LIÈGE université

ELEC0018-1 Energy Markets

Lecture 4: Day-ahead market

Damien Ernst

and

Thibaut Théate

Antoine Dubois

Adrien Bolland

Victor Dachet

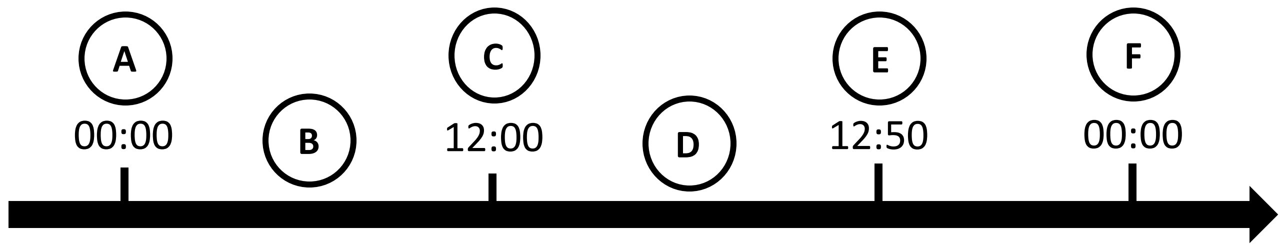
Context

- One day before delivery time.
- Adapt your position for the 24 hours of the next day.
- Producers want to sell energy if they expect to make a profit (they are said to be **in the market**) or want to buy the energy they have to deliver if it is less expensive than producing it by themselves (**out of the market**).
- Retailers want to buy energy for their consumers. They buy or sell depending on if they expect a surplus or a shortage depending on their forward contracts.

Day-ahead market (EPEX SPOT)

- Also called electricity **spot** market.
- Pool market for buying energy : the agents can **submit offers** during the opening hours and the market is cleared after closure.
- **Hourly products** : buy or sell electricity for each hours of the next day.
- Market operator: EPEX SPOT

Day-ahead market – Timeline



A. Opening of the day-ahead market for all hours of the following day.
B. Market participants submit their bids and asks to the order book (simple orders, block orders, exclusive orders, curtailable orders, …).
C. Closing of the day-ahead market for all hours of the following day.
D. Execution of the market clearing algorithm.
E. Notification of the market participants and system operators about the market clearing outcomes.
F. Beginning of the delivery of electricity for the entire day.

Terminology

On the day-ahead market, we trade **energy**. Nevertheless, we often speak about capacity, we mean this capacity for one hour.

An offer for buying or selling energy is called an **order or a bid**.

An order for selling energy is called a **sell** order or a **bid** order.

An order for buying energy is called a **buy** order or an **ask** order.

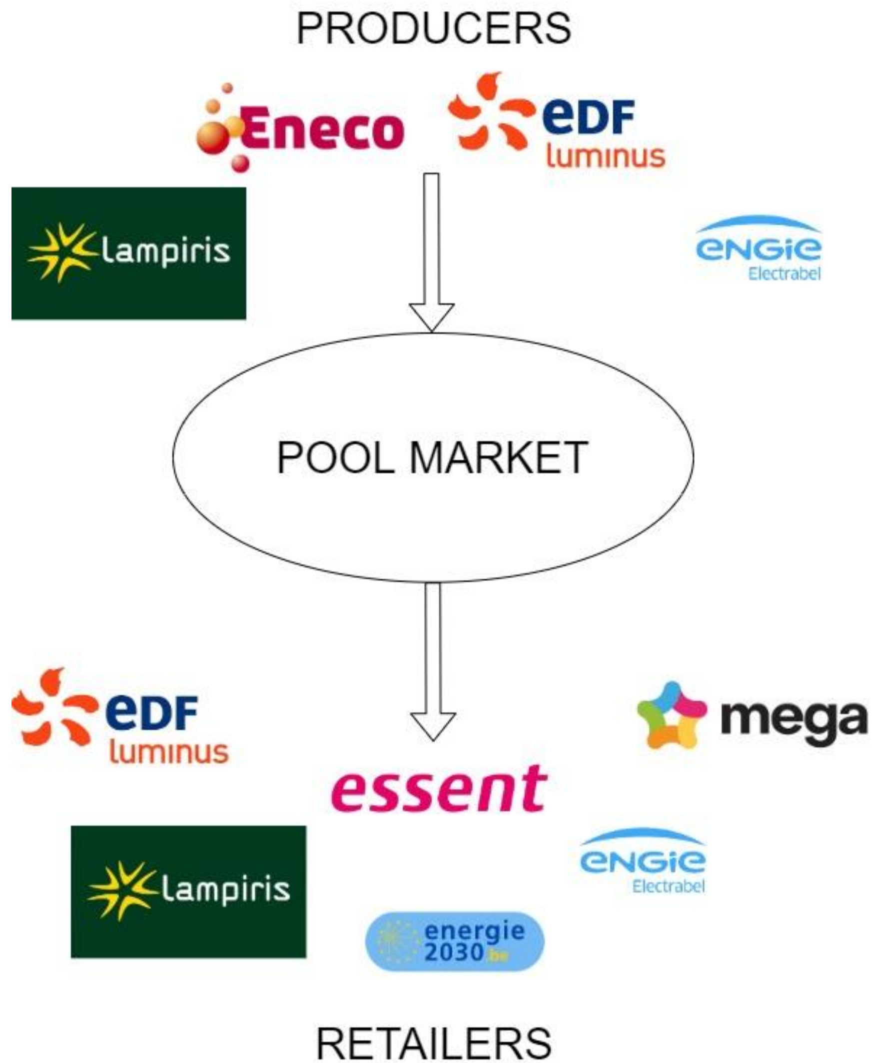
Participating in the market

Agents can submit bids/offers in the pool
Bid = sell/buy + price + quantity + hour

The bids represent the **willingness to pay** or to be paid. How much an agent valorizes the energy.

Bids are **anonymous**.

Producers and retailers do not interact aside of the market even if they are from the same firm. All bidding decisions must be based on public information !



Market clearing - Exercise

Assuming you are the market operator and you see these bids in the pool:

- What minimum price should a consumer pay for buying 20 MWh? What is the cost of the last unit of energy?
- What maximum revenue will a producer receive for selling 20 MWh? What is the cost of the last unit of energy?
- What is the answer for x MWh?

Sell	50 MWh	20 €/MWh
	100 MWh	10 €/MWh
	20 MWh	30 €/MWh
	200 MWh	5 €/MWh
	10 MWh	0 €/MWh
Buy	50 MWh	1 €/MWh
	100 MWh	15 €/MWh
	200 MWh	20 €/MWh
	50 MWh	30 €/MWh

Market clearing - Exercise

What minimum price should a consumer pay for buying 20 MWh?

10 MWh * 0€/MWh + 10 MWh * 5€/MWh = 50€

What is the cost of the last unit of energy?

5€ - the marginal cost for a consumer

Sell	50 MWh	20 €/MWh
	100 MWh	10 €/MWh
	20 MWh	30 €/MWh
	200 MWh	5 €/MWh
	10 MWh	0 €/MWh
Buy	50 MWh	1 €/MWh
	100 MWh	15 €/MWh
	200 MWh	20 €/MWh
	50 MWh	30 €/MWh

Market clearing - Exercise

What maximum revenue will a producer receive for selling 20 MWh?

20 MWh * 30 €/MWh = 600 €

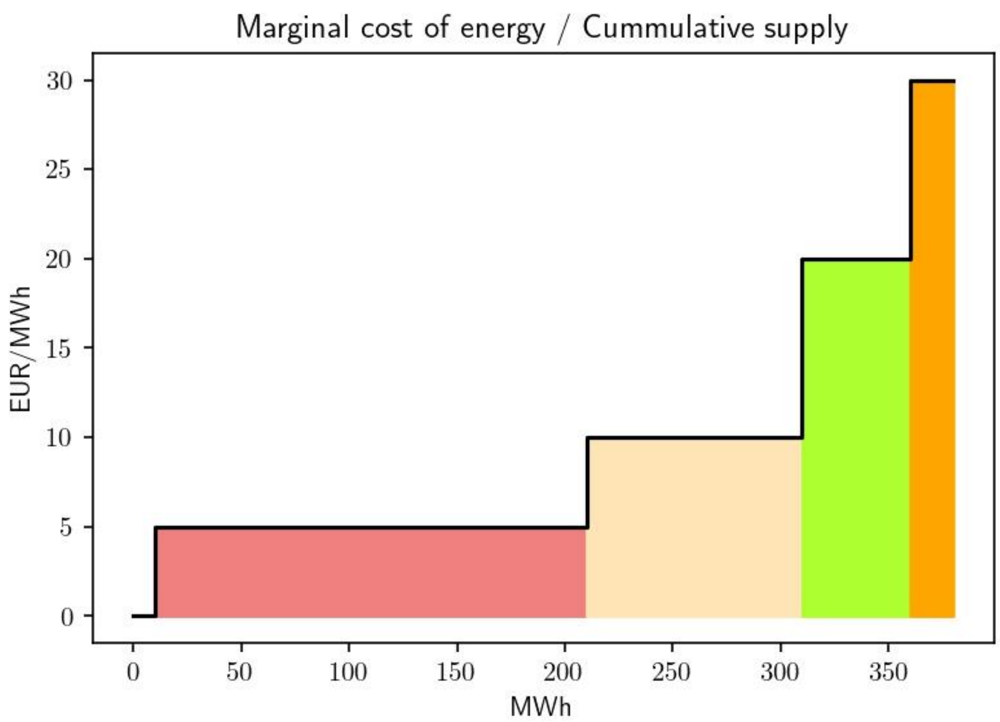
What is the cost of the last unit of energy?

30 € - Marginal revenue for the producer

Sell	50 MWh	20 €/MWh
	100 MWh	10 €/MWh
	20 MWh	30 €/MWh
	200 MWh	5 €/MWh
	10 MWh	0 €/MWh
Buy	50 MWh	1 €/MWh
	100 MWh	15 €/MWh
	200 MWh	20 €/MWh
	50 MWh	30 €/MWh

Market clearing - Exercise

Marginal cost for x MWh?



Sell	50 MWh	20 €/MWh
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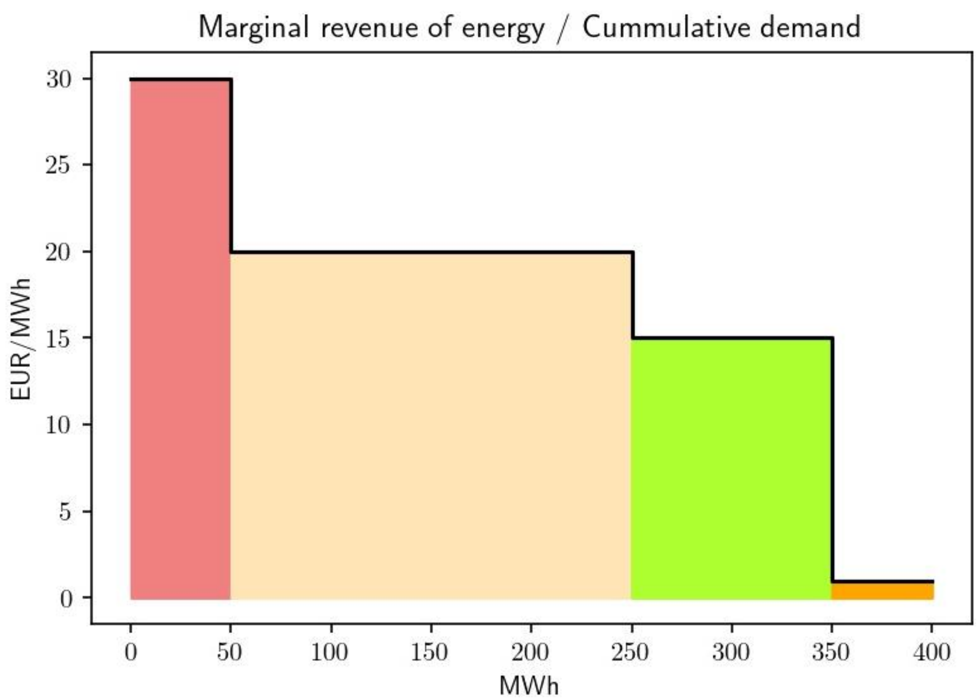
	10 MWh	0 €/MWh
Buy	50 MWh	1 €/MWh
	100 MWh	15 €/MWh
	200 MWh	20 €/MWh
	50 MWh	30 €/MWh

Market clearing - Exercise

Marginal revenue for x MWh?



Sell	50 MWh	20 €/MWh
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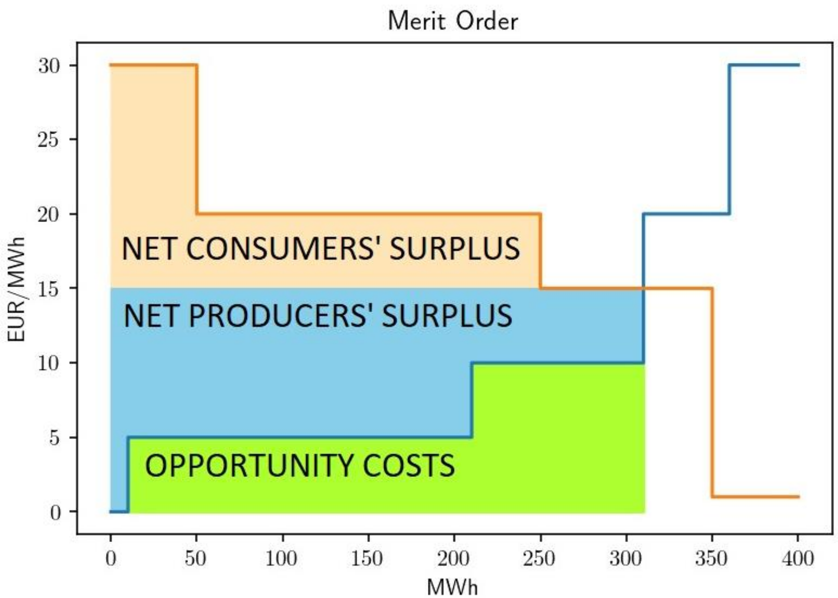
	10 MWh	0 €/MWh
Buy	50 MWh	1 €/MWh
	100 MWh	15 €/MWh
	200 MWh	20 €/MWh
	50 MWh	30 €/MWh

Merit order

Merit Order : ordering of the bids.

- The marginal **cost** represents the cumulative **supply** curve.
- The marginal **revenues** represents the cumulative **demand**.

Social welfare : area between supply and demand curves. It equals to the sum of the net consumers' surplus and the net producers' surplus.

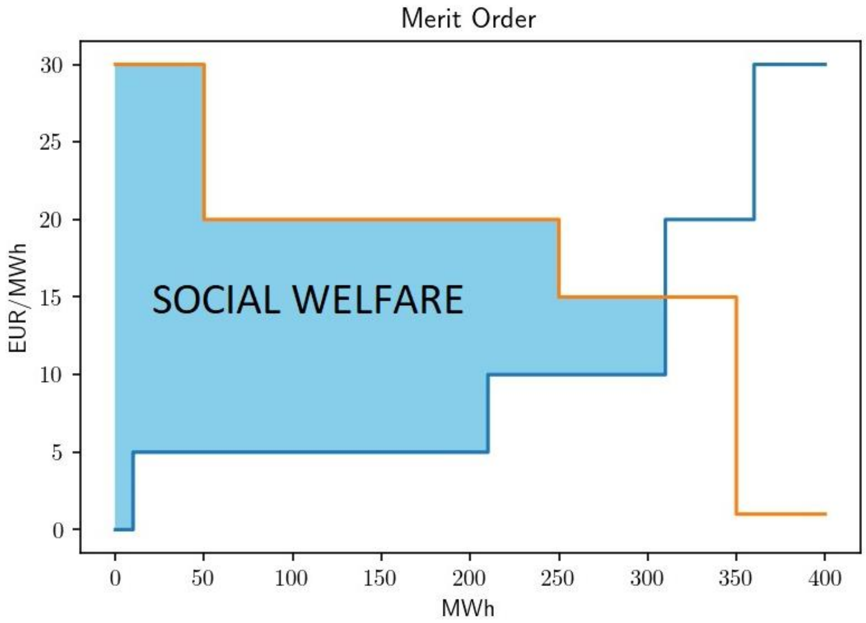


Merit order – Market clearing

Equilibrium price p_{eq}: intersection of supply and demand

Social welfare represents the 'benefit of the clearing if paid at the equilibrium price'.

The objective of the market operator is to clear (accept) the bids to **maximise social welfare.**



Market clearing - Settlement

What is the final cost of electricity?

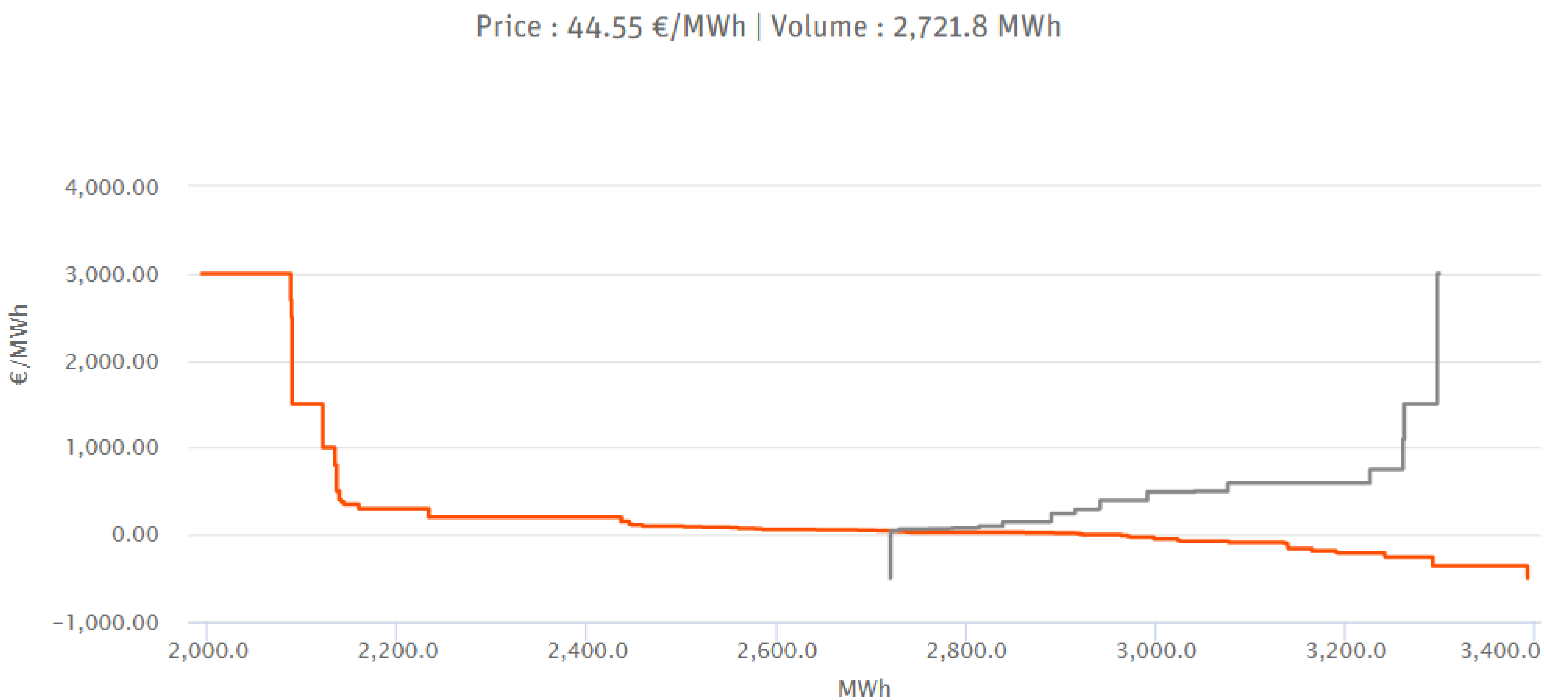
Two payment mechanisms:

- **Pay-as-bid**: each agent receives the amount of money they bid
- **Pay-as-clear** (or uniform pricing): a single price is fixed as the market price

EPEX: pay-as-clear at the equilibrium price.

With pay-as-clear, the agents have the incentive to bid at their marginal cost.

EPEX auction - 03/09/2020 product of 00h00-01h00



https://www.epexspot.com/en/market-data?market_area=BE&trading_date=2020-09-02&delivery_date=2020-09-03&underlying_year=&modality=Auction&sub_modality=DayAhead&product=60&data_mode=aggregated&period=


Price
€/MWh
50.00
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Hours

Optimisation problem - Overview

Assumptions:

- Given a set of bids for a given hour of the day.
- A bid can be partially clear. We can thus buy a portion of the quantity.
- Pay-as-clear at the equilibrium price p_{eq}

Objective:

- Maximise social welfare.

Main constraint:

- Demand and supply must be equal at each hour.

Optimisation problem - Formulation

Demand bids:

- N_D demand bids: set of offers $L_D = \{D_i | i = 1, \cdots, N_D\}$
- Quantity for offer D_i: E_i^D
- Price for offer D_i: p_i^D

Generation bids:

- N_G demand bids: set of offers $L_D = \{G_j | j = 1, \cdots, N_G\}$
- Quantity for offer G_j: E_j^G
- Price for offer G_j: p_j^G

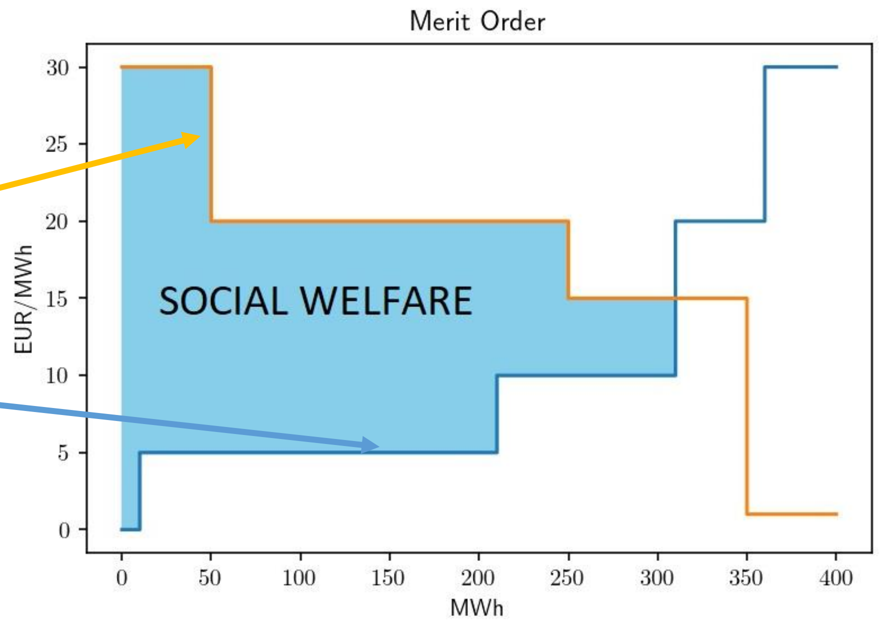
Variables of the problem:

- Consumption level y_i^D: how much energy is cleared from bid D_i at price p_i^D
- Generation level y_j^G: how much energy is cleared from bid G_j at price p_j^G

Optimisation problem - Objective

Objective: find the **dispatch** $\{y_i^{D^*}\}, \{y_j^{G^*}\}$ maximising social welfare *i.e.* area between the cleared supply and demand bids. This area is positive if the demand price is greater than the supply price.

$$\max_{\{y_i^D\},\{y_j^G\}} \sum_{i=1}^{N_D} p_i^D y_i^D - \sum_{j=1}^{N_G} p_j^G y_j^G$$



This equation is only valid if the cumulative demand equals the cumulative supply!

Optimisation problem - Constraints

Demand (consumption) and supply (generation) must be equal:

$$\sum_{i=1}^{N_D} y_i^D - \sum_{j=1}^{N_G} y_j^G = 0$$

A bid can be **partially cleared,** but we cannot accept less energy than zero from a bid or more than the quantity proposed at the given price:

$$0 \le y_i^D \le E_i^D, \qquad \forall i = 1, \cdots, N_D$$
$$0 \le y_j^G \le E_j^G, \qquad \forall j = 1, \cdots, N_G$$

Optimisation problem

$$\max_{\{y_i^D\},\{y_j^G\}} \sum_{i=1}^{N_D} p_i^D y_i^D - \sum_{j=1}^{N_G} p_j^G y_j^G$$

subject to

$$\sum_{i=1}^{N_D} y_i^D - \sum_{j=1}^{N_G} y_j^G = 0$$

$$0 \le y_i^D \le E_i^D, \qquad \forall i = 1, \cdots, N_D$$

$$0 \le y_j^G \le E_j^G, \qquad \forall j = 1, \cdots, N_G$$

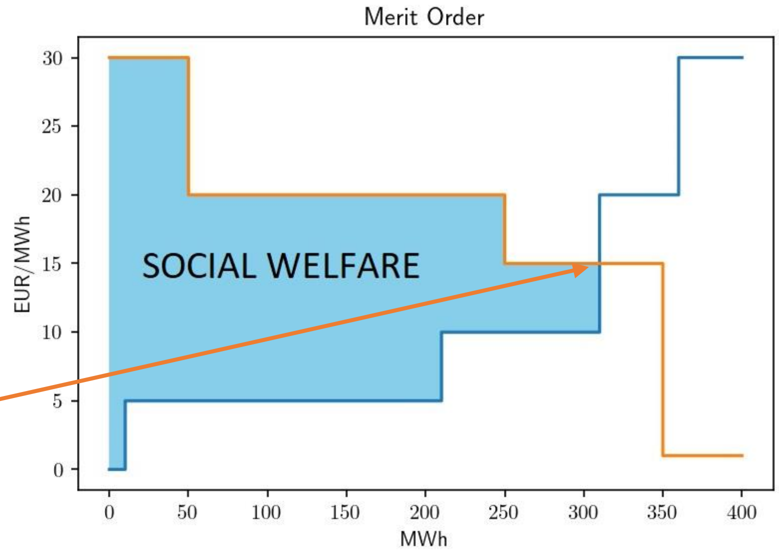
The solution to the problem is the **optimal dispatch** for the market participants: the sequence of generation and consumption levels $\{y_i^{D^*}\},\{y_j^{G^*}\}$ of each offer maximising social welfare.

Optimisation problem - Settlement

In order to have the complete market clearing, the **system price** should be known in addition to the optimal dispatch.

The equilibrium price p_{eq} is the marginal price of electricity at the point where the supply equals the demand. It corresponds to the influence of a small variation ϵ of the equality between supply and demand on the objective function.

$$\Delta\left(\sum_{i=1}^{N_D} y_i^D - \sum_{j=1}^{N_G} y_j^G\right) = \epsilon$$



Finding the marginal costs of variations of the constraints on the objective is achieved solving so-called **dual optimisation problem.**

Linear programming – Dual problem

Solving the dual problem consists in finding the **smallest upper bound** on the objective function that respects the constraints.

In linear programming it is achieved as follows:

- For each constraint, define a dual variable.
- Multiply the constraints by their respective dual variables and sum them up.
- Upper bound the coefficients of the objective function with the coefficients of the equation from point 2.
- The signs of the dual variables are such that the constant term (with respect to the primal variables) of the equation from point 2 upper bounds the objective function.
- The smallest upper bound in function of the dual variables equals the optimal primal objective (strong duality in linear programming).

Dual clearing problem – Formulation

1. Let ν_{eq}, ν_i^D and ν_j^G be the dual variables corresponding respectively to the equality constraint, to the inequalities $y_i^D \leq E_i^D$ and to the inequalities $y_j^G \leq E_j^G$.

2. Let us linearly combine these constraints with $\nu_i^D \geq 0$ and $\nu_j^G \geq 0$:

$$\nu_{eq}\left(\sum_{i=1}^{N_D} y_i^D - \sum_{j=1}^{N_G} y_j^G\right) + \sum_{i=1}^{N_D} \nu_i^D y_i^D + \sum_{j=1}^{N_G} \nu_j^G y_j^G \leq \sum_{i=1}^{N_D} \nu_i^D E_i^D + \sum_{j=1}^{N_G} \nu_j^G E_j^G$$

3. We want the left-hand side to be an upper bound on the objective:

$$\sum_{i=1}^{N_D} p_i^D y_i^D - \sum_{j=1}^{N_G} p_j^G y_j^G \leq \nu_{eq}\left(\sum_{i=1}^{N_D} y_i^D - \sum_{j=1}^{N_G} y_j^G\right) + \sum_{i=1}^{N_D} \nu_i^D y_i^D + \sum_{j=1}^{N_G} \nu_j^G y_j^G$$

Since the primal variables are positive, it implies that:

$$\nu_i^D + \nu_{eq} \geq p_i^D$$
$$\nu_j^G - \nu_{eq} \geq -p_j^G$$

Dual clearing problem – Formulation

4. The signs of the dual variables were chosen so as to have the left-hand side smaller than the right-hand side in the equation.

5. The dual objective is to minimise the upper bound:

$$\min_{\nu_{eq},\{\nu_i^D\},\{\nu_j^G\}} \sum_{i=1}^{N_D} \nu_i^D E_i^D - \sum_{j=1}^{N_G} \nu_j^G E_j^G$$

subject to

$$\nu_i^D + \nu_{eq} \geq p_i^D, \qquad \forall i = 1, \cdots, N_D$$
$$\nu_j^G - \nu_{eq} \geq -p_j^G, \qquad \forall j = 1, \cdots, N_G$$
$$\nu_i^D \geq 0, \qquad \forall i = 1, \cdots, N_D$$
$$\nu_j^G \geq 0, \qquad \forall j = 1, \cdots, N_G$$

Dual clearing problem – Dual variables

For the optimal dispatch and the optimal dual variables, we have that the upper bound of the equation at point 2 equals the maximal social welfare:

$$\sum_{i=1}^{N_D} p_i^D y_i^{D^*} - \sum_{j=1}^{N_G} p_j^G y_j^{G^*} = \nu_{eq}^* \left(\sum_{i=1}^{N_D} y_i^{D^*} - \sum_{j=1}^{N_G} y_j^{G^*} \right) + \sum_{i=1}^{N_D} \nu_i^{D^*} y_i^{D^*} + \sum_{j=1}^{N_G} \nu_j^{G^*} y_j^{G^*}$$

By how much will the social welfare increase for a variation ϵ of the equality constraint?

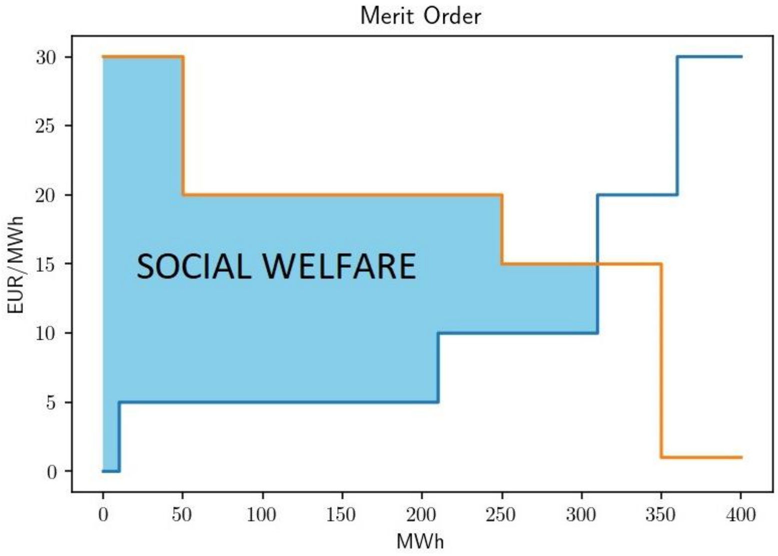
$$\Delta \left(\sum_{i=1}^{N_D} y_i^D - \sum_{j=1}^{N_G} y_j^G \right) = \epsilon$$

Dual clearing problem – Dual variables

If we change by ϵ the equality constraint, the equations show that the social welfare will change by $\nu_{eq}^{*}\epsilon$.

Graphically, a change in the social welfare at the optimum corresponds to a change in area of width ϵ and with height $p_{eq}\epsilon$.

It follows that $\nu_{eq}^{*} = p_{eq}$ is the cost for producing the most expensive unit of electricity in the merit order. It is the **clearing price**!



Linear programming

The optimisation problem for finding the optimal dispatch is linear. It can thus be written as follows (**primal** form):

$$\max_{y} c^T y$$

subject to

$$A_{eq}^T y = b_{eq}$$
$$A^T y \leq b$$
$$y \geq 0$$

Its **dual** form writes as:

$$\max_{y} c^T y$$

subject to

$$A_{eq} \nu_{eq} + A\nu \geq c$$
$$\nu \geq 0$$

Inelastic demand - Overview

What if there is a demand D that **must be delivered** whatever the price?

The social welfare is infinite since the consumer is ready to pay an infinite price in the worst case. It is only infinite since the **net consumers' surplus is infinite**.

In this context, maximising the social welfare corresponds to maximising the net producers' surplus. Equivalently, the optimal dispatch is the one that maximises the area under the cleared generation bids. This area is called **opportunity cost**.

$$\min_{\left\{y_j^G\right\}} \sum_{j=1}^{N_G} p_j^G y_j^G$$

subject to

$$\sum_{j=1}^{N_G} y_j^G = D$$

$$0 \leq y_j^G \leq E_j^G, \qquad \forall j = 1, \cdots, N_G$$

Inelastic demand – In Practice

In practice, it might happen that all the supply does not cover the demand. The previous optimisation problem has no solution.

We can add to the objective the participation of the cost p_{shed} for the part of the demand ΔD that is not supplied. This price corresponds to the **Value Of Loss Load** (VOLL) and is usually set to $p_{shed} = 1000$ €/MWh.

$$\min_{\{y_j^G\},\Delta D} \sum_{j=1}^{N_G} p_j^G y_j^G + p_{shed} \Delta D$$

subject to

$$\sum_{j=1}^{N_G} y_j^G + \Delta D = D$$

$$0 \leq \Delta D \leq D$$

$$0 \leq y_j^G \leq E_j^G, \qquad \forall j = 1, \cdots, N_G$$

Shifting demand

Shifting demand: rather than reducing their demand, the consumers may decide to delay this demand until the prices are lower. This concept exists for a long time with for example the night and day tariffs.

There exist many opportunities for shifting demand that can still be exploited, even for small customers (e.g., turning off the fridge for half an hour, delaying a laundry).

Investments in systems to exploit these shifting demand opportunities important in a landscape where more and more electricity is produced by renewables.

Investments: recording consumers' consumption for every market period (essential for not purchasing anymore electricity on the basis of a tariff), automatic devices installed in homes for shifting loads, etc.

Negative market prices

At how much do we bid the nuclear capacity and the RES?

What is the marginal cost of stopping a nuclear plant?

Do we stop a wind farm from producing? The energy is available whatever the demand? How does the government policies keep it interesting for wind plant to produce?

- **Premium support** : RES producers receive a fix support on top of the market price.
- **Feed-in tariff support** : RES producers are paid a guaranteed price if the market price is below it, otherwise they receive the market price.

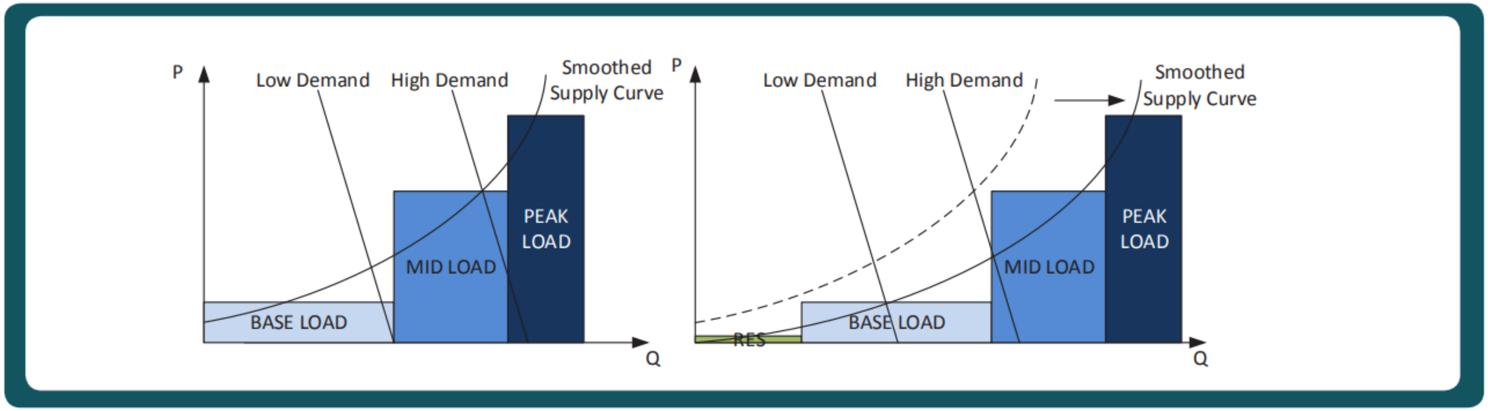


Figure 1: Theoretical merit order without (left) and with renewable energy sources (right)

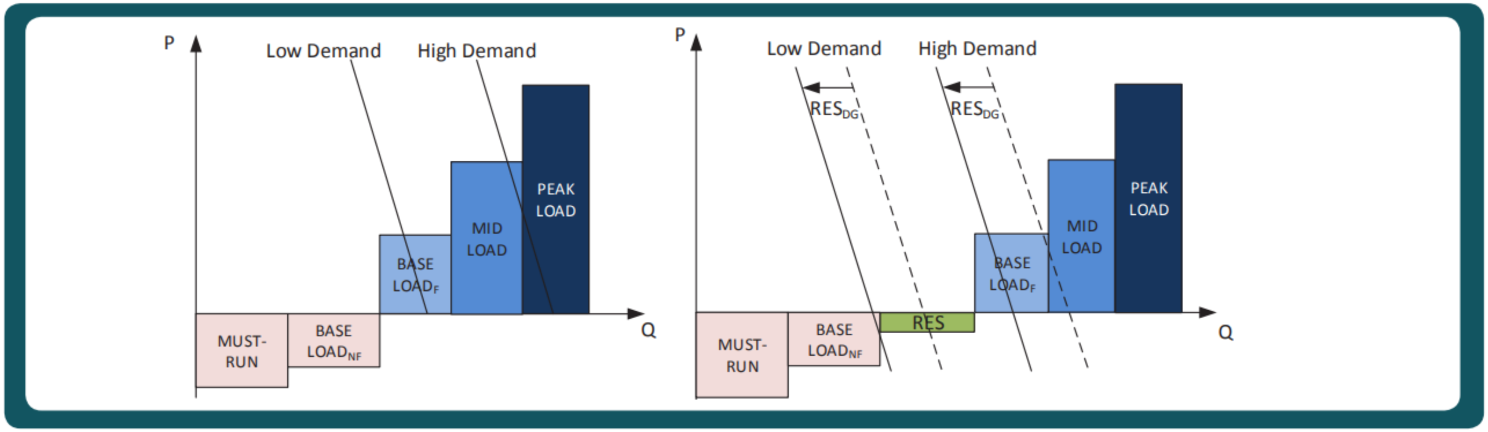


Figure 2: Practical merit order without (left) and with renewable energy sources (right); RES_{DG} expected renewable generation production of distributed nature; F flexible; NF non-flexible

References

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