ELEC0080-1 ENERGY NETWORKS
Partim1: Electrical Energy Systems

Lecture 4. Electricity markets

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Common abbreviations

TSO – Transmission system operator

GRT – Gestionnaire du réseau de transmission

DSO – Distribution system operator

GRD – Gestionnaire du réseau de distribution

IEA – International Energy Agency

ISO - Independent System Operator

SMP - System Marginal Price (or Equilibrium Price or Market Clearing Price)

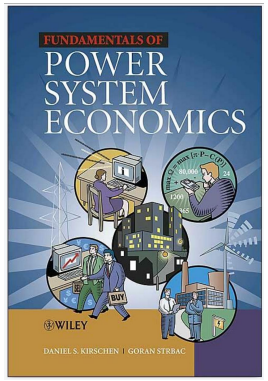
BRP - Balance Responsible Party

BSP - Balance Service Provider

Sources for this course

Book:

1. *Fundamentals of Power System Economics*, Daniel S.Kirschen, Goran Strbac



Course:

1. *Energy markets*, Damien Ernst, ULiège
   - http://blogs.ulg.ac.be/damien-ernst/teaching/elec0018-1-energy-markets/
2. *Renewables in Electricity Markets*, Pierre Pinson, DTU
   - http://pierrepinson.com/index.php/teaching/

People: Adrien Bolland, Jonathan Dumas, Thibaut Théate

Part 1. Electricity markets: what and why?

What are electricity market**s**?

1. What is a market ? [Investopedia]

"Place where two parties can gather to facilitate the exchange of goods and services. The parties involved are usually buyers and sellers. The market may be physical like a retail outlet, where people meet face-to-face, or virtual like an online market, where there is no direct physical contact between buyers and sellers.

2. What is an **electricity** market?

- product → electricity (both energy and power)
- buyers → retailers & sellers → producers
- mostly virtual

3. Why an *'s'* in market**s**?

Electricity has some special properties → several ways to exchange it

Why study electricity markets?

1. Impacts YOU directly even though you do not participate directly
    a. Influence the total price on your electricity bill
    b. Determine future investments
2. Increasing number of prosumers
3. Increasing penetration of renewables

Questions we are trying to answer

1. How is an electricity market organized? Who are the different actors and how is the electricity exchanged between them?

2. What are the different electricity markets ?

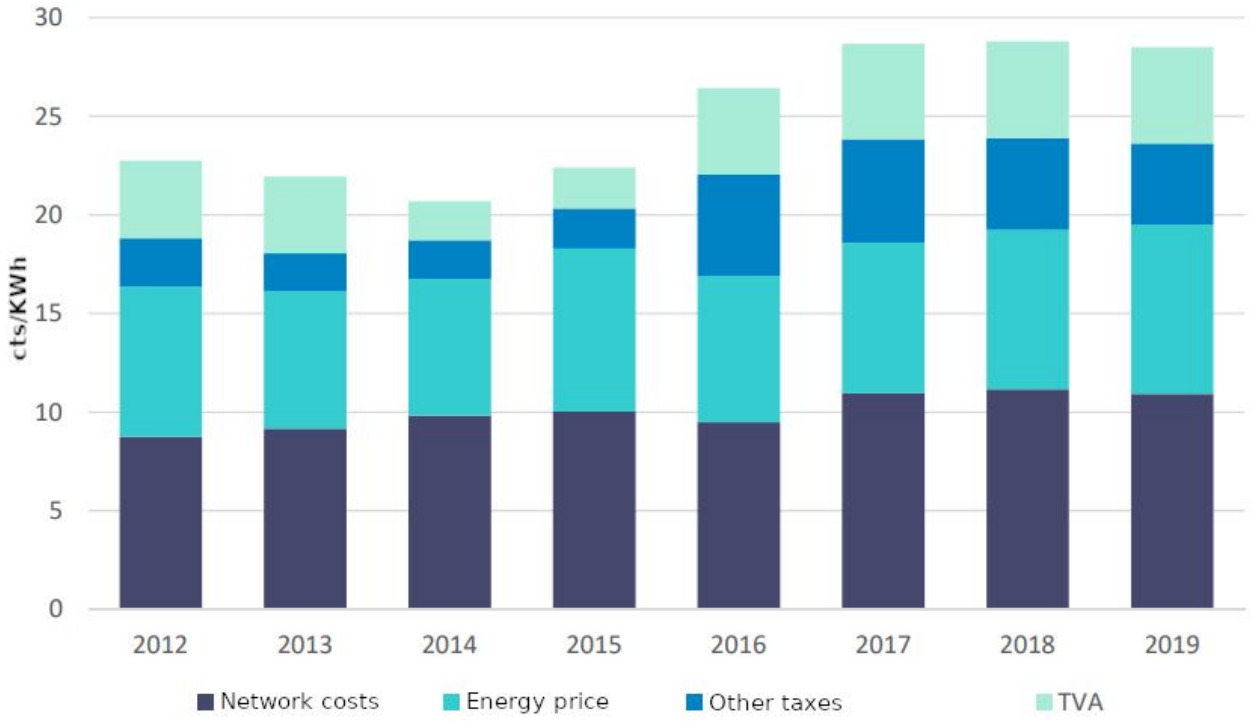
3. How does increasing renewable energy use impact markets?

Part 2. Electricity sector structure

Part 2.1. You (the small consumer)

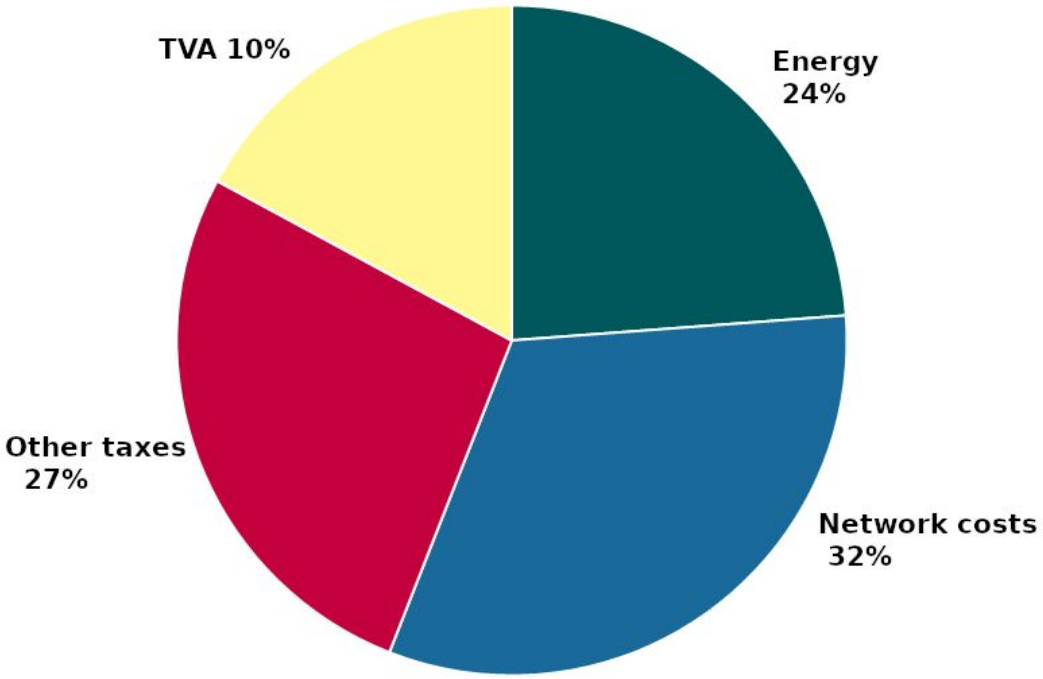
Your point of view (the small consumer)

- Average residential price in Belgium 2019: 0.285€/kWH
- Average energy consumption per consumer: 2.5 to 5MWh
- ⇒ between 712.5 and 1425 € per year
- ⇒ between 60 and 120€ per month



Your point of view (the small consumer)

- In the price you pay → **only ¼ for energy!**
- Only this part is affected by electricity markets



Your point of view (the small consumer)

- Small consumers pay a **fixed price per kWh** (per month)
- Some pay a price that vary every three months or so
- ⇒ very different to what happens on markets

Price

MCV Volume

Part 2.2. The flow of energy

The flow of energy - How electricity reaches you

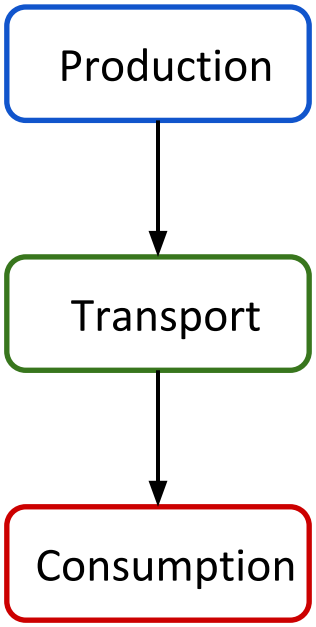
When you plug something in → electricity flows in.

How?

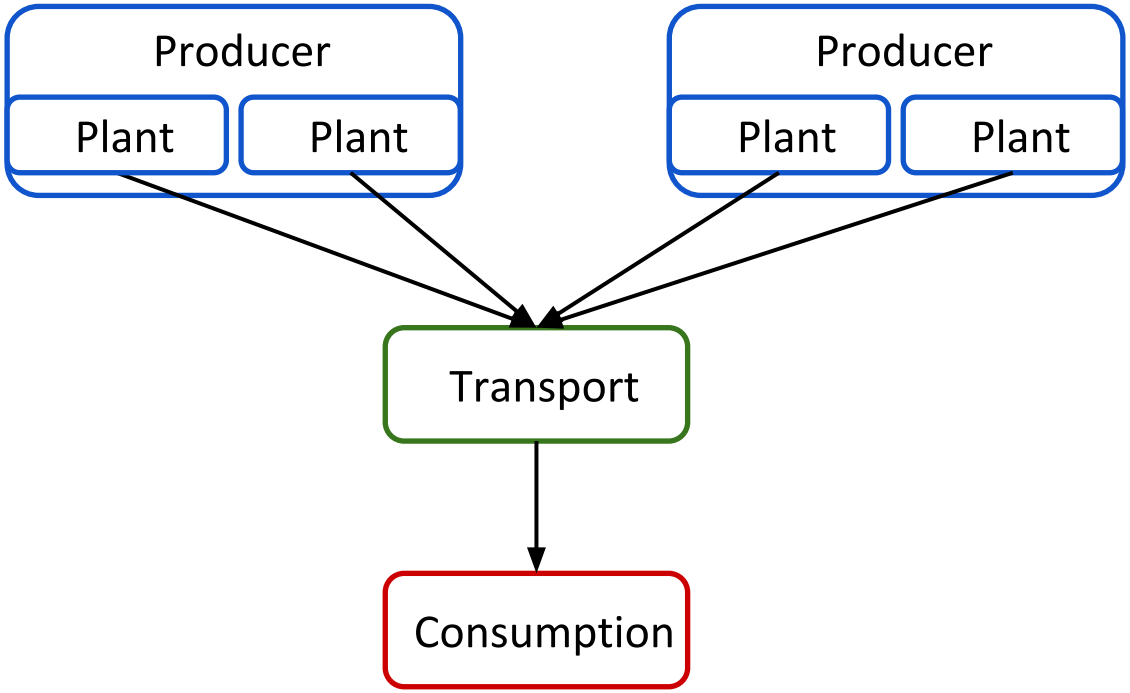
Quick overview of the 3 components of the electricity network:

- Production
- Transport
- Consumption

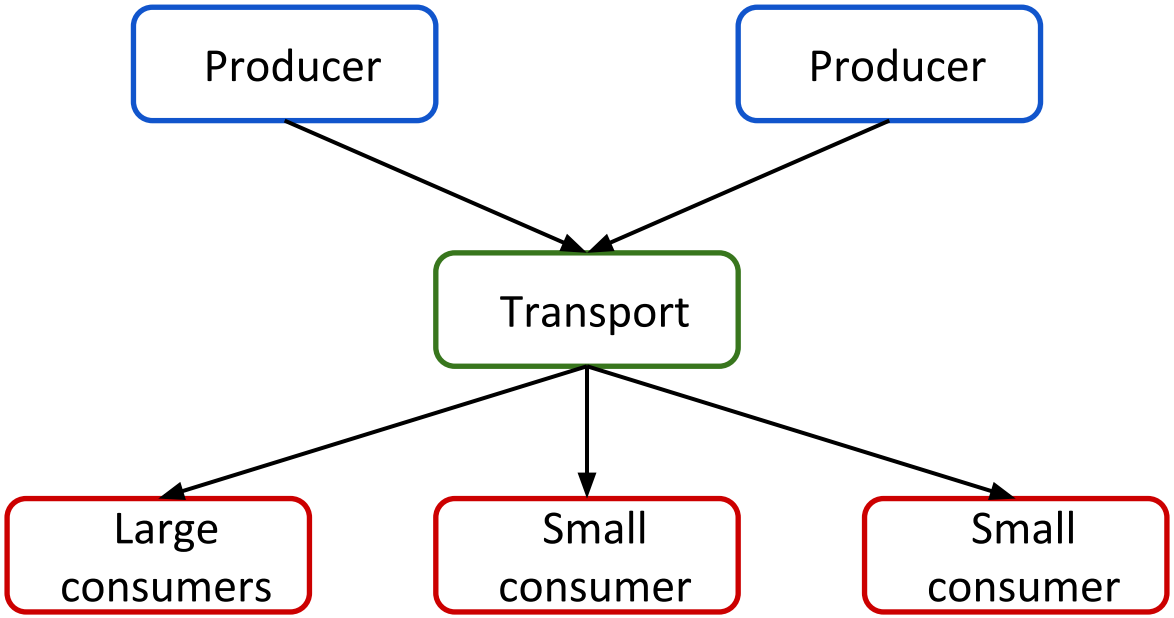
The flow of energy - 3 main components



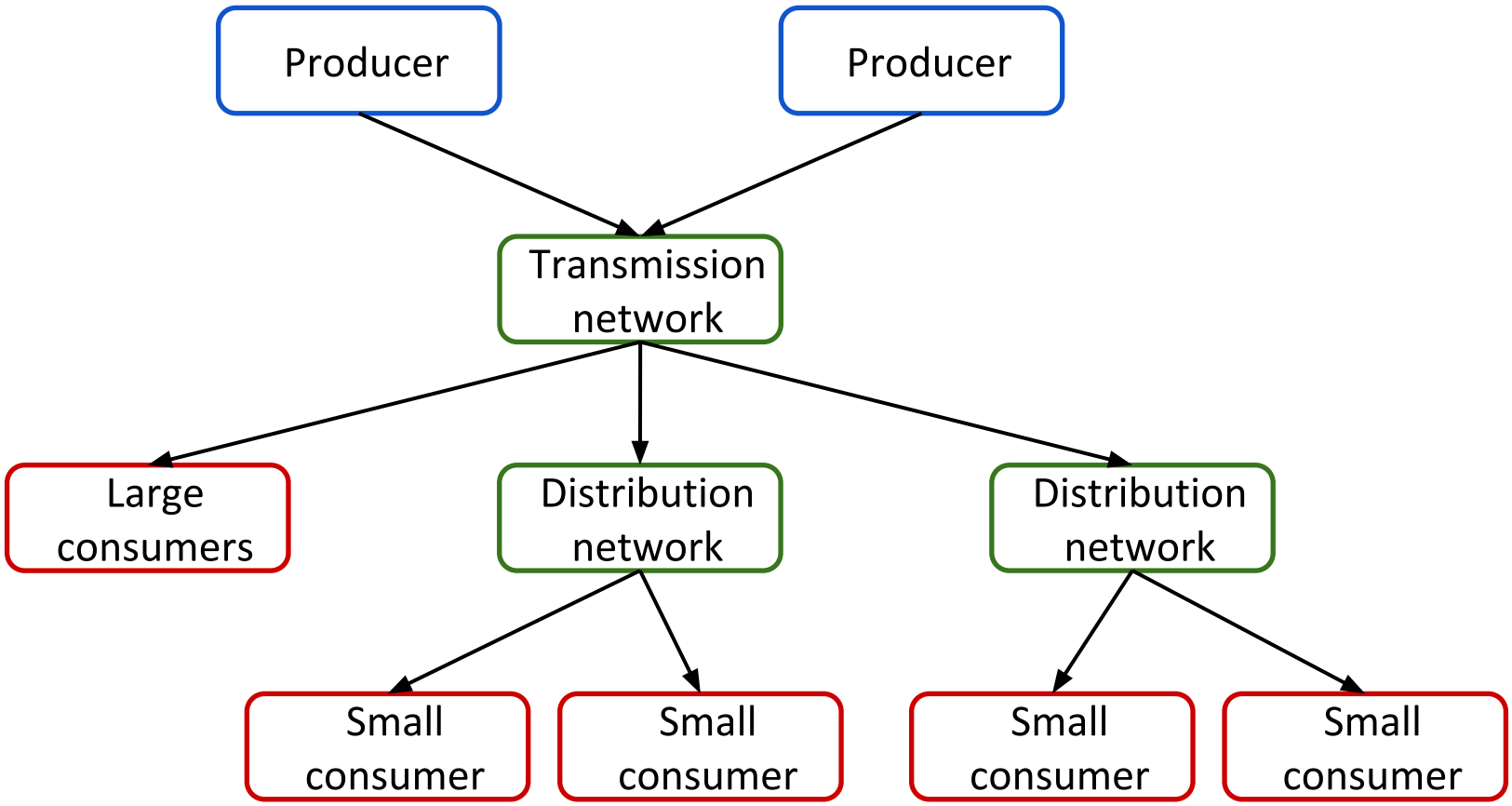
The flow of energy - Production



The flow of energy - Consumption



The flow of energy - Transport



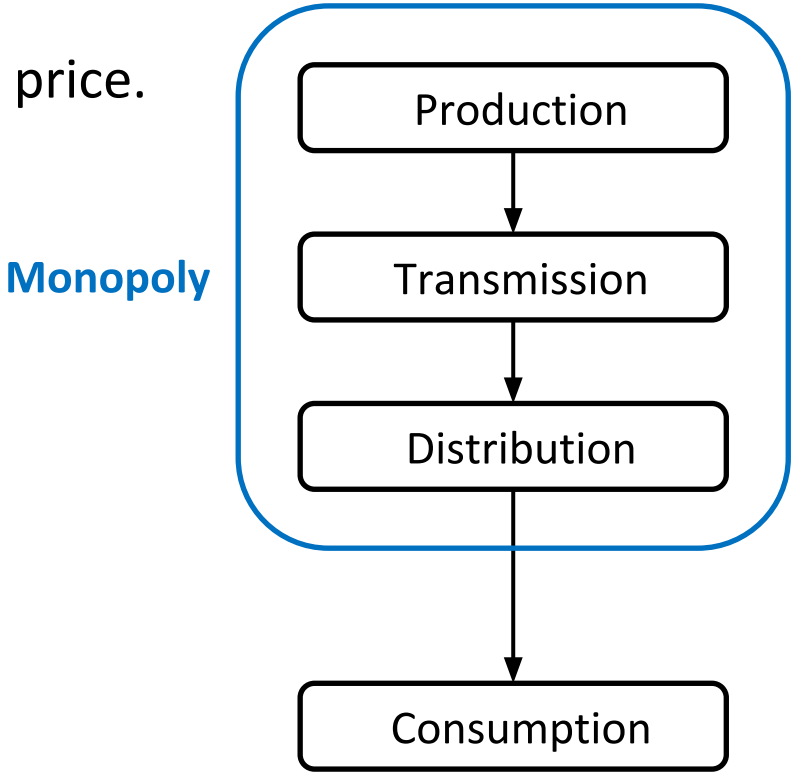
Part 2.3. Liberalization and actors

The time of monopolies

Until the 1980s, no choice when buying electricity, suppliers of electricity had a monopoly over the area were a consumer lived.

Suppliers were:

1. vertically integrated
2. imposed a single regional price.



Benefits:

1. Contributed remarkably to economic activity and quality of life
2. For several decades, amount of delivered energy double about every 8 years
3. Average consumer deprived of electricity for less than two minutes per year (in 2004)

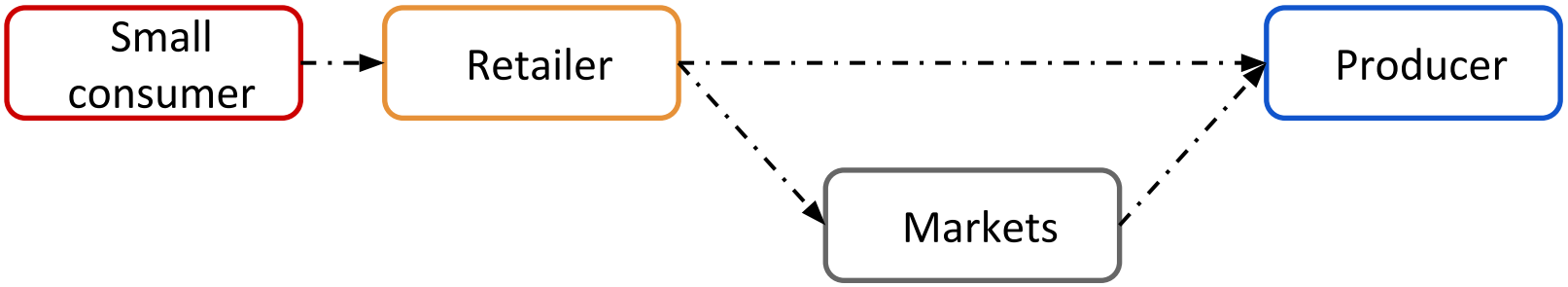
Main problem: not considered to be economically efficient

1. No incentives to operate efficiently
2. Encourages unnecessary investments
3. Government interfering in public entities
4. **Higher prices** than in a market

Liberalization ⇒ lower prices!

Towards liberalization

1. Opening production to competition
2. Introducing a new actor: the **retailer** (or provider)
   - Intermediary between producer and small consumer
   - Protect small consumers from price variation
3. Retailers buy electricity from producers
   - Bilateral contracts
   - Centralized market ⟶ operated by a **market operator**



Towards liberalization

4. Open transmission and distribution to competition?

→ **No** ⇒ electricity transport is a **natural monopoly**

At the national level

→ transmission network operated by the **TSO** (Transmission system operator)

At the regional level

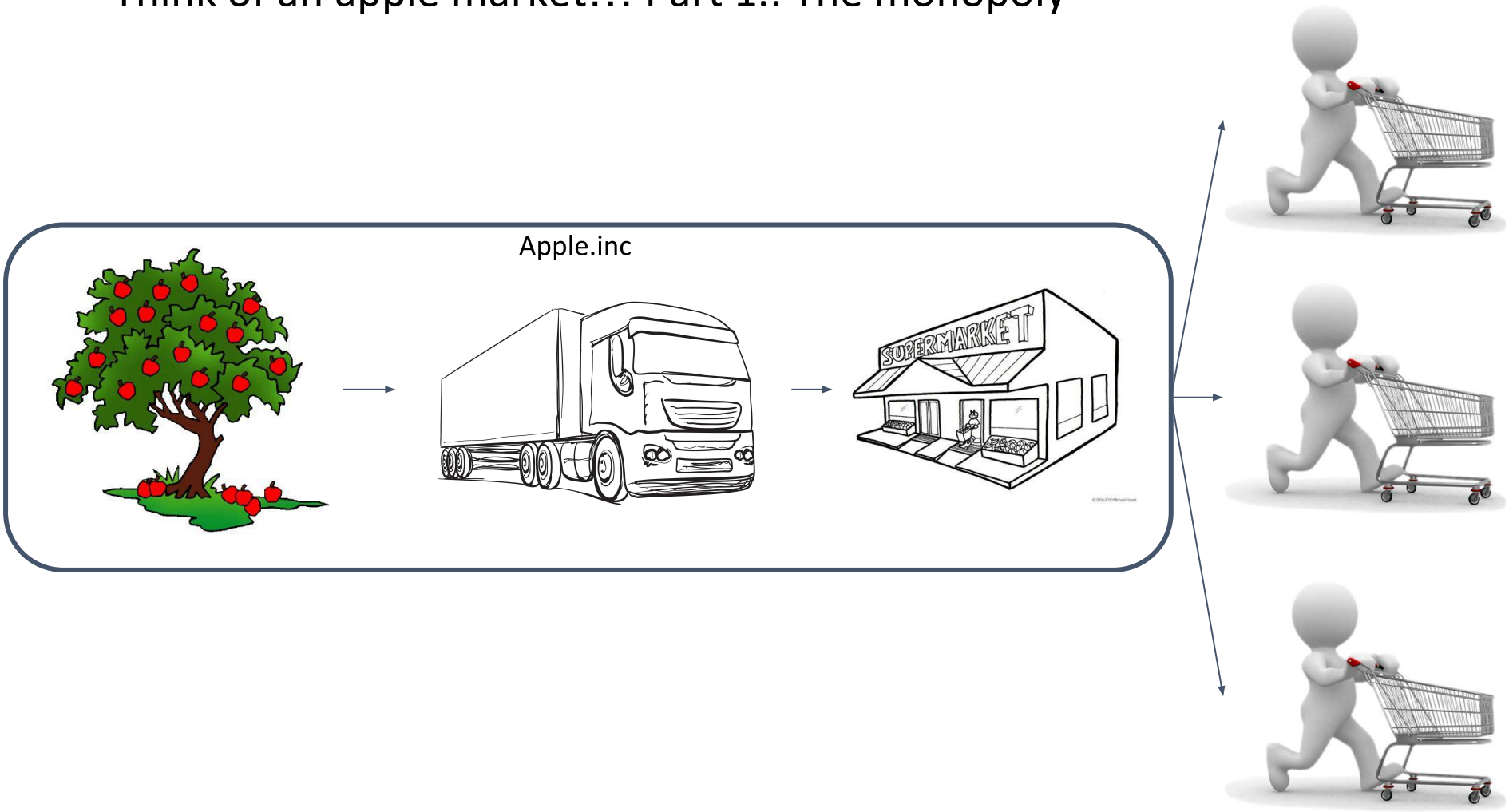
→ distribution network operated by the **DSO** (Distribution system operator

5. Introduction of the **ISO** (Independent system operator)

- Responsible for maintaining the security of power system operation
- Can be managed by the **TSO**

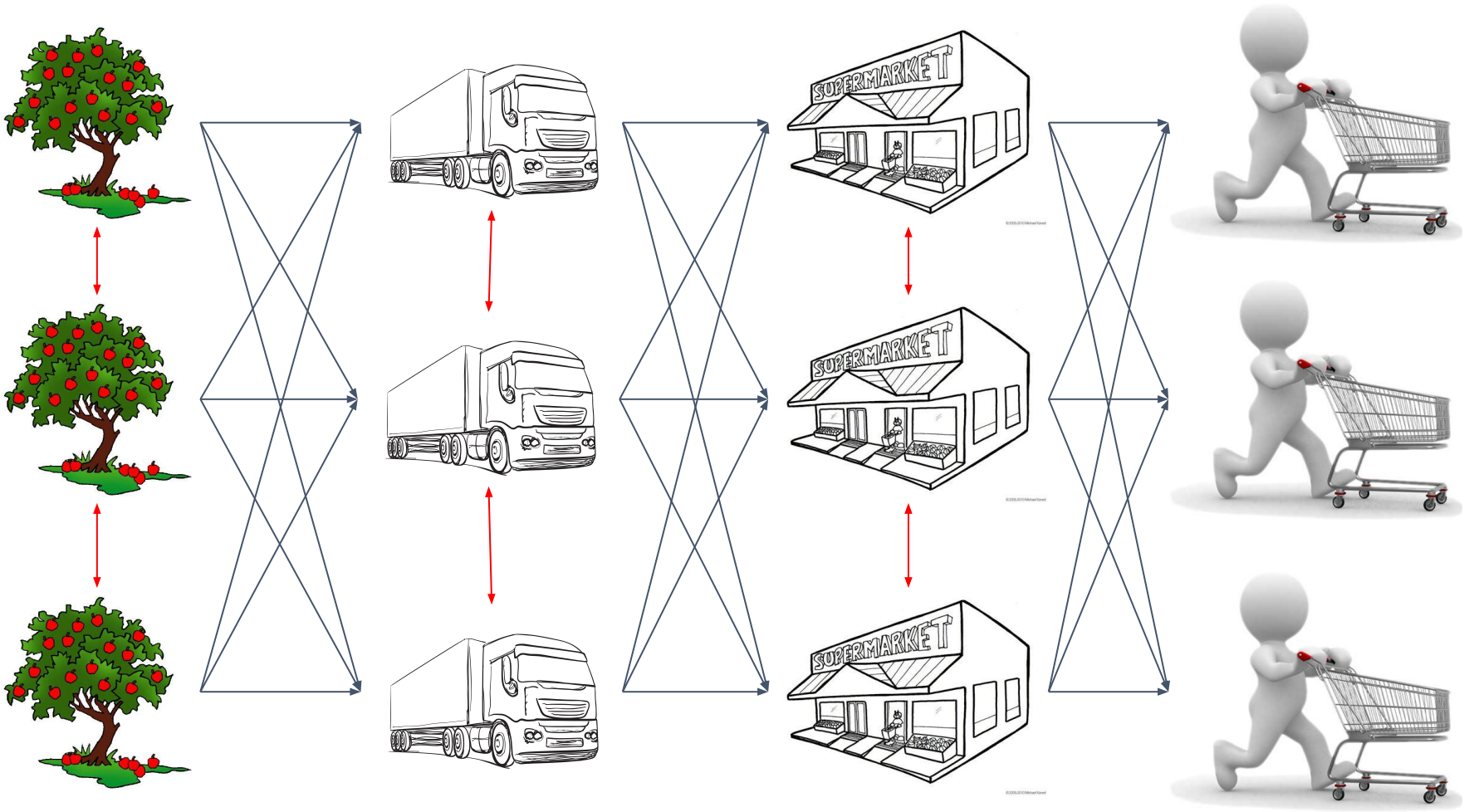
Apple market analogy

Think of an apple market… Part 1.: The monopoly



Apple market analogy

Think of an apple market… Part 2: Liberalization



Apple market analogy

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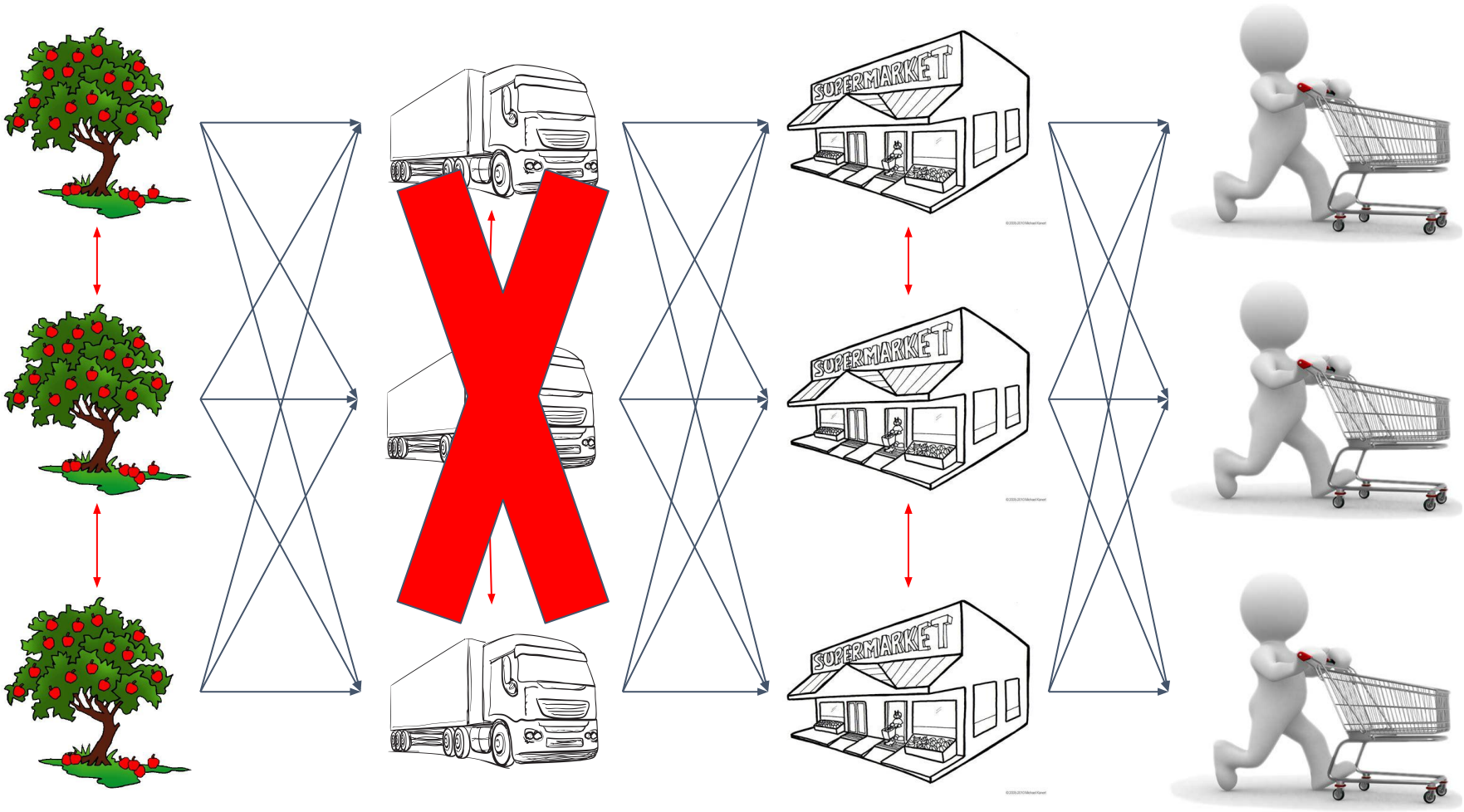

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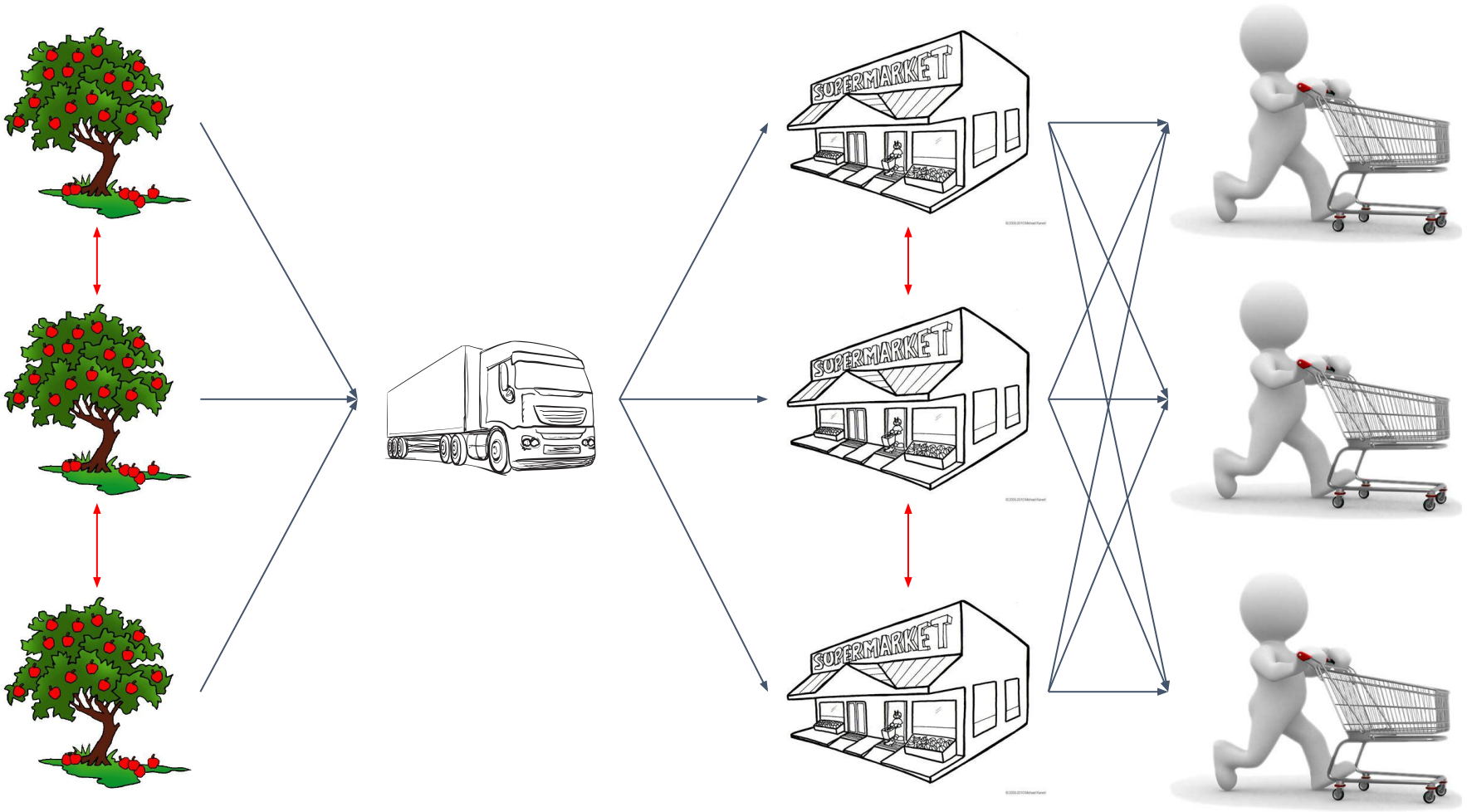
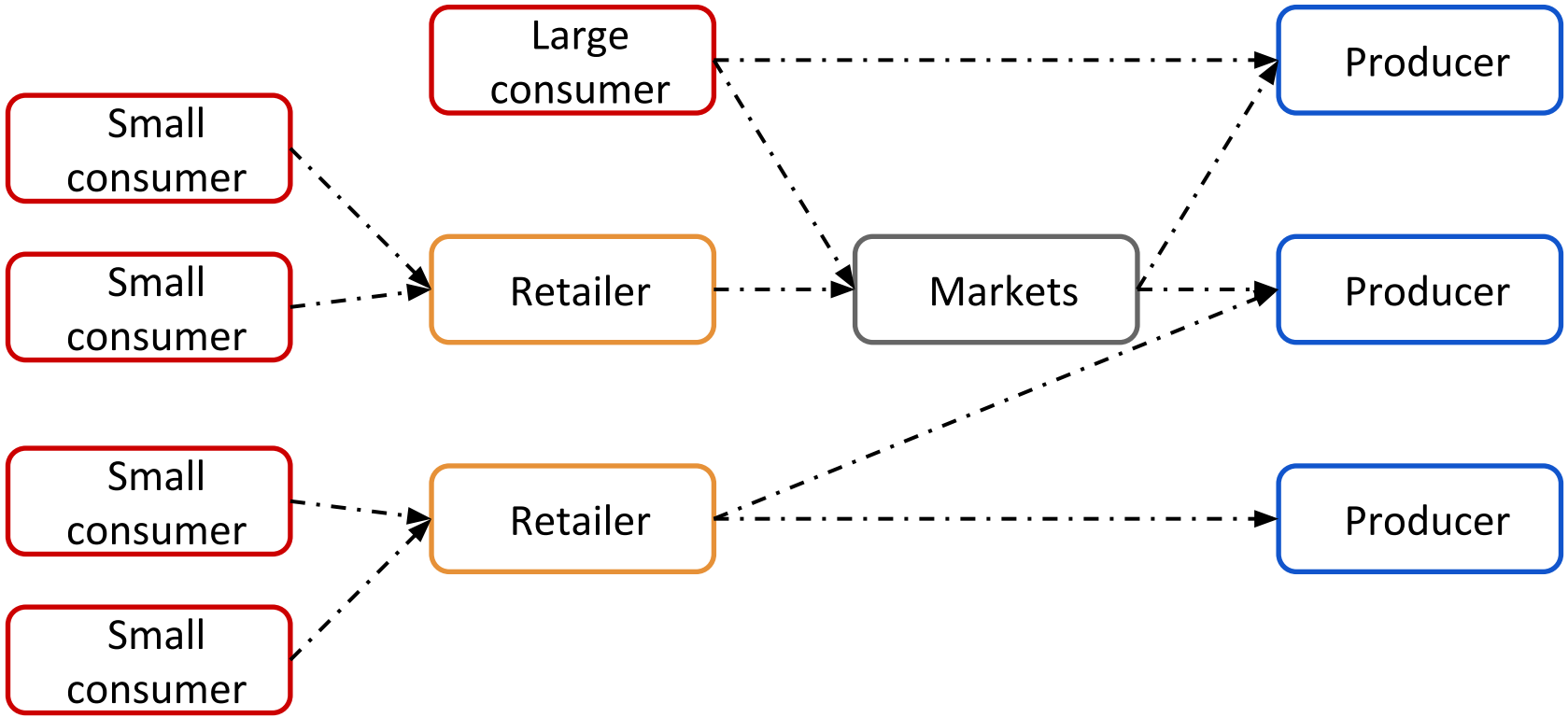


The flow of money



The flow of money

Note that this is still a **very simplified view** of money flows.

Among others, this **does not show**:

- Payment of taxes and network fees. These are included in the price paid by the small consumers to the retailers which then pay those taxes and fees.
- Buying from producers/selling from retailers. Sometimes, as we will see later, producers (retailers) can be incentivized to buy (sell) energy, instead of selling (buying-it.
- Balancing fees
- Payments for capacity mechanisms
- Guarantees of Origin

The last actor

The **regulator**:

- Determines or approves the electricity market rules,
- Investigates the suspected cases of abuse (market power),
- Sets or controls the prices of products and services in the case of monopolies (e.g. distribution network fees)

Actors recap and examples

Generating company/producers:

1. Own one or several power plants
2. Sell electrical energy produced by these plants
3. Can also compete to sell ancillary services

Generation companies having assets in Belgium:

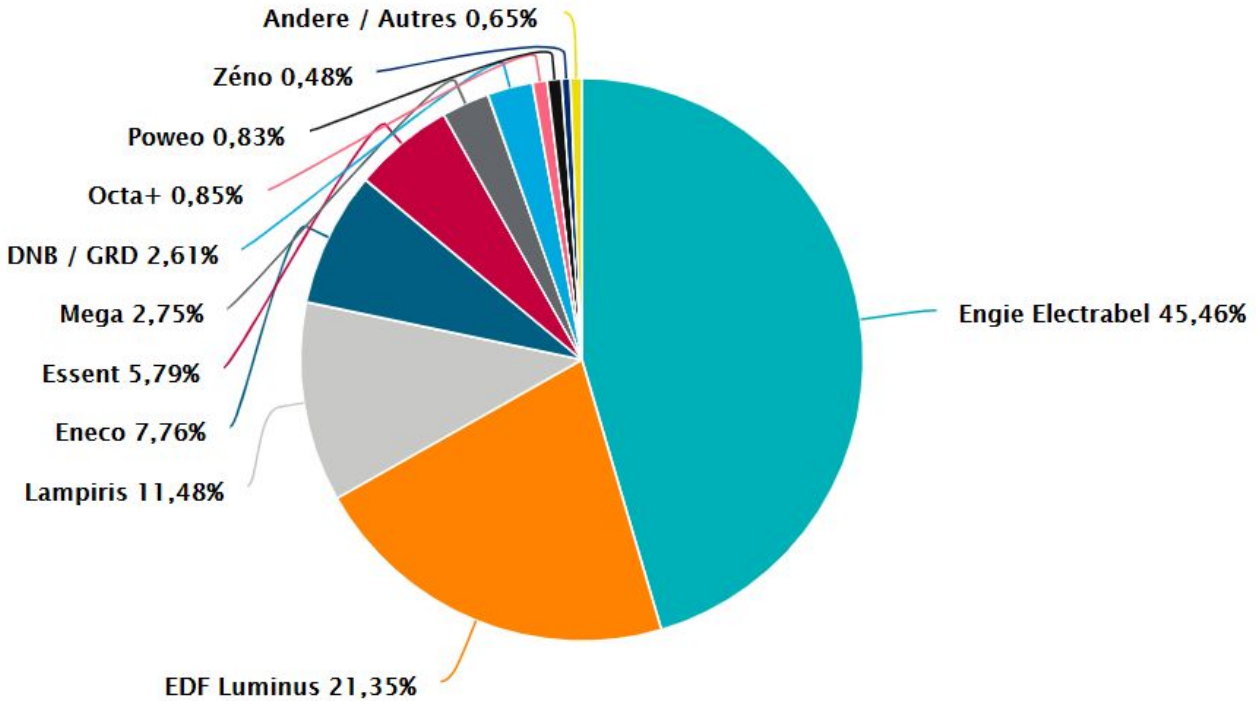
- Engie Electrabel (9 GW of installed capacity)
- EDF Luminus (2 GW)
- Eneco
- Lampiris, Ecopower, Energie 2030 et Wase Wind

Actors recap and examples

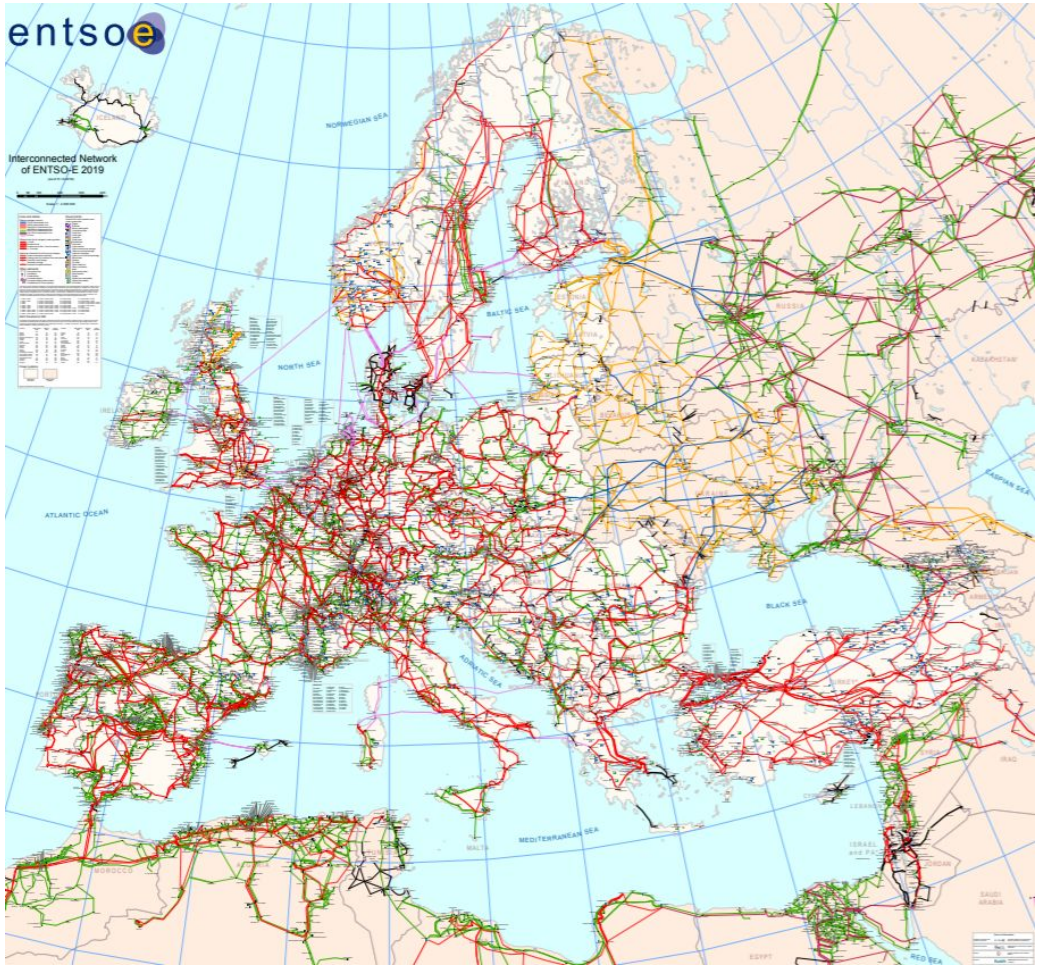
Retailer:

- Sell electricity to small consumers through a **retail market**
- Buy electricity from generation company on the **wholesale market**
- A generation company can also be a retailer.

Market share of retailers in Wallonia (Belgium)



The Belgian example – Note on the European network



Actors recap and examples

TSO - manages the transmission network
ISO - maintains the security of the network:

- In Belgium, TSO = ISO → Elia

At European level:

- **ENTSO-E** – European network of transmission system operators for electricity

Actors recap and examples

Several **DSO**s for the three Belgian regions:

- *Wallonia*: Ores, Resa, Régie de Wavre, AIESH, AIEG
- *Brussels-Capital region*: Sibelga
- *Flanders*: Eandis, Infrax

source: site Elia -http://www.elia.be/en/about-elia/electricity-market-players
Image source: Damien Ernst Facebook

Actors recap and examples

1 country, 4 **regulators**:

1. *National* : CREG – Commission de Régulation de l'Electricité et du Gaz
2. *Wallonia* : CWAPE – Commission Wallonne Pour l'Energie
3. *Brussels-Capital* : BRUGEL – Brussels Gaz and Electricity
4. *Flanders* : VREG – Vlaamse Regulator van de Elektriciteits- en Gasmarkt

CREG

brugel

LE REGULATEUR BRUXELLOIS POUR L'ENERGIE

CWaPE

Commission
Wallonne
pour l'Energie

vreg

VLAAMSE REGULATOR VAN DE
ELEKTRICITEITS- EN GASMARKT

Actors recap and examples

Market Operator

- Matches generating bids (from sellers) and consumption offers (from buyers)
- Takes care of the settlement of the accepted bids and offers

The market operator depends on the type of market.

Moreover, most European markets have been integrated.

Typical market operators include EPEX SPOT, EEX and ICE Endex.

Electricity sector structure: Open questions about liberalization

Main benefit of monopoly utility model: the operation and development of the power system was taken within a single organization

As it is not the case anymore with liberalization:

1. Is it possible to coordinate the different entities to achieve least cost operation? (e.g., maintenance of transmission system done jointly with the maintenance of operation line, coordination of long-term development in generation and in transmission, etc.)
2. Will free markets ensure that generation will always match demand?
3. How to optimize future investments?

Part 3. Electricity markets with an S

Part 3. The peculiarities of electricity

The problem with storage

It is **not possible to store** electricity on a large-scale.

1. Not enough capacity
2. Uneconomical

⇒ when electricity is produced, it must be consumed immediately.

The problem with storage

Electricity can not be stored as such. It has to be converted.

⇒ Leads to additional costs

Expl:

A Tesla Powerwall (2019 numbers):

- 10000 € (with installation)
- Guaranteed to work for ~38MWh of stored electricity
- ⇒ For each MWh of electricity that is produced, if it is stored we need to add a cost of 10000/38 = 263€
- Price of PV-generated electricity: < 100€/MWh
- ⇒ The price of each MWh of electricity that is stored (in this manner) is more than tripled!

Must-serve nature

Electricity → considered essential by most consumers.

To measure that:

“**Value of Lost Load (VOLL)**. This value is "obtained through surveys of consumers and represents the average price per megawatt-hour that consumers would be willing to pay to avoid being disconnected without notice" [Kirschen].

Based on some surveys ⇒ VOLL ~ 10€/kWh >> 0.285€/kWh

In other words, **demand must be satisfied at all times**.

Production = Demand

No storage + must-serve nature ⇒ at all times:

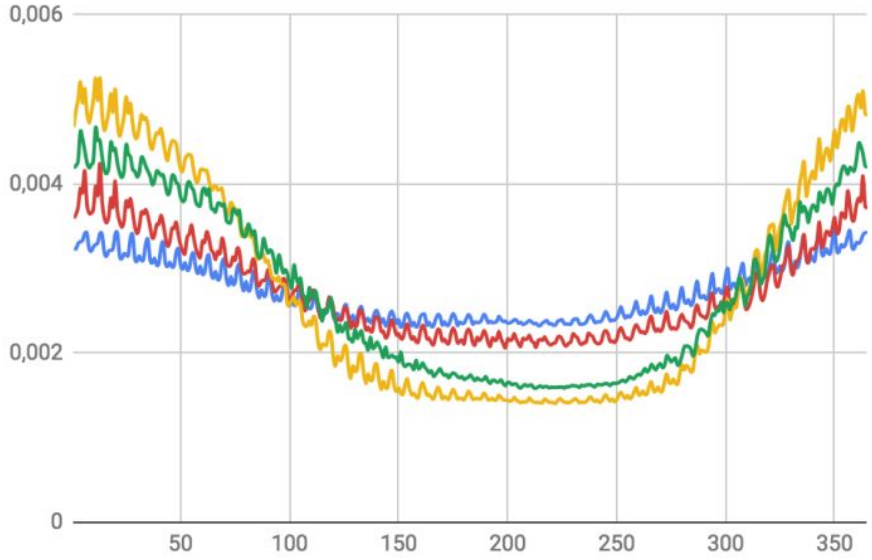
Production = Demand

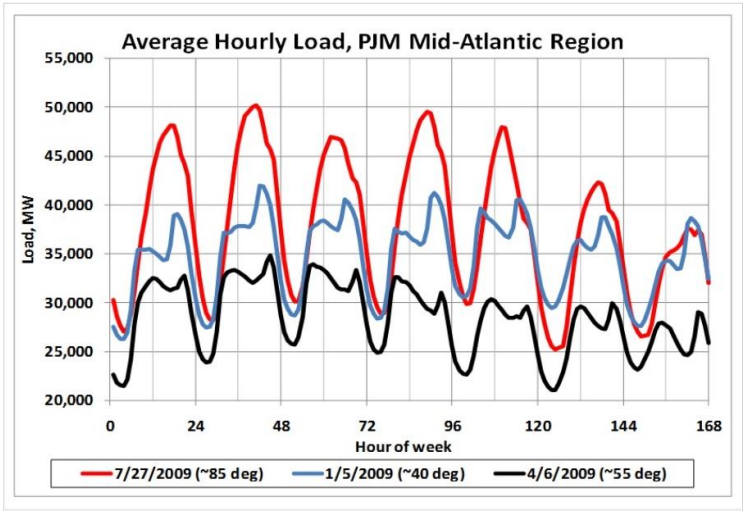
Note: see previous class for frequency deviations problem

Is this constraint difficult to respect?

Forecasting is difficult

Yearly - Weekly - Daily patterns





Estimates/prediction based on past data

- Never perfect
- Improves when closer to real time

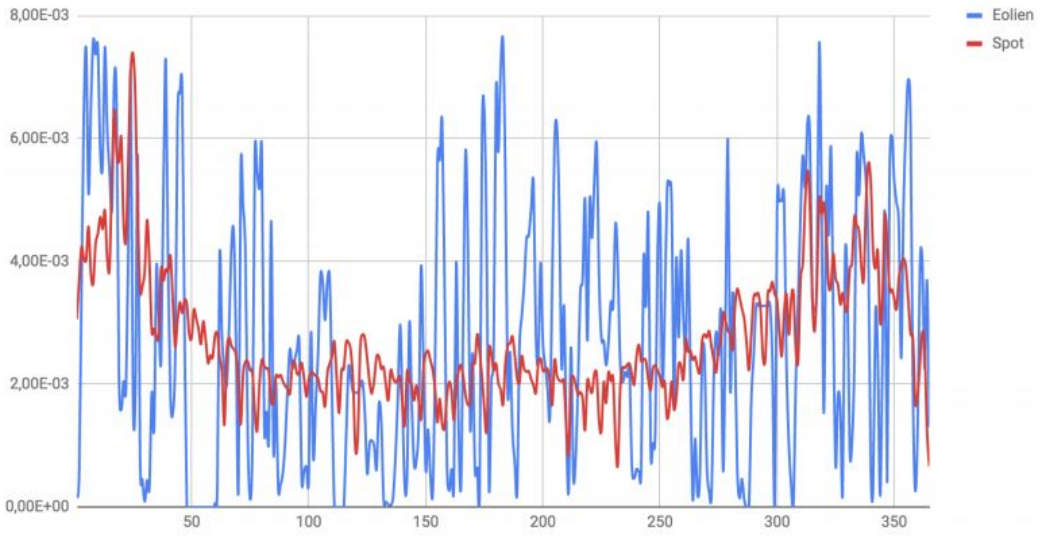
Forecasting is difficult

1. **Demand** is difficult to forecast

2. **Production** can be difficult to forecast too!

Why?

- Some plants might have unexpected failures
- Increasing share of **volatile** renewables in the energy mix



Sequential markets

Conclusion: Demand must be equal to production at all times but both of them are difficult to forecast.

How do we deal with that?

⇒ Solution: the markets must offer to participants the possibility to correct their buying/selling positions until the moment of delivery.

Example:

- A wind farm sells 10 MWh one week in advance to a retailer.
- One day before delivery, based on new forecasts, production will be 9 MWh.
- To honor the contract ⇒ need to find a place to buy 1 MWh.

Sequential markets

Markets are organized in a sequential way.

⇒ Some operate **years** in advance and some others **minutes** before delivery.

Question you might ask yourself:

Why not just buy all electricity at the last moment?

⇒ Main reason: protect oneself from price spikes.

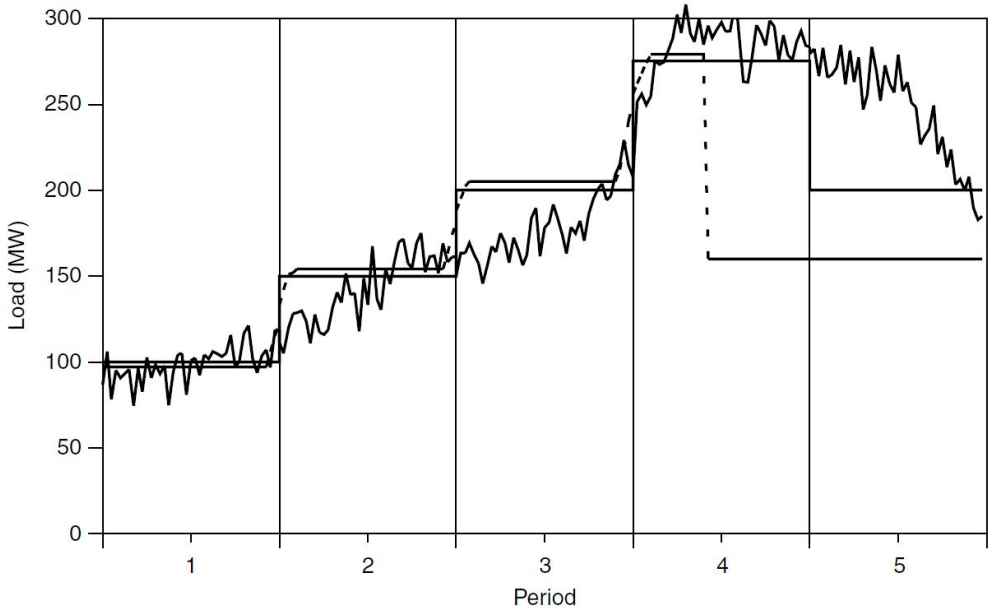
- Closer to real-time: more and more participants have already fixed their buying/selling positions
- Less choice in terms of who you can buy/sell to
- More risk of having to buy at a high price/sell at a low price

A second-by-second market?

For a series of reasons, it is not possible currently to trade on a second-to-second basis.

Consequence: Markets are organized based on longer periods of different lengths in different countries:

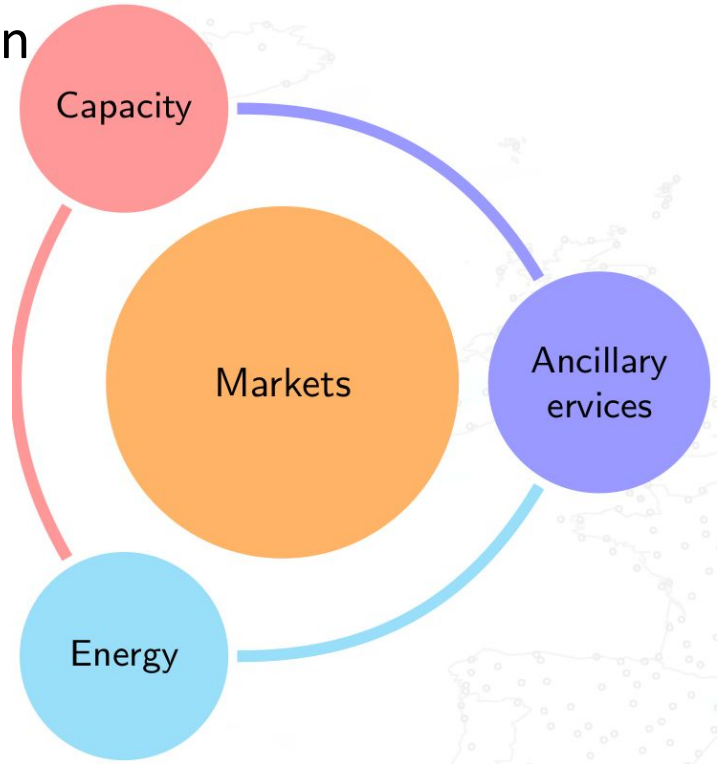
- 1h
- 30 min
- 15 min



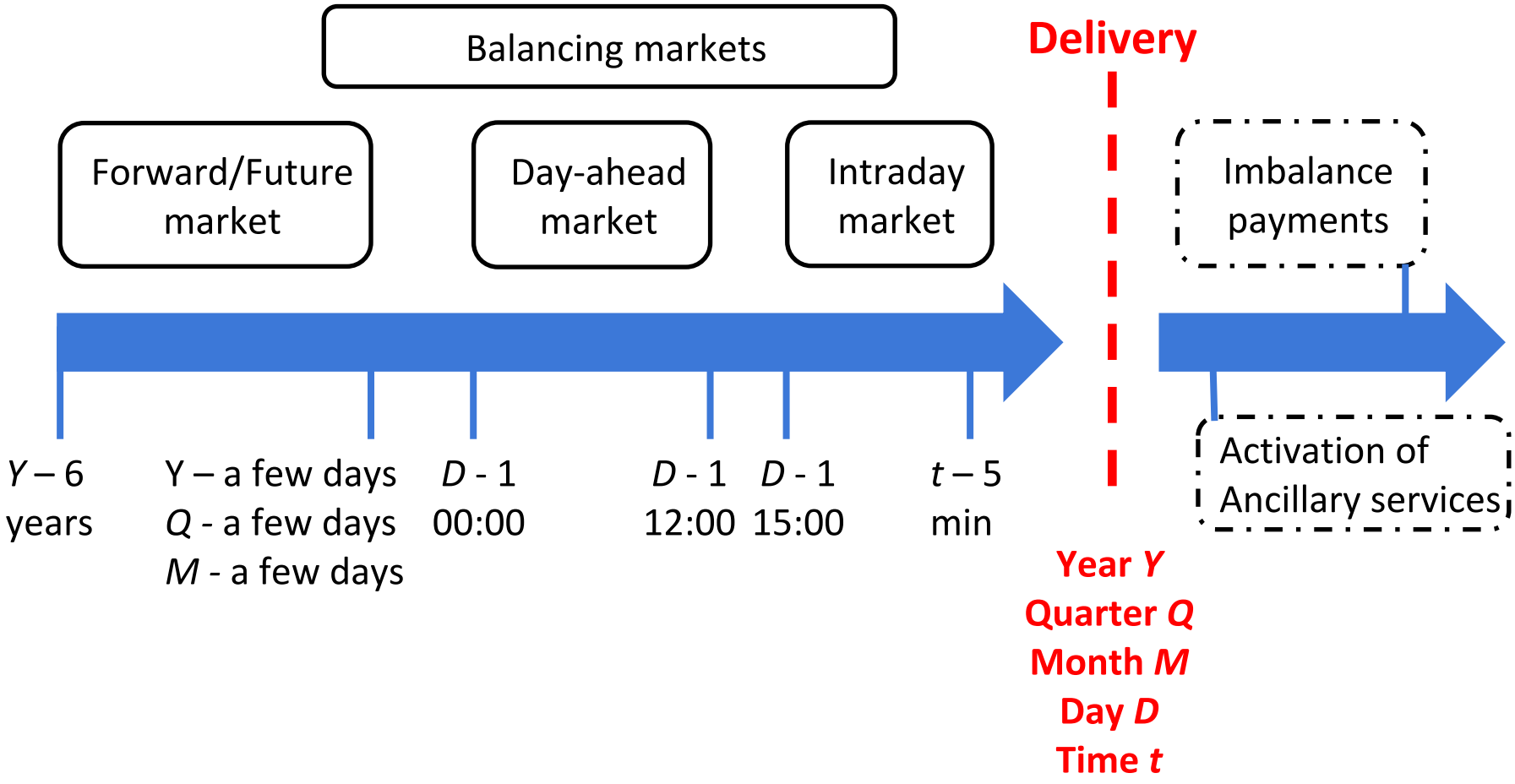
Part 3.2. The markets

Types of markets

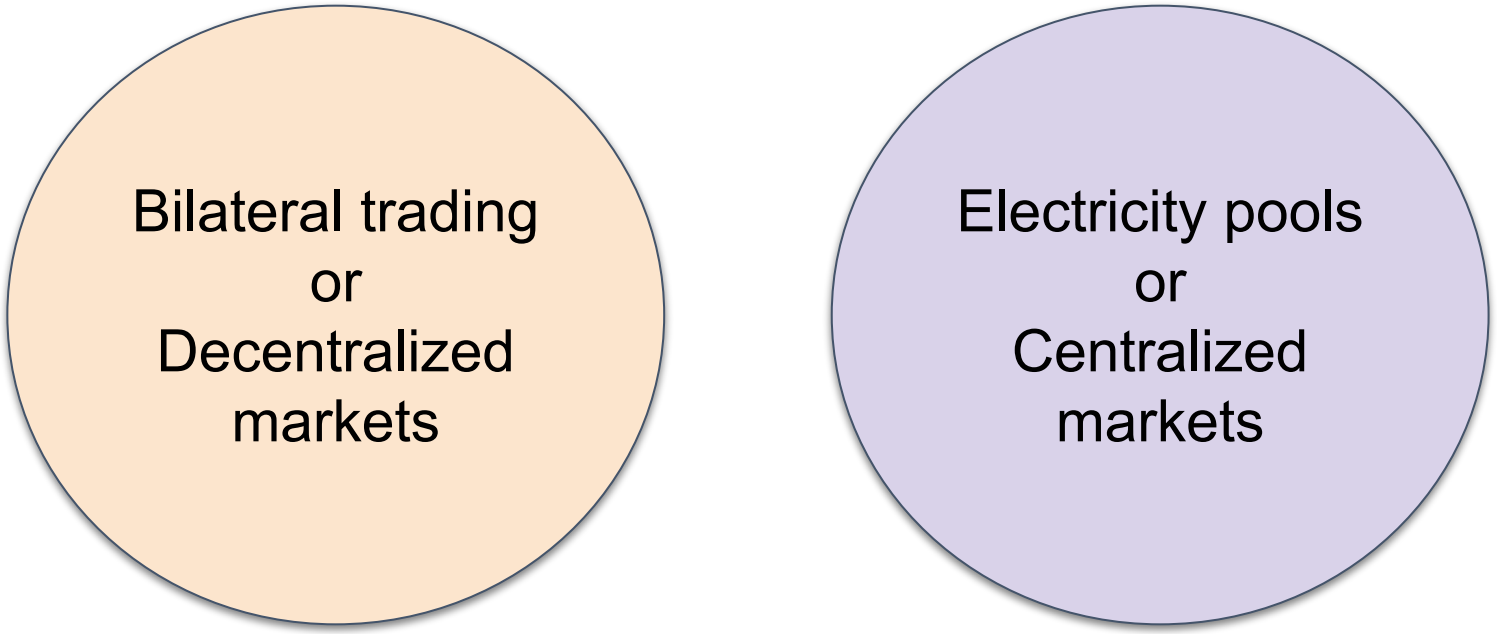
- **Capacity**: for the ISO to ensure that sufficient generation capacity is present for reliable system operation in future years at competitive prices
- **Energy**: central place for the optimal scheduling and settlement of energy exchanges
- **Ancillary service**: any type of service that supports power system operations, directly bought by the ISO e.g.
  - Primary/secondary/tertiary reserves
  - Black start capability, short-circuit power, reactive reserves and voltage control



Chronology of markets



Two families of markets



Bilateral Trading

Involves a buyer, a seller and no third parties.

Different coexisting forms of bilateral trading depending on the amount of energy to be traded and the time available.

1. Customized long-term contracts: negotiated privately; usually involve the sale of large amounts of energy; large transaction costs
2. Trading "over the counter": Involve smaller amount of energy to be delivered according to a standard profile (how much energy should be delivered during the different periods of the day and the week). Much lower transaction costs; use to refine positions.

Bilateral Trading

3. Electronic trading: Offers to buy energy or bids to sell energy are traded. Bids and offers can be seen by everyone but they are anonymous.
   a. When party enters new bid, the system checks to see whether it matches an existing offer (offer with a price greater or equal to the bid).
   b. If yes, a deal is struck. Otherwise, bid add to the list of the bids.
   c. Similar procedure with offers.

Remarks: Electronic trading is fast and cheap. Used to refine positions in the minutes before the market closes

Electricity pools

Electricity naturally pooled when flowing from the generators to the loads ⇒ It was felt that trading could be done in a centralized manner through electricity pools.

No repeated interactions between suppliers and consumers to reach the market equilibrium.

A pool provides a mechanism for reaching this equilibrium in a systematic way.

How do they work?

Generators submit bids for the period under consideration.

Bids = amount of electrical energy at a certain price. Bids are ranked according to increasing price and a supply curve of the market is built.

Consumers submit offers (amount of energy they are willing to buy at a certain price). A demand curve is built.

⇒ These two curves define the merit order.

Intersection of demand and supply curves represent the market equilibrium price (also called the system marginal price, SMP).

Bids inferior to the market equilibrium price and offers above this price are accepted.

Example: Bidding supply and demand curves from bids and offers

Bids	Company	Quantity (MWh)	Price ($/MWh)
	Red	200	12.00
	Red	50	15.00
	Red	50	20.00
	Green	150	16.00
	Green	50	17.00
	Blue	100	13.00
	Blue	50	18.00
Offers	Yellow	50	13.00
	Yellow	100	23.00
	Purple	50	11.00
	Purple	150	22.00
	Orange	50	10.0
	Orange	200	25.00

Merit-order

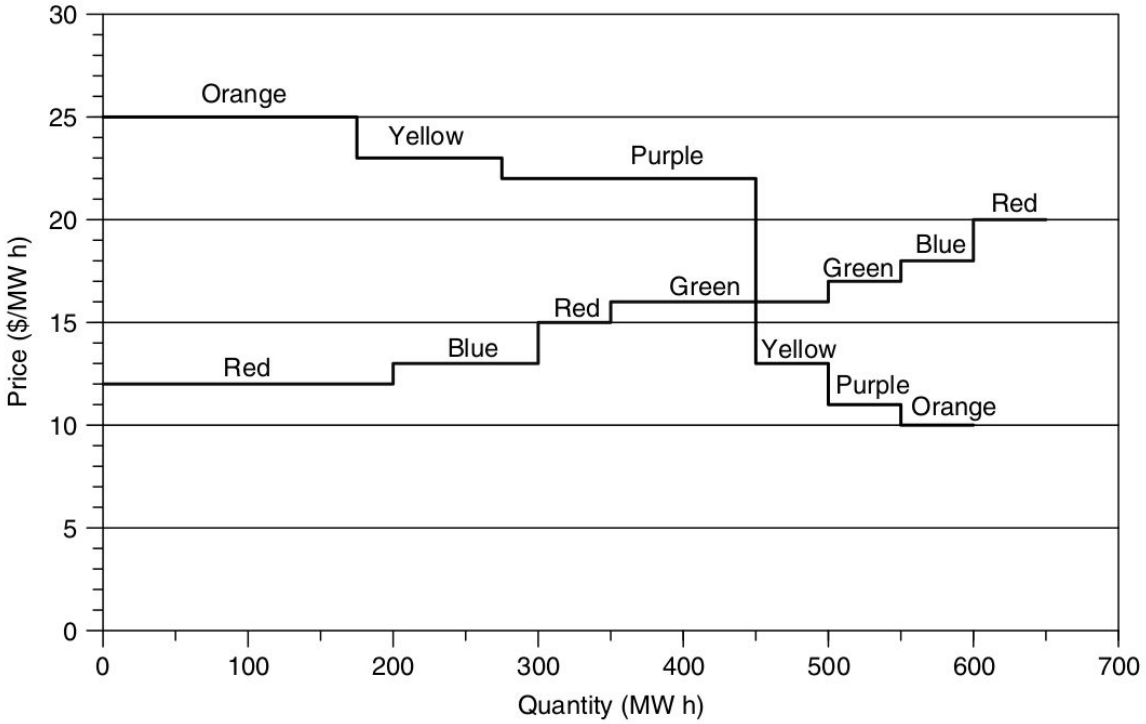


Figure 3.1 Stacks of bids and offers of Example 3.2

Merit-order - Exercice

- Assuming you are the market operator and you see those bids in the pool
  - How much shall a consumer **pay at least** for buying 20 MWh? What is the cost of the last unit of energy?
  - How much will a producer **get paid at most** for selling 20 MWh? What is the cost of the last unit of energy?
  - More generally 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

Merit-order - Exercice

How much shall a consumer pay at least for buying 20 MWh?

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

What is the cost of the last unit of energy?

→ 5€

Marginal cost of energy for a consumer

⇒ Marginal cost 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
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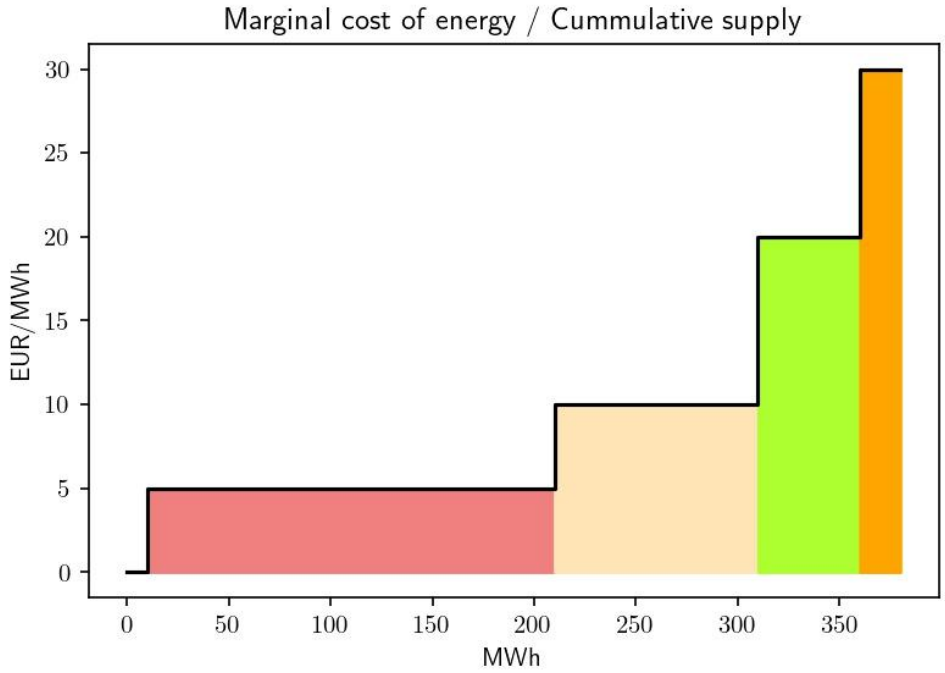
Merit-order - Exercice

Marginal cost for *x* MWh?



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Buy	50 MWh	1 €/MWh
	100 MWh	15 €/MWh
	200 MWh	20 €/MWh
	50 MWh	30 €/MWh

Merit-order - Exercice

How much shall a producer get paid at most for buying 20 MWh?

→ 20 MWh * 30€/MWh = 600€

What is the cost of the last unit of energy?

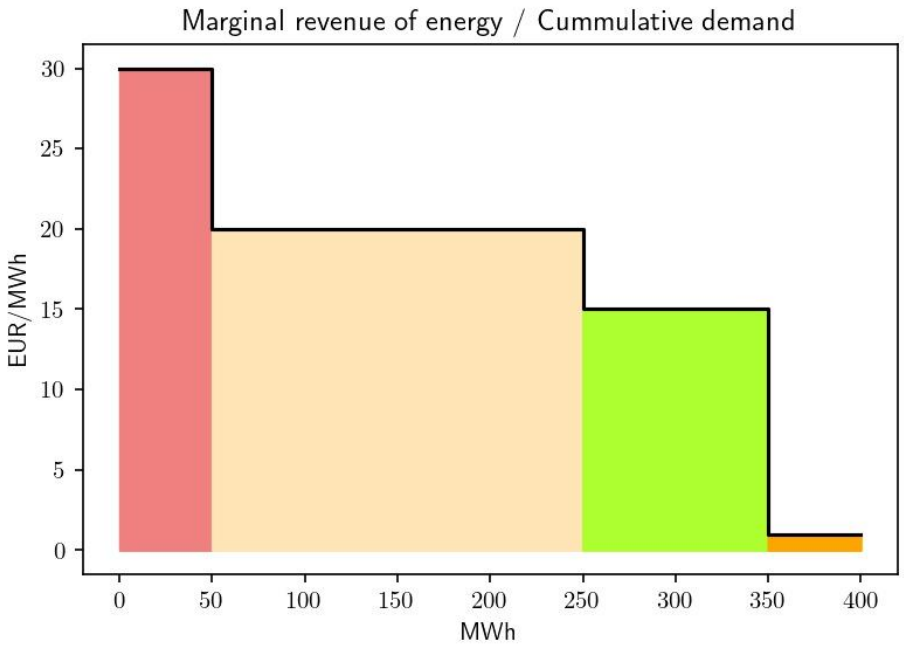
→ 30€

Marginal revenue of energy for a 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

Merit-order - Exercice

Marginal revenue for *x* MWh?



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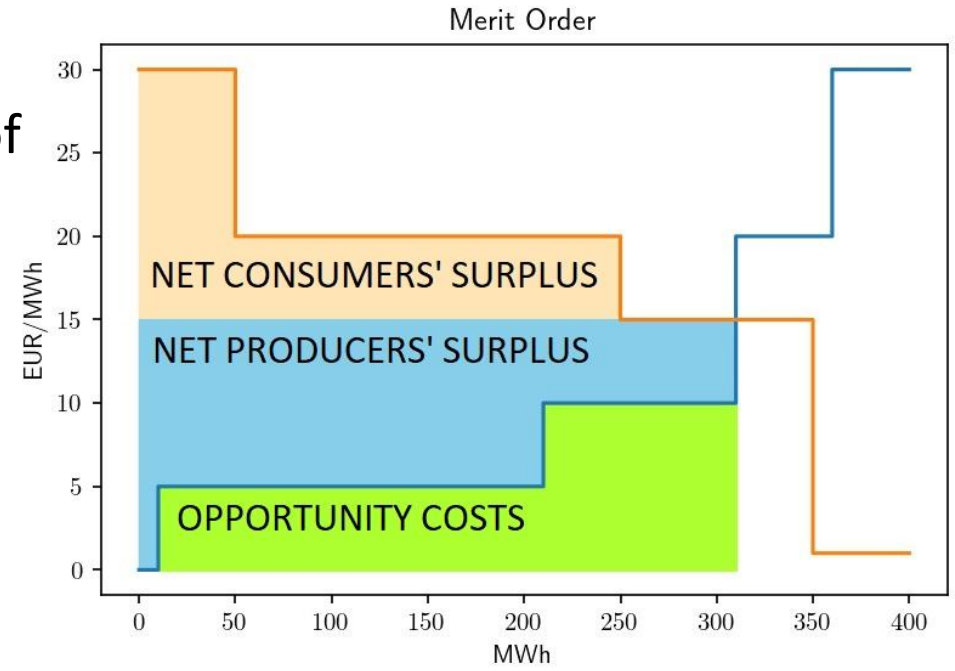
Buy	50 MWh	1 €/MWh
	100 MWh	15 €/MWh
	200 MWh	20 €/MWh
	50 MWh	30 €/MWh

Merit Order

- **Merit Order** : ordering of the bids.
- **Equilibrium price:** intersection of supply and demand

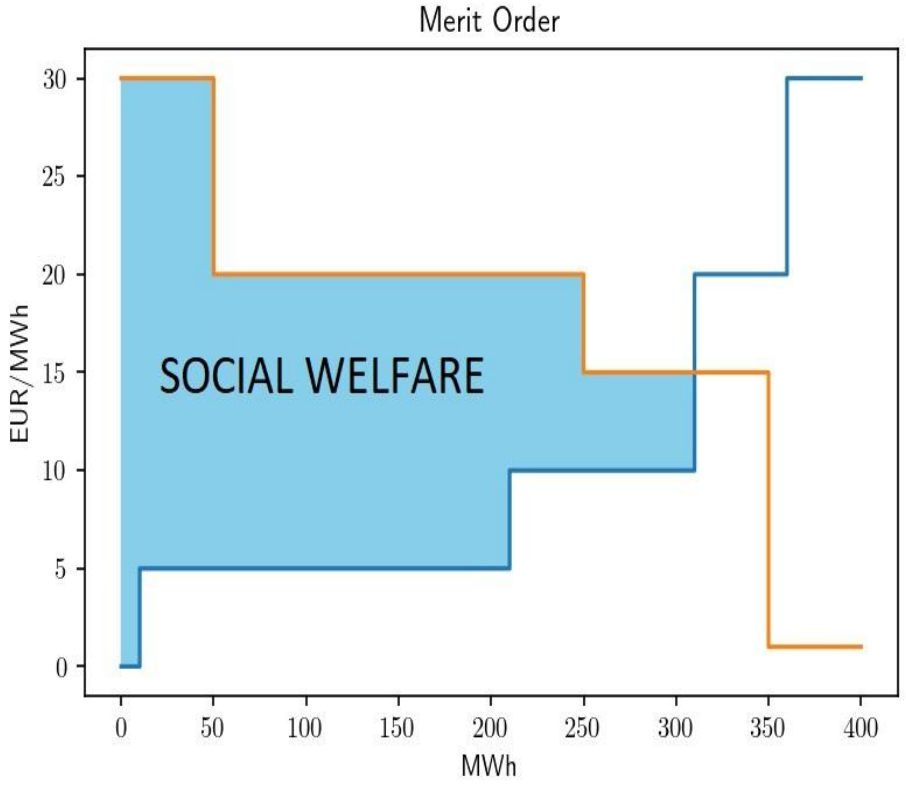


Social welfare

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

- The 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 so as to **maximize the social welfare**.



Settlement

What is the final cost of electricity?

- Two paying mechanisms :
  - **Paid-as-bid** : each agent receives the amount of money they bid.
  - **Uniform pricing** : a single price is fixed as the market price.
- EPEX : uniform pricing at the equilibrium price.
- With uniform pricing, the agents have the incentive to bid at their marginal cost.

Remarks on electricity pools

Why are all generators paid the SMP?

- They could be paid only the price of their bids which could lead to a decrease of the price of electricity.

- But, with such a scheme, all the generators will try to guess the system marginal price and, eventually, some cheap generators may be left out of the scheduling).

- May lead to an inefficient use of resources and even possible increase of the price of SMP (generators are likely to increase their prices to compensate for the risk of being left out of scheduling).