Power spot price

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Agenda

- **The monopoly case**
  - Cost definitions
  - Adapted power generation system
  - Pricing at the marginal cost
- **The spot market**
- **Illustration**
  - Some key units
  - Offer curve construction

The monopoly case

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- The “control variables” are :
  - the production structure: capacity for each type of production plant;
  - the pricing structure of electricity (price level, structure...).
- The main uncertainty is the consumption.
- In the monopoly case, the objective is to **minimize** the production cost under the constraint of satisfying the demand.

Cost definitions: cost referred to a technology

Fixed cost

The fixed cost is the cost generated by a plant outside of any production. It can be expressed:

- in monetary unit per power unit (€/MW);
- in monetary unit per power unit per year (€/MW/year).

Variable operating cost

The variable operating cost is the cost induced by the production of electricity. It is expressed in monetary unit per produced energy unit (€/MWh). In consists of the fuel price and the maintenance cost.

Complete cost

The complete cost of a plant (or a technology) is the sum of the fixed cost and the variable cost with respect to a duration of use.

Cost definitions: cost referred to the system

(Short-term) Marginal cost

The marginal cost is the production cost needed to produce one unit of power, additionally to the current demand (the marginal demand). We define it “short-term” marginal cost because it is referred to a fixed generation system.

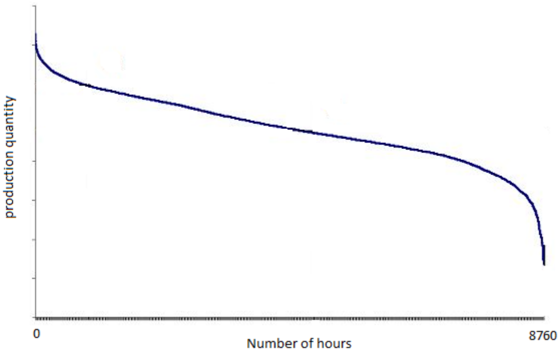
Long-term marginal cost or developing cost

The long-term marginal cost of a technology is the sum of its variable costs and a part of its fixed cost. It is used to anticipate the future marginal cost in the case of generation system evolution.

Construction of an adapted generation system: the Boiteux principle

Demand as a load curve

- The electricity demand is viewed as an expectation of the total electricity consumption for one year.
- The consumption is aggregated to build the load curve $P(h)$: the quantity P of electricity needed as a function of the number h of hours in a year.



Construction of an adapted generation system

- We assume we have N technologies. For each technology $n = 1, \dots, N$ we define
  - fixed cost C_n^f, in €/MW/year
  - variable cost C_n^v in €/MWh

  Given h the number of hours the technology i is used to produce electricity, we assume the complete cost to be affine

$$C_n^c = C_n^f + C_n^v h$$

The case of 2 technologies i and j

Suppose $C_i^f < C_j^f$ and $C_i^v > C_j^v$. The numbers $h_{i,j}$ of hours where it is equivalent to produce from technology i or technology j is

$$h_{i,j} = \frac{C_j^f - C_i^f}{C_i^v - C_j^v}$$

- Below $h_{i,j}$, the technology i is cheaper, whereas technology j becomes cheaper over $h_{i,j}$ of production.

Construction of an adapted generation system

- By extending the reasoning to N technologies we can determine the **sequence** of technologies to be used as a function of the number of hours for production.

Adapted generation system

- Find technology n_1 of cheaper fixed cost. Initialise $\mathcal{N} = \{n_1\}$
- for $k = 2 : N$

$$h_{n_{k-1},n_k} = \min\left\{h_{n_{k-1},n}\ ;\ n \in \{1,\ldots,N\} \cap \mathcal{N}^c\right\}$$

and set $\mathcal{N} = \mathcal{N} \cup \{n_k\}$

Remark

The algorithm may stop before interation N once $h_{n_k} > 8760$ (i.e. 1 year), which means that the remaining technologies are never competitive.

Optimal capacity structure

- Given the load curve $P(h)$, and the sequence $\left(h_{n_1,n_2},\dots,h_{n_{N-1},n_N}\right)$ the capacity needed for each technology is given by the following algorithm.

Optimal capacity structure

- The capacity Q_1 for technology n_1 is given by $Q_1 = P(0) - P(h_{n_1,n_2})$.
- The capacity Q_i, for $i = 2,\dots,N-1$, for technology n_i is given by $Q_i = (P(h_{n_i-1,n_i}) - P(h_{n_i,n_i+1}))$.
- The capacity Q_N for technology n_N is given by $Q_N = P(h_{n_{N-1},n_N})$.

Optimal capacity structure: Illustration

- Example of optimal capacity structure in the case of 3 technologies

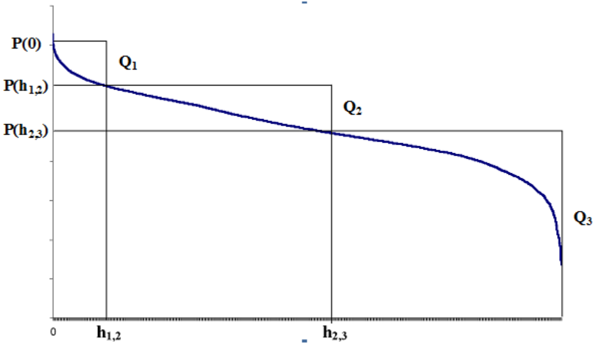


Figure: Optimal capacity structure

- This also gives an piecewise constant approximation of the load curve.

Pricing

- The optimal capacity structure leads to a minimal global production cost for one year of electricity consumption.
- Question: what is the optimal (minimal) price for selling electricity ?

Pricing at the marginal cost

Assume a piecewise constant selling price structure $(P_1, \ldots, P_N)$ corresponding to the number of technologies: we consider a "state variable" defining the marginal capacity and a price as a function of this state variable. Therefore the minimal price for selling electricity is the complete cost for the most expensive technology and the marginal cost for the others:

$$
\begin{aligned}
P_1 &= \frac{C_1^f}{h_{1,2}} + C_1^v \\
P_i &= C_i^v, \quad i = 2, \ldots, N
\end{aligned}
$$

Pricing at the marginal cost

- First consider technology n_1, only called for $h_{1,2}$ hours. The complete cost per MWh is $\frac{1}{h_{1,2}}(C_1^f + C_1^v h_{1,2})$. Therefore the minimal selling price P_1 is such as it exactly covers the complete cost:

$$P_1 = \frac{C_1^f}{h_{1,2}} + C_1^v$$

- Technology n_2 is called $h_{2,3}$ hours. The income for the first $h_{1,2}$ hours is:

$$\begin{aligned} P_1 h_{1,2} Q_2 &= C_1^f Q_2 + C_1^v h_{1,2} Q_2 \\ &= C_2^f Q_2 + C_2^v h_{1,2} Q_2 \\ &= C_2^f Q_2 + C_2^v h_{1,2} Q_2 \end{aligned}$$

  This income completely covers the fixed cost of technology n_2, the price P_2 between $h_{1,2}$ and $h_{2,3}$ is then the marginal cost $P_2 = C_2^v$

- Same idea for all remaining technologies

Conclusion

Conclusion

- In the case of a monopoly, the objective of the electricity producer is to build an adapted power generation system.
- Selling at the marginal costs is, with an adapted power generation system, the optimal strategy to cover the total production cost.

Market creation

- The French power generation system is not adapted.
- The open market lets free to propose any price superior to the marginal cost (but limited by competition).
- However in electricity markets the price offers are close to the marginal cost.
- It gives a strong relationship, then, between the electricity spot price and the fuel spot prices.

Spot market

- Fixing on October 28th, 2011.

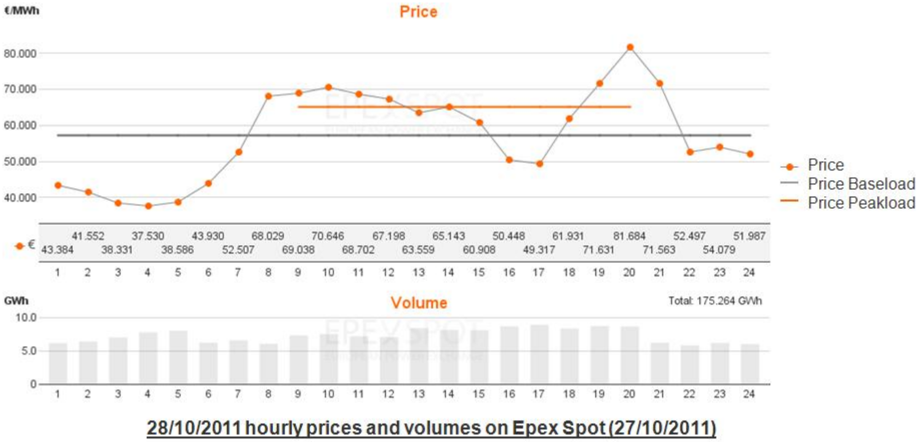
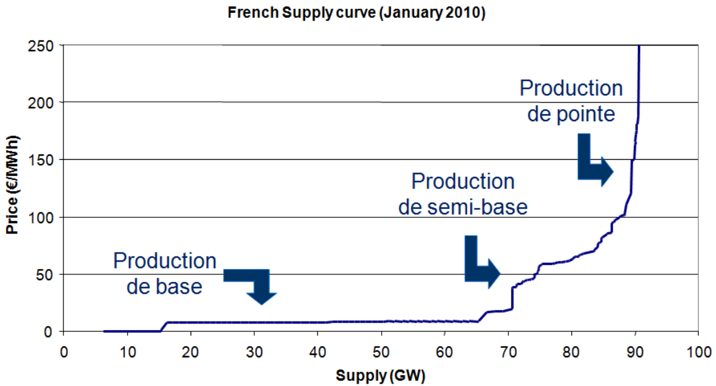


Figure: French power spot prices on October 28th, 2011

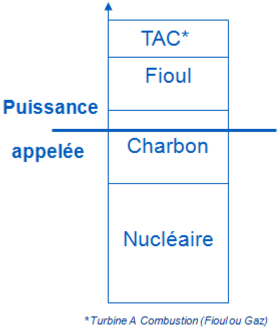
Spot market: offer curve

- Typical offer curve in the French market



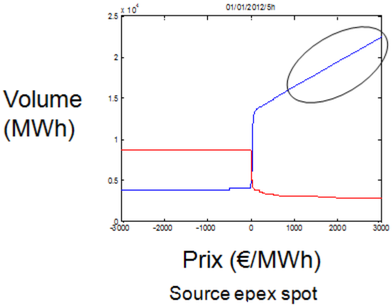
- **Key notion: Merit order**

- Not easy in practice
  - storage management
  - maintenance planning
  - system services
  - dynamic constraints (starting, minimal power...)
  - coupling constraints

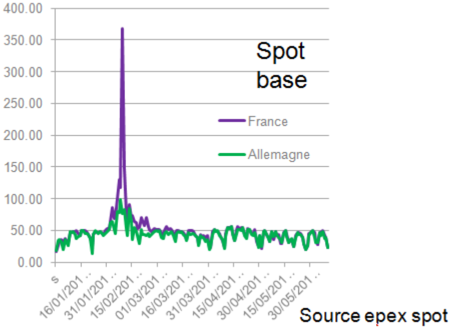


Spot market

- The spot price is not always the marginal cost
  - Non consistent price offers with respect to marginal cost
  - Some price levels (spikes) do not correspond to any marginal cost

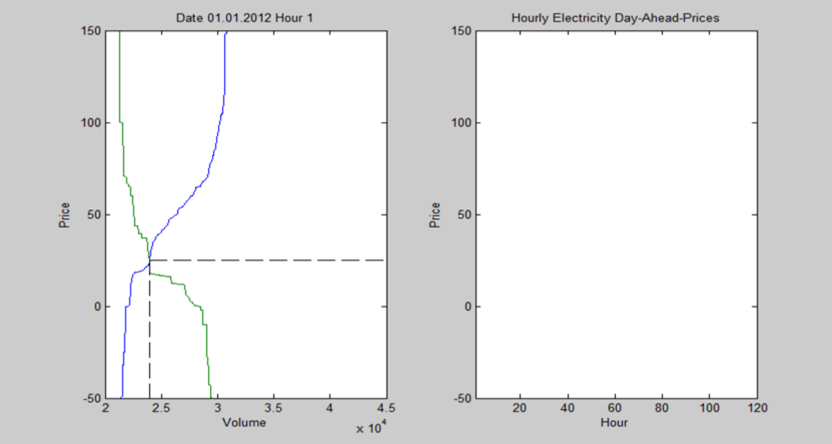


French offer (01.01.2012 5h)



Spot prices (spike 1785€/MWh at 02.09.2012 9h)

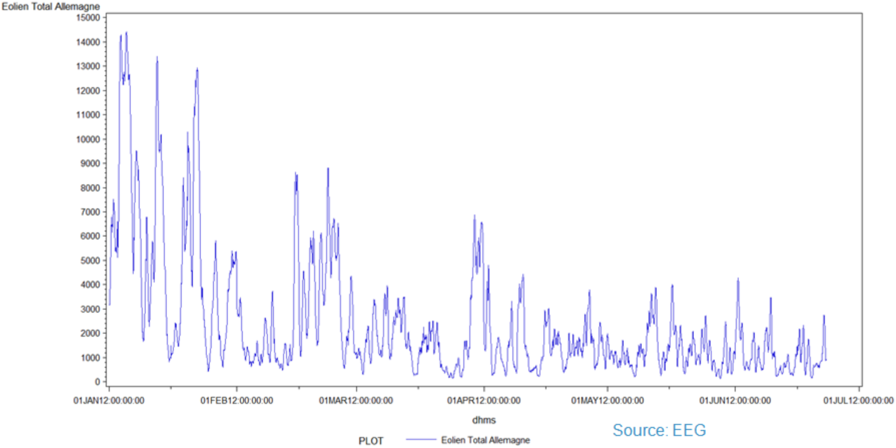
Spot market



Date 01.01.2012 Hour 1
Price
Volume
x 10^4
150
100
50
0
-50
2
2.5
3
3.5
4
4.5
Hourly Electricity Day-Ahead-Prices
Price
Hour
20
40
60
80
100
120

Spot market

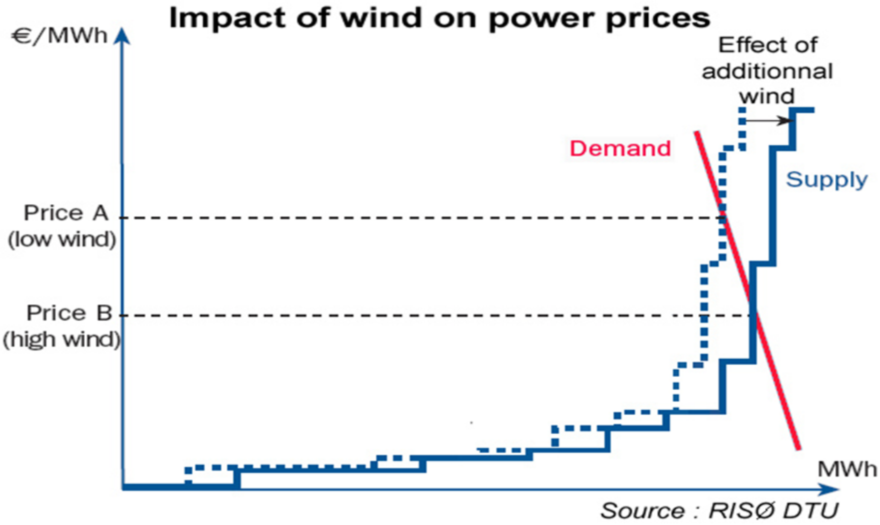
- The case of wind: uncertainty in the production capacity



Source: EEG

Spot market

- The case of wind: uncertainty in the production capacity



Spot market

Conclusion

- Spot prices are not exactly the marginal cost
  - Dynamic (temporal and geographical) constraints
  - Storage management (water, gas, ...)
  - *etc*

Illustration

Production cost: some key units

	Commodity	Heat rate (or return)
Electricity	€/MWh	-
Gas	€/MWh €/therm €/mmBtu	% therm/MWh mmBtu/MWh
Oil	€/t €/gal €/bbl	t/MWh gal/MWh bbl/MWh
Coal	€/t	t/MWh
Carbon	€/t_{carbon}	

Case study: one market

- Consider a simple generation structure

Technology	Capacity	Heat rate	Emission coef.	Spot price
Gas	250 MW	250%	0.2 tCO2/MWh	24 €/MWh
Coal	500 MW	0.5 tC/MWh	2.5 tCO2/tC	100 €/tC
Fuel Oil	100 MW	1.5 bbl/MWh	0.5 tCO2/bbl	80 €/bbl

Question

Build the offer curve

Case study: one market

- **First case:** Carbon emission price = 10 €/tCO_2

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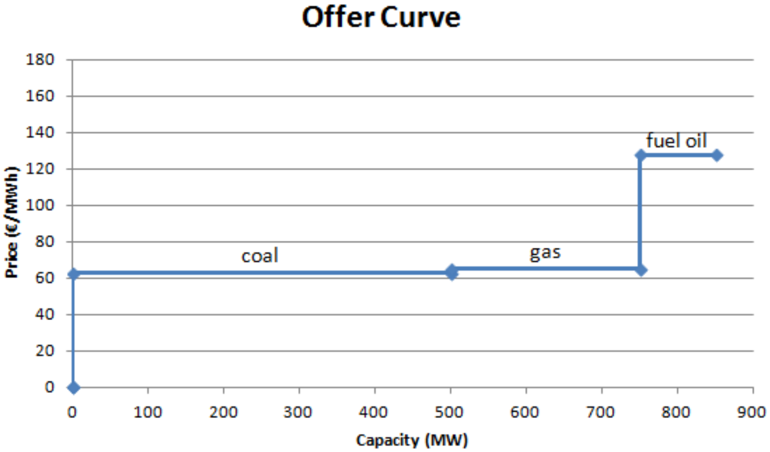

Case study: one market

- **Second case:** Carbon emission price = 50 €/tCO_2

Case study: one market

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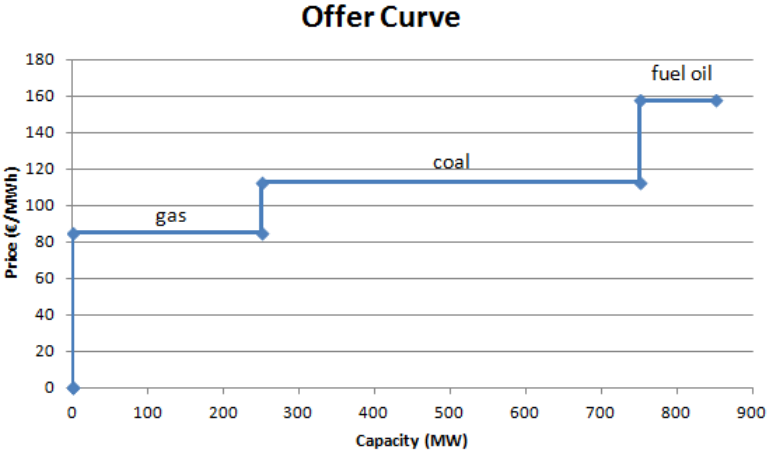


Case study: one market with renewables

- Consider a simple generation structure

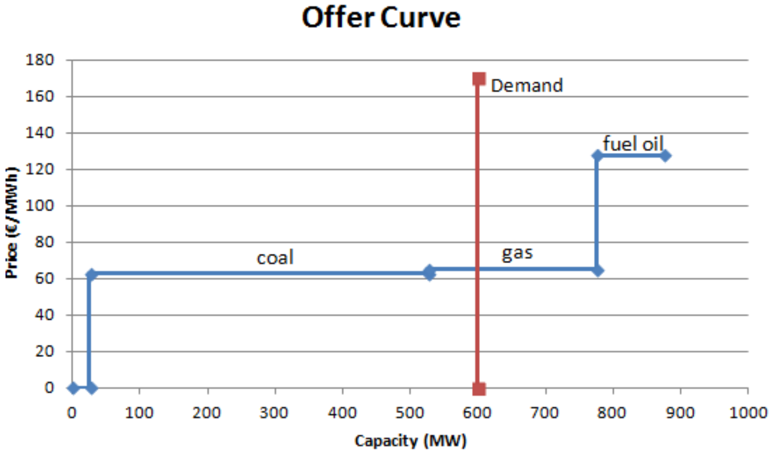
Technology	Capacity	Heat rate	Emission coef.	Spot price
Gas	250 MW	250%	0.2 tCO2/MWh	24 €/MWh
Coal	500 MW	0.5 tC/MWh	2.5 tCO2/tC	100 €/tC
Fuel Oil	100 MW	1.5 bbl/MWh	0.5 tCO2/bbl	80 €/bbl
Wind Power	100 MW	25% (return)	0	0 €/MWh

Question

Build the offer curve

Case study: one market with renewables

- Carbon emission price = 10 €/tCO2
- Demand level: 600 MW



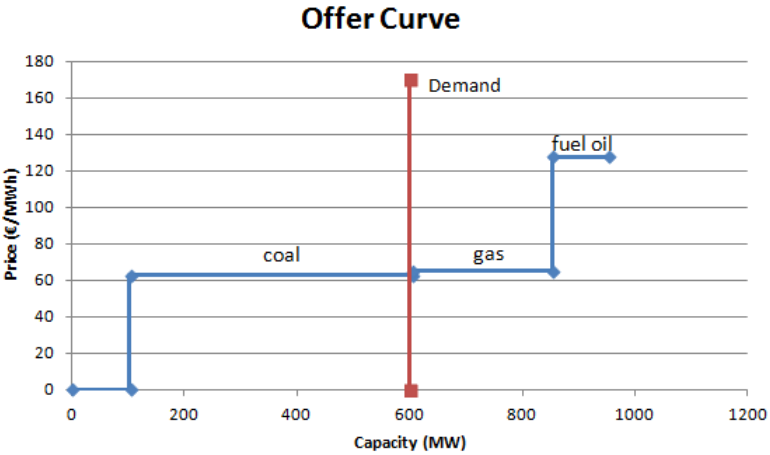
Case study: one market with renewables

Question

How much renewables capacity is needed to change the system marginality and decrease the spot price?

Case study: one market with renewables

- Carbon emission price = 10 €/tCO2
- Demand level: 600 MW
- Answer: **400 MW of renewables**



Case study: two interconnected markets

- **Market 1**

Technology	Capacity	Heat rate	Emission coef.	Spot price
Gas	250 MW	250%	0.2 tCO2/MWh	24 €/MWh
Coal	500 MW	0.5 tC/MWh	2.5 tCO2/tC	100 €/tC
Fuel Oil	100 MW	1.5 bbl/MWh	0.5 tCO2/bbl	80 €/bbl
Wind Power	100 MW	25% (return)	0	0 €/MWh

- **Market 2**

Technology	Capacity	Heat rate	Emission coef.	Spot price
Gas	200 MW	250%	0.2 tCO2/MWh	22 €/MWh
Coal	300 MW	0.5 tC/MWh	2.5 tCO2/tC	100 €/tC
Fuel Oil	100 MW	1.5 bbl/MWh	0.5 tCO2/bbl	80 €/bbl
Wind Power	500 MW	25% (return)	0	0 €/MWh

- Demand market 1: 850 MW
- Demand market 2: 300 MW

Case study: two interconnected markets

Interconnect. capacity	Spot price market 1	Spot price market 2	Comment
0MW	127.5 €/MWh	60 €/MWh	Prices without connection
50MW	127.5 €/MWh	62.5 €/MWh	Only increasing of Market 2
200MW	65 €/MWh	62.5 €/MWh	Effects in both markets
500MW	62.5 €/MWh	62.5 €/MWh	Perfect price convergence