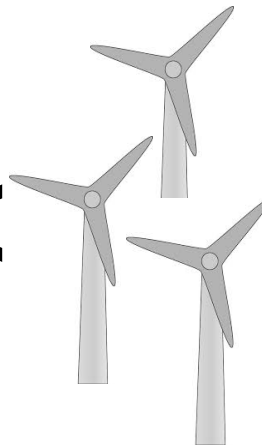
Maximize profit

Day-ahead

Balancing



$<$

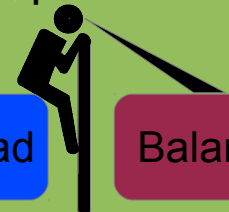


Investment (Stoc MC)

Maximize profit

Day-ahead

Balancing



Paper with all details

Submitted to *Operations Research*
manuscript (Please, provide the manuscript number!)

Modeling the Impact of Imbalance Costs on Generating Expansion of Stochastic Units

Salvador Pineda

University of Copenhagen, s.pineda@math.ku.dk

Juan M. Morales

Technical University of Denmark, jmmgo@imm.dtu.dk

Thanks for your attention!
Questions?

