



ELEC0080-1 ENERGY NETWORKS

Partim1: Electrical Energy Systems

Lecture 4 & 5. Electricity markets

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2. Electricity sector structure
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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. [Kirschen] *Fundamentals of Power System Economics*, Daniel S.Kirschen, Goran Strbac

Courses:

1. [Ernst] *Energy markets*, Damien Ernst, ULiège
 - <http://blogs.ulg.ac.be/damien-ernst/teaching/elec0018-1-energy-markets/>
2. [Pinson] *Renewables in Electricity Markets*, Pierre Pinson, DTU
 - <http://pierrepinson.com/index.php/teaching/>
3. [Dumas] Lectures on residential energy supplier and residential electricity pricing
 - <https://github.com/jonathandumas/ELEC0018-1-energy-markets-retailers>

Special thanks to Adrien Bolland, Jonathan Dumas and Thibaut Théate for their support.



Part 1. Electricity markets: what and why?



What are electricity markets?

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 markets?

Electricity has some special properties → several ways to exchange it



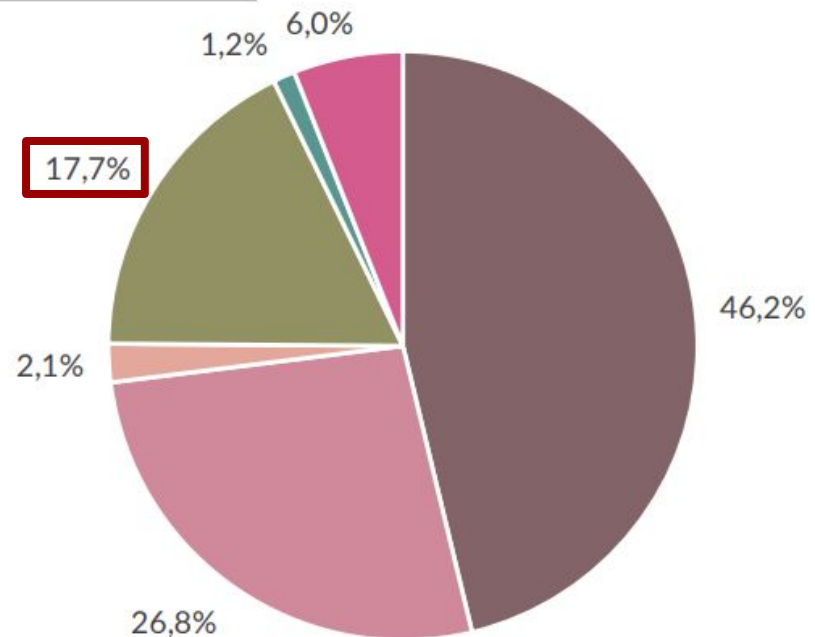
Why study electricity markets?

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



The relative weight of electricity

Energy source		Mtep
Oil products		17,7
Natural gas		10,3
Solid fossil fuels		0,8
Electricity		6,8
Heat		0,5
Renewables & Waste		2,3
Total		38,4





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)

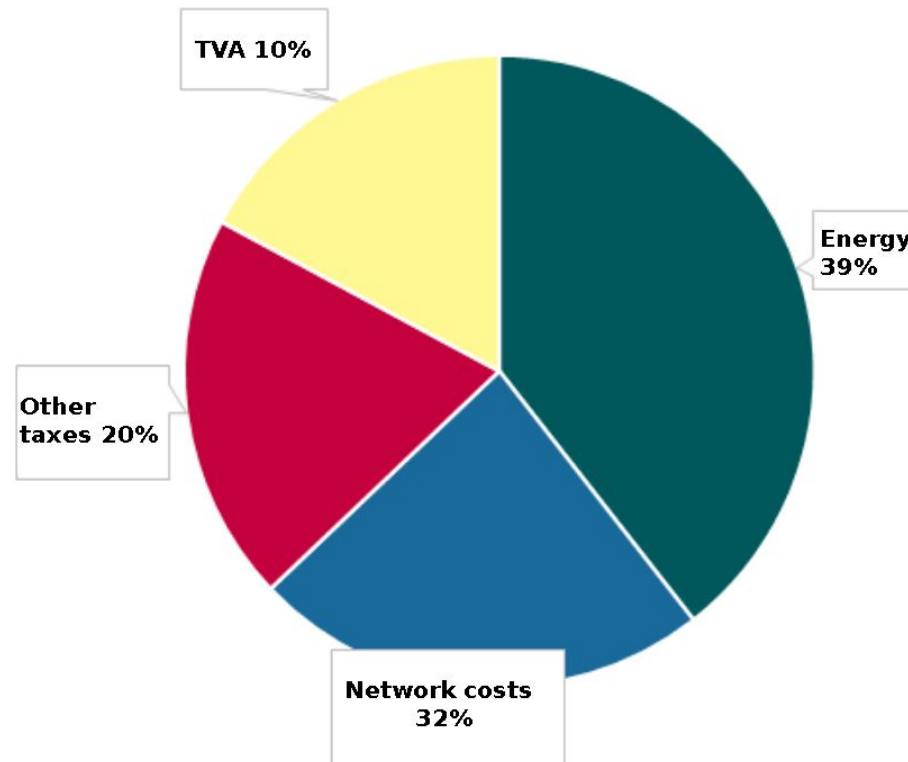
- Average residential price in Belgium 2020: 0.275€/kWh
- Average energy consumption per consumer: 2.5 to 5 MWh/year
- ⇒ between ~700 and 1400 € per year
- ⇒ between 57 and 115€ per month





Your point of view (the small consumer)

- In the price you pay → **less than 50% 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
- \Rightarrow very different to what happens on markets

Auction > Day-Ahead > 60min > BE > 05 November 2021

Last update: 04 November 2021 (12:49:12 CET/CEST)





Part 2.2. The flow of energy



The flow of energy - How electricity reaches you

When you plug something in → electricity flows in.

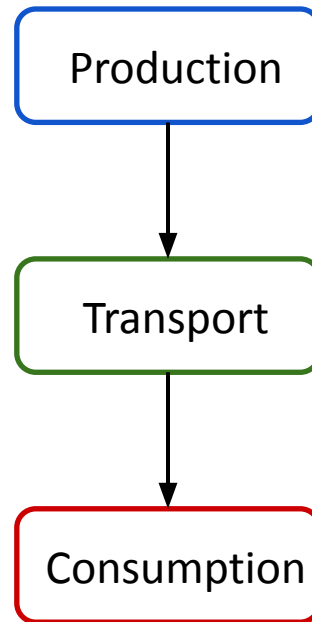
How?

Quick overview of the 3 components of the electricity network:

- Production
- Transport
- Consumption

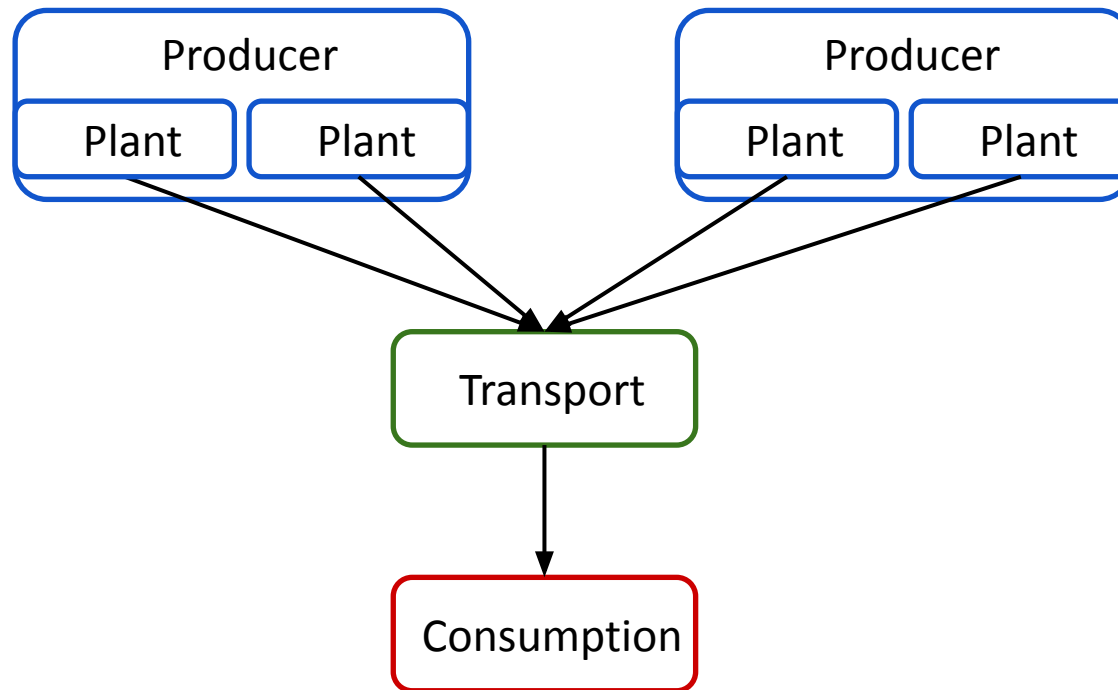


The flow of energy - 3 main components



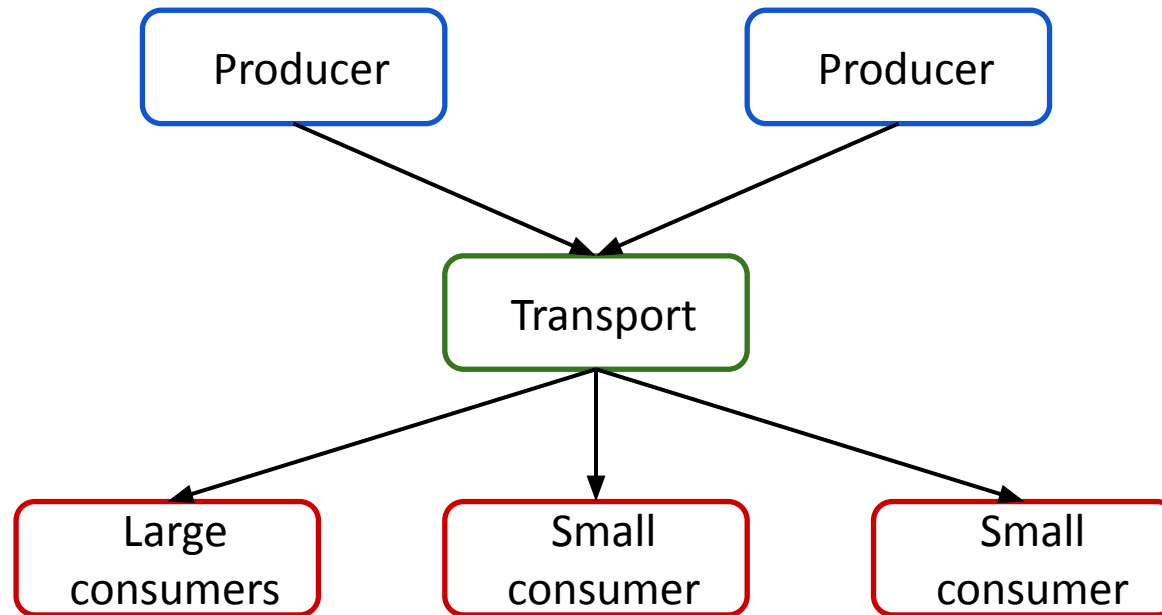


The flow of energy - Production



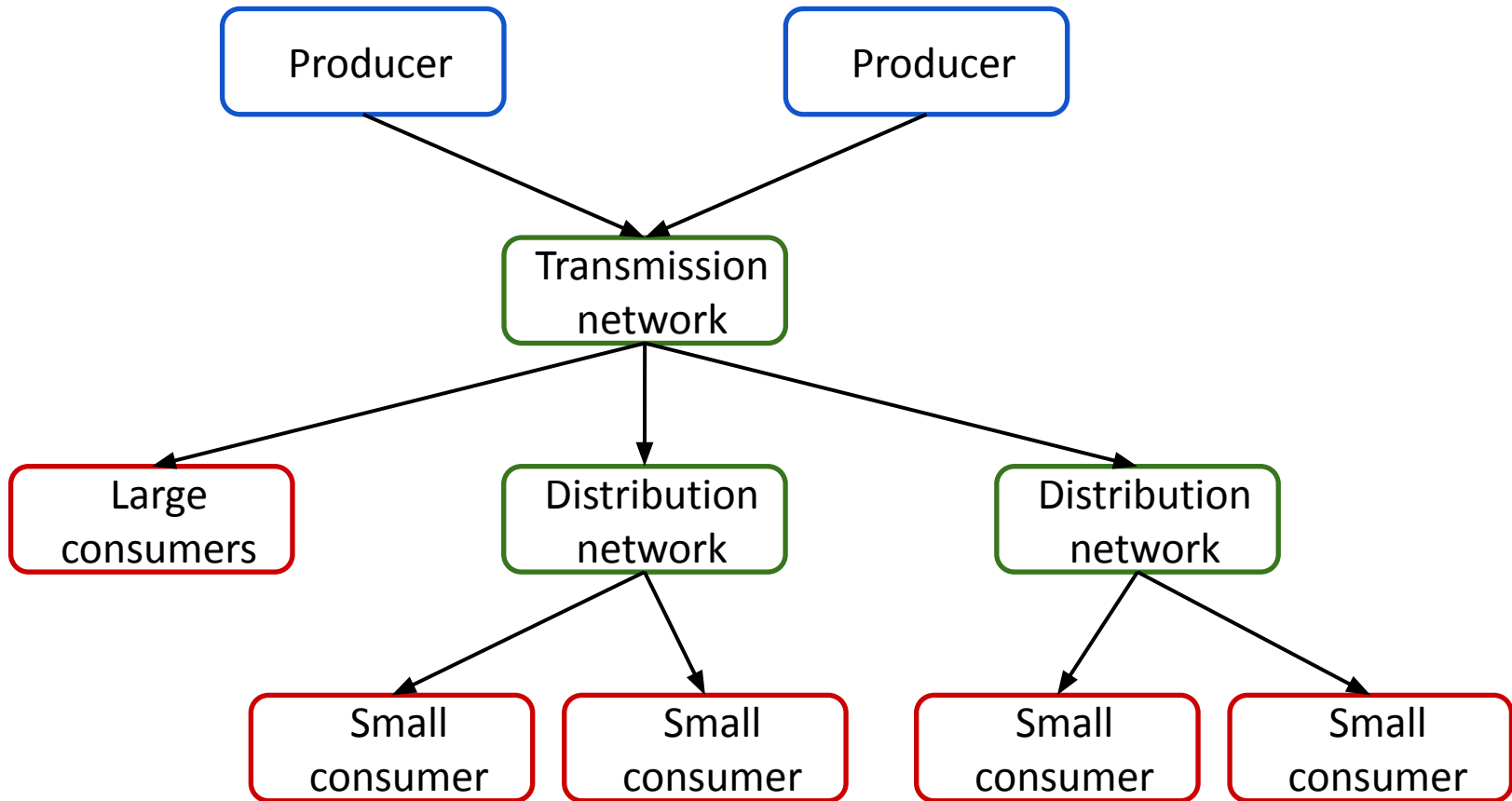


The flow of energy - Consumption





The flow of energy - Transport





Part 2.3. Liberalization and actors



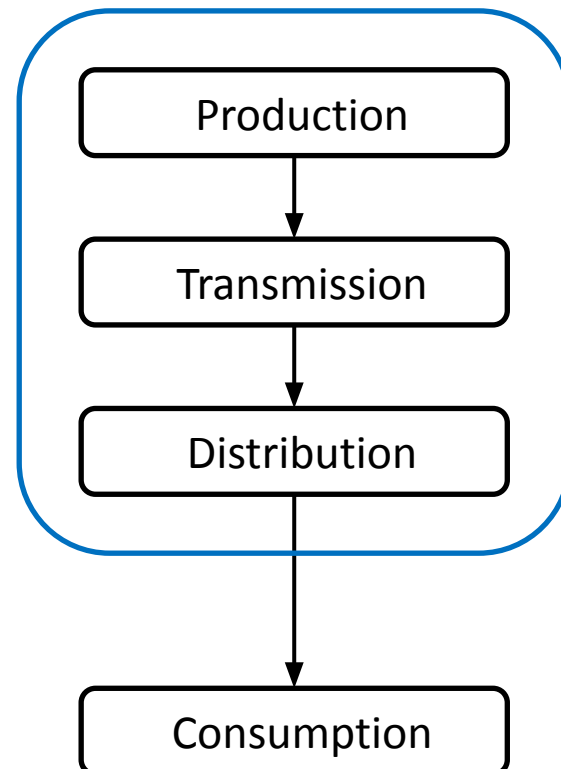
The time of monopolies

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

Suppliers were:

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

Monopoly





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

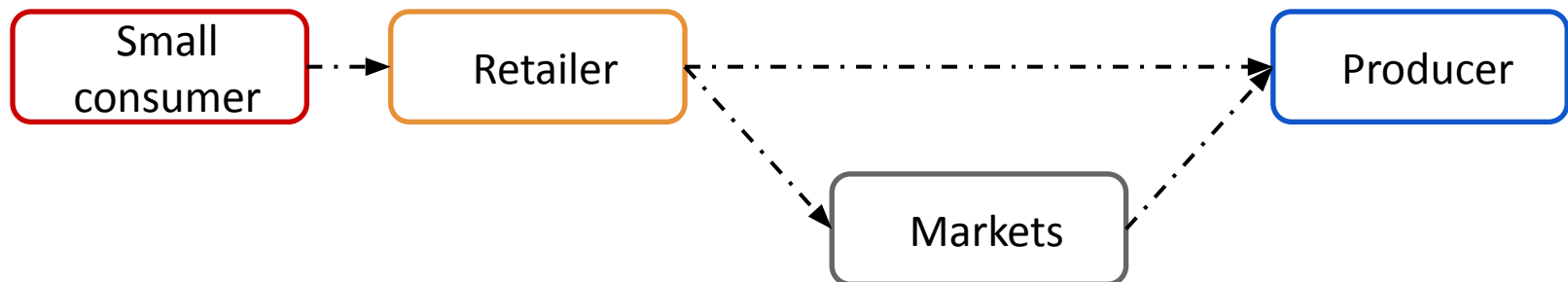
1. No incentives to operate efficiently
2. Encourages unnecessary investments
3. Government interfering in public entities
4. **Higher prices** than in a market

Liberalization \Rightarrow 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)

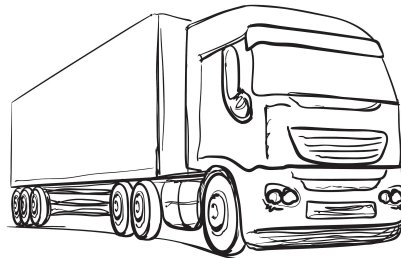
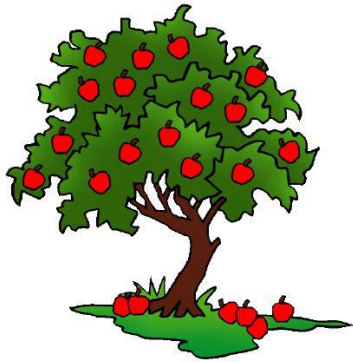
- Responsible for **maintaining the security** of power system operation
- Can be managed by the **TSO**



Apple market analogy

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

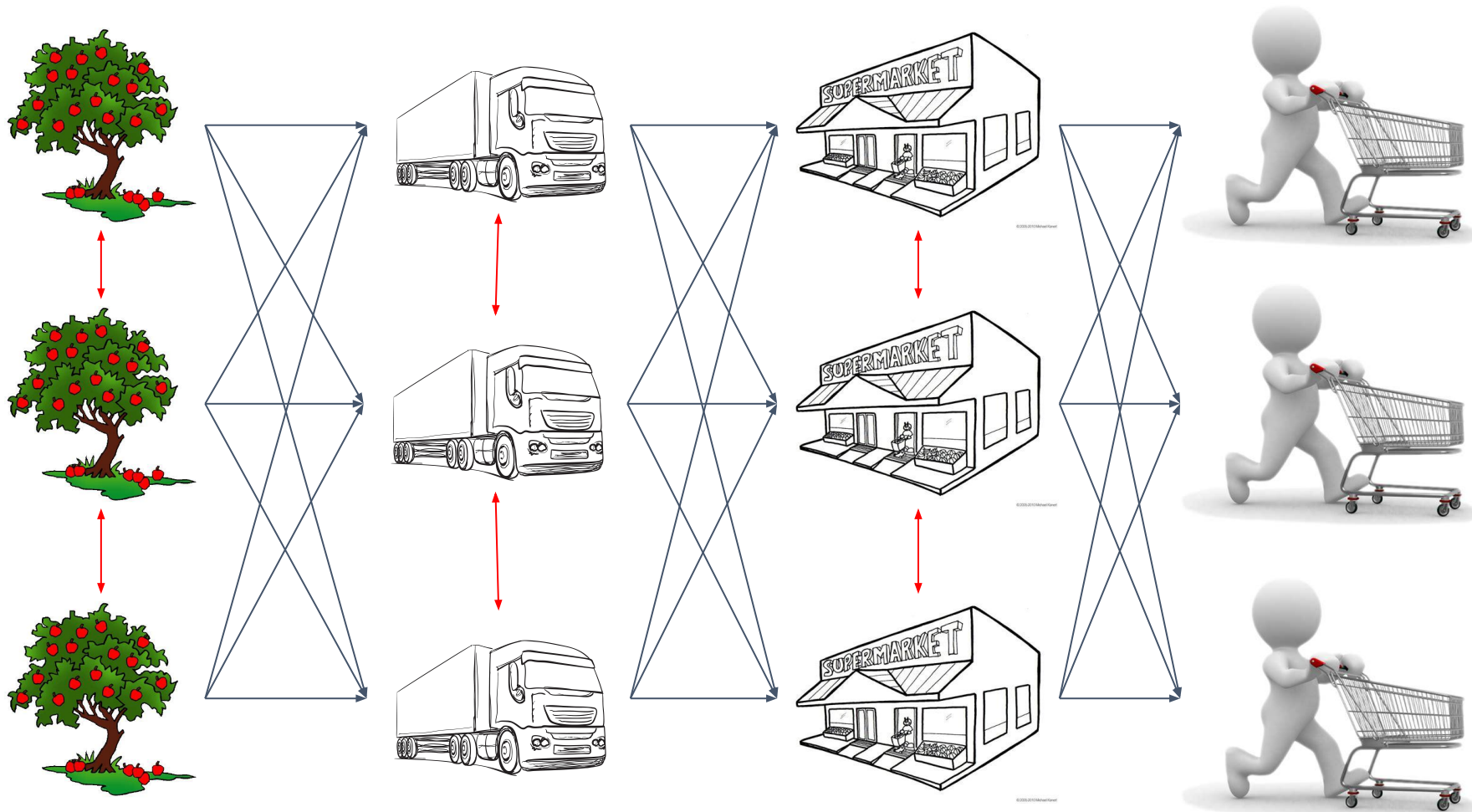
Apple.inc





Apple market analogy

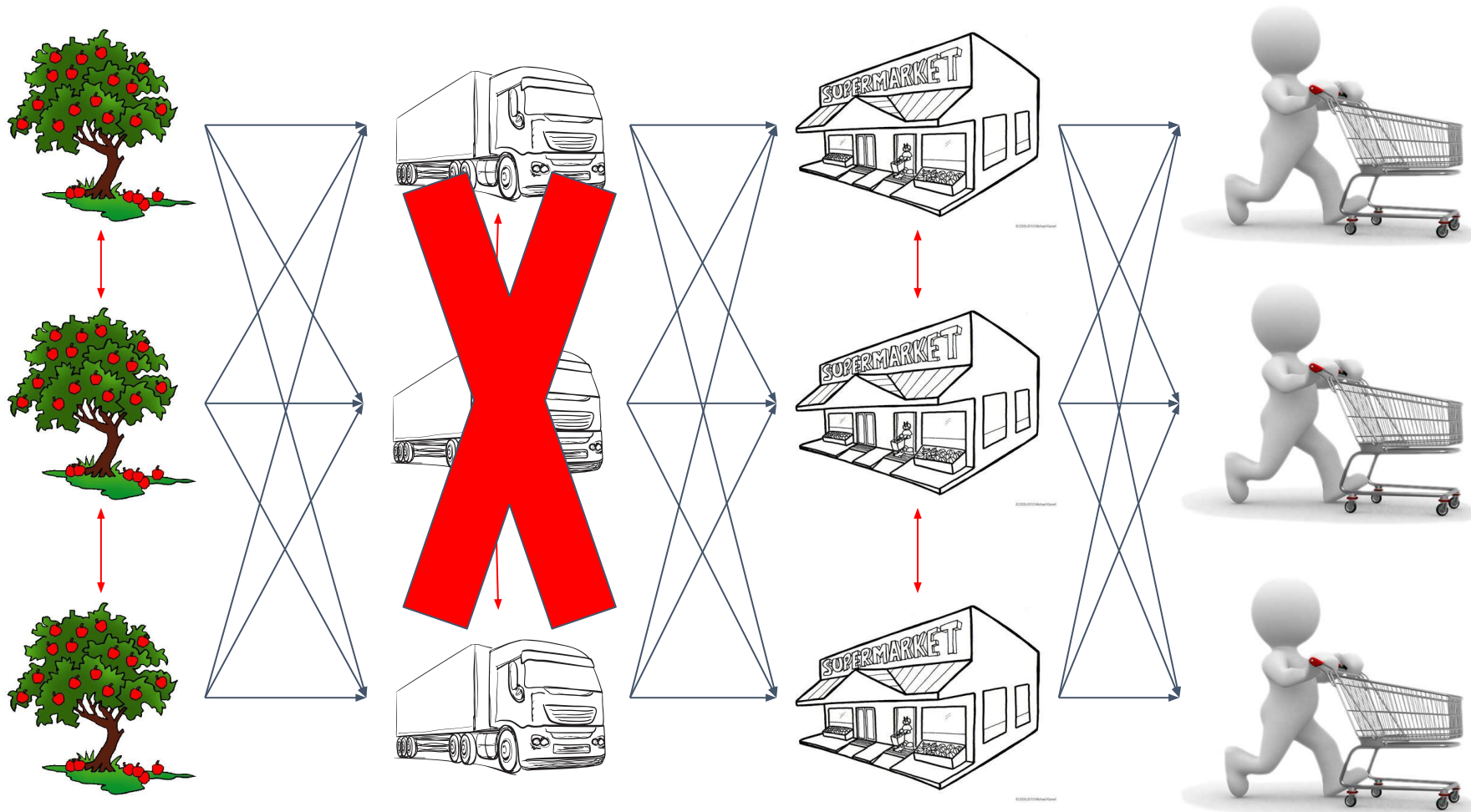
Think of an apple market... Part 2: Liberalization





Apple market analogy

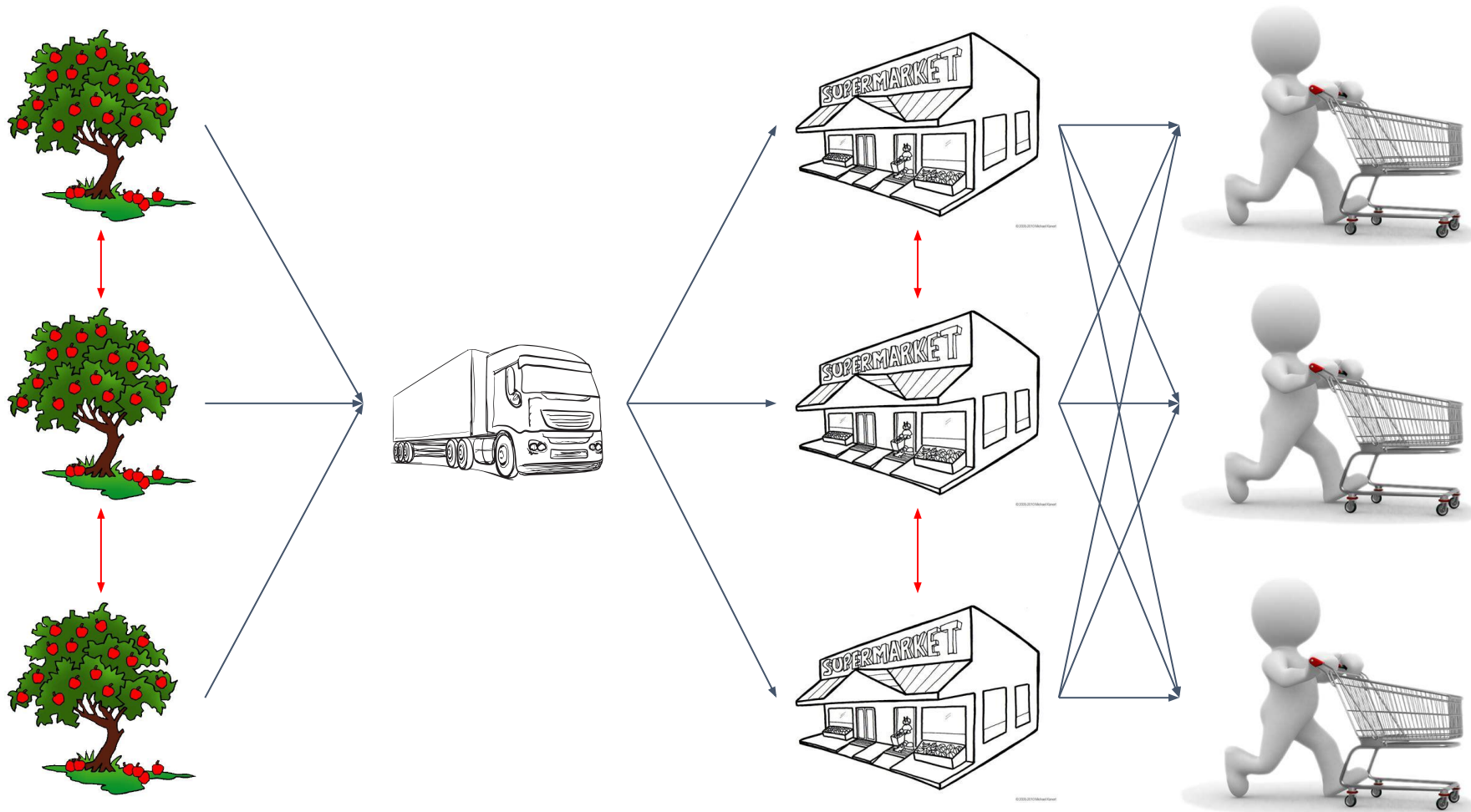
Think of an apple market... Part 2: Liberalization





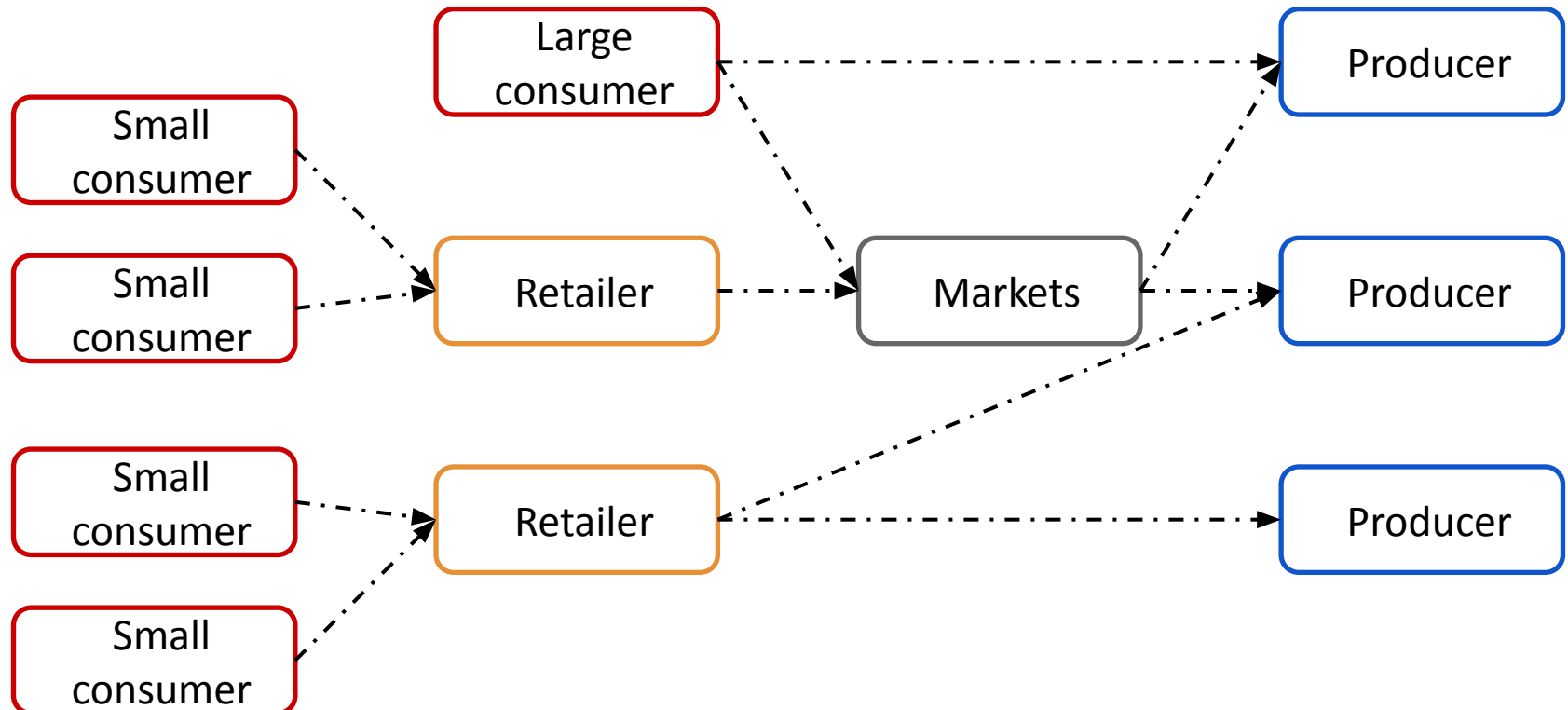
Apple market analogy

Think of an apple market... Part 2: Liberalization





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



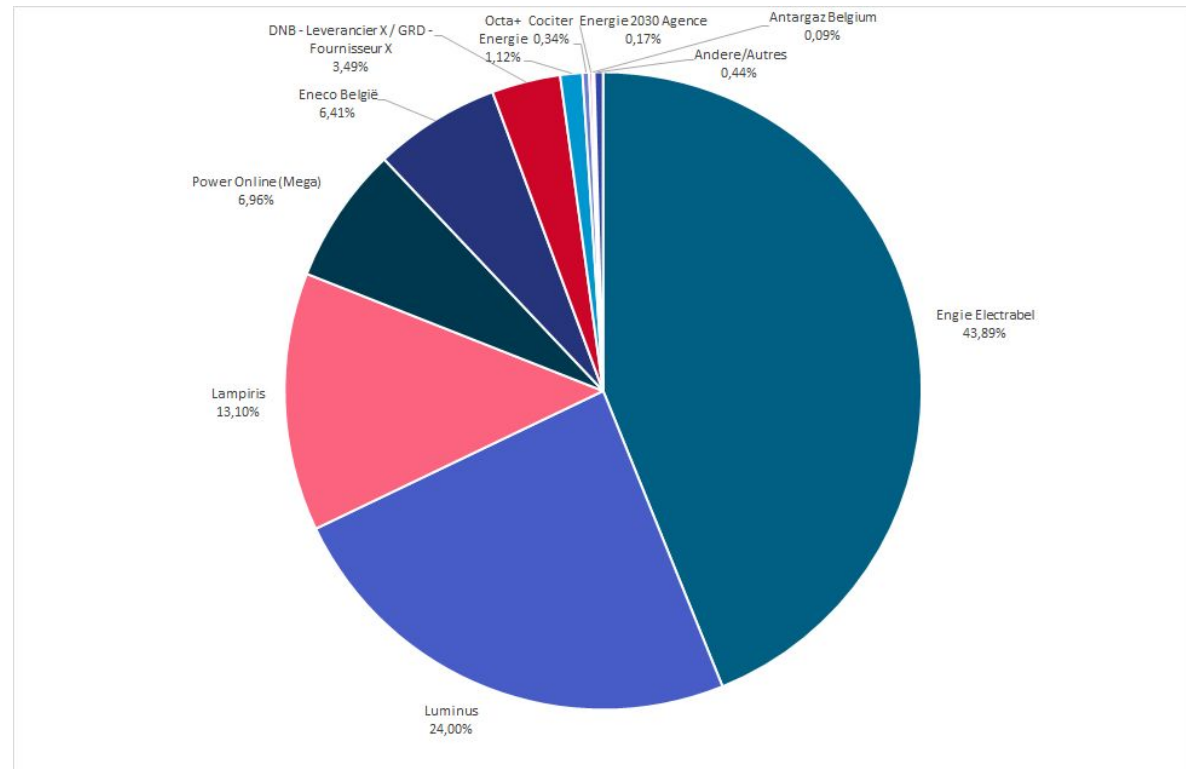


Actors recap and examples

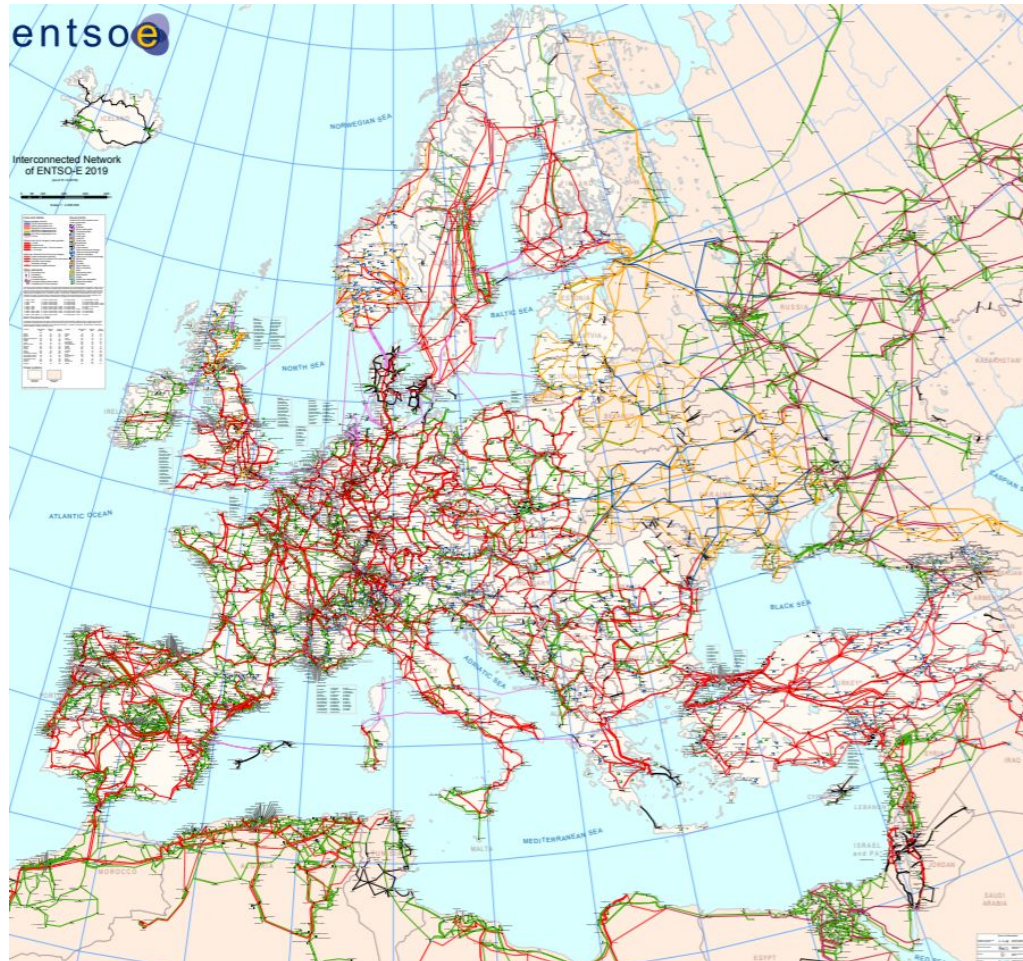
Retailer:

- 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 **DSOs** for the three Belgian regions:

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





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 $10000/38 = 263\text{€}$
- Price of PV-generated electricity: $< 100\text{€/MWh}$
- ⇒ The price of each MWh of electricity that is stored (in this manner) is more than tripled!

Note: Might change in the future as the cost of storage decrease with technological innovation.



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 \Rightarrow $VOLL \sim 10\text{€/kWh} \gg 0.285\text{€/kWh}$

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

Note: The development of demand-response technologies that allow adapting demand to production might slightly shift this paradigm in the future.



Production = Demand

No storage + must-serve nature \Rightarrow at all times:

Production = Demand

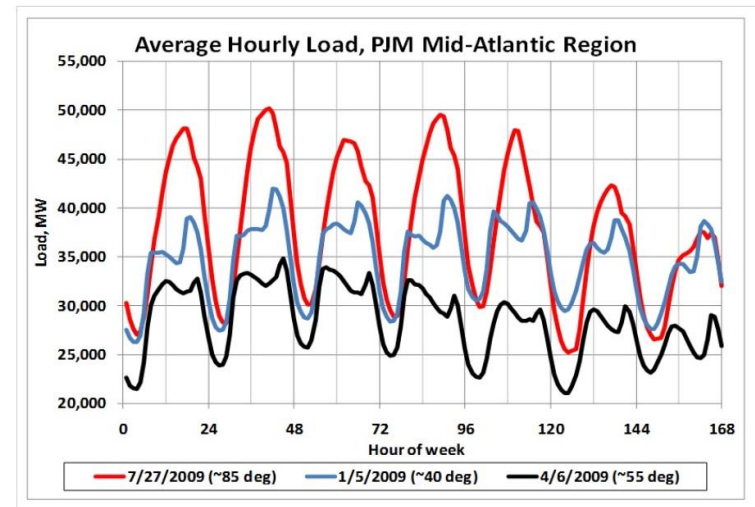
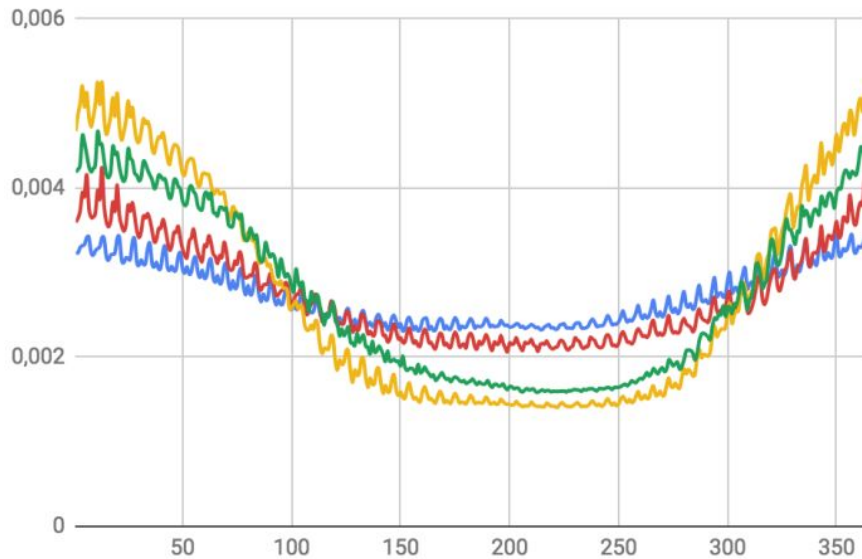
Note: see previous class for frequency deviations problem

Is this constraint difficult to respect?



Forecasting is difficult

Yearly - Weekly patterns - Daily



Estimates/prediction based on past data

- Never perfect
- Improves when closer to real time

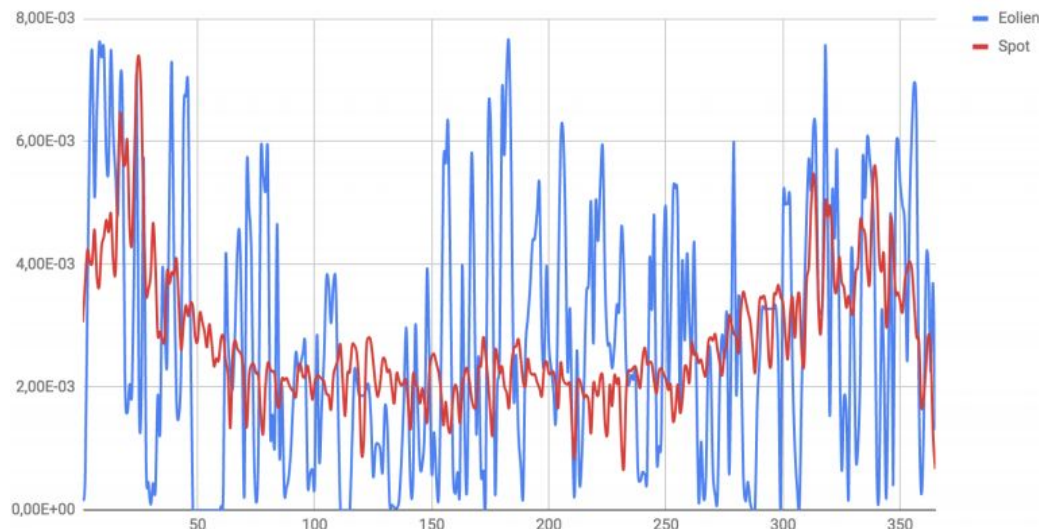


Forecasting is difficult

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

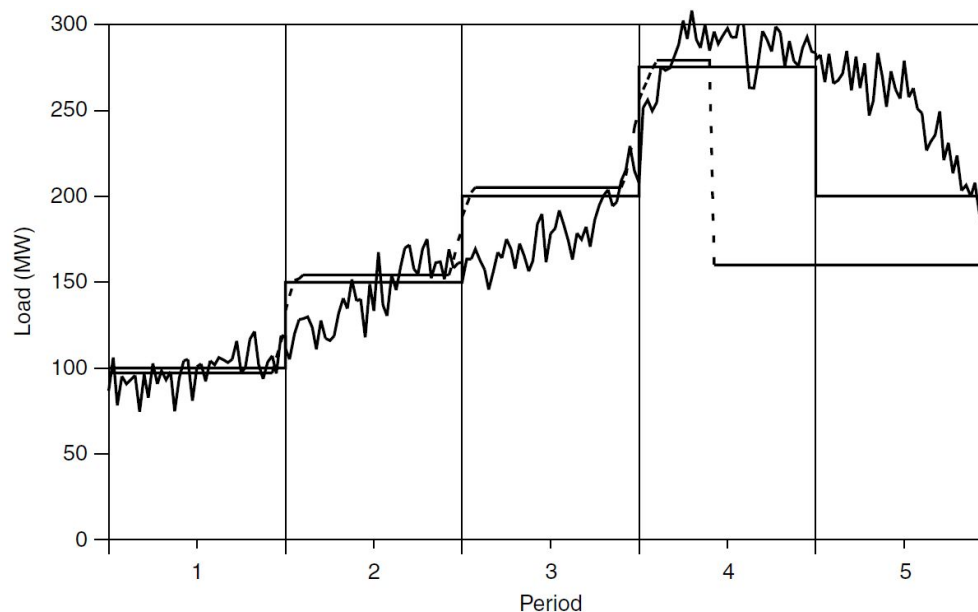


A second-by-second market?

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



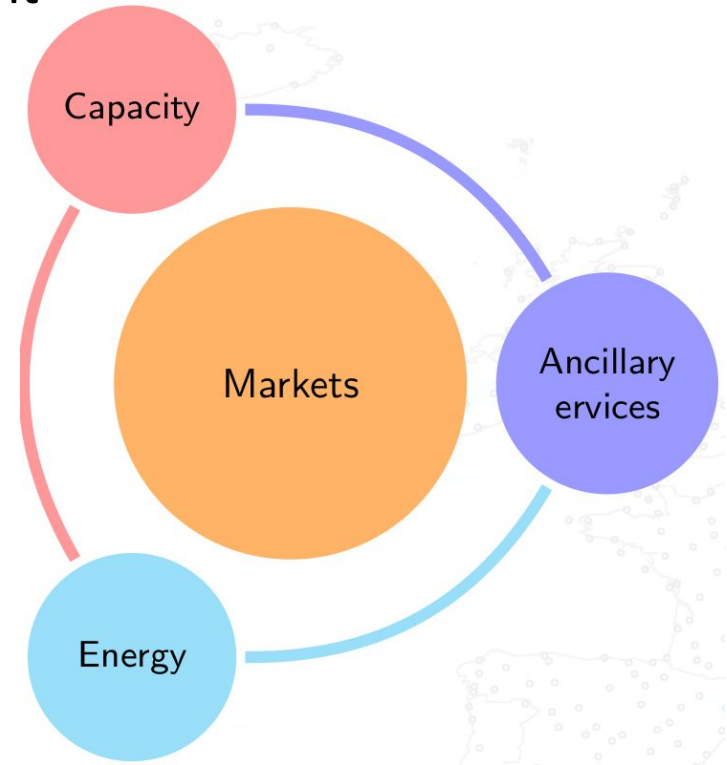


Part 3.2. The markets

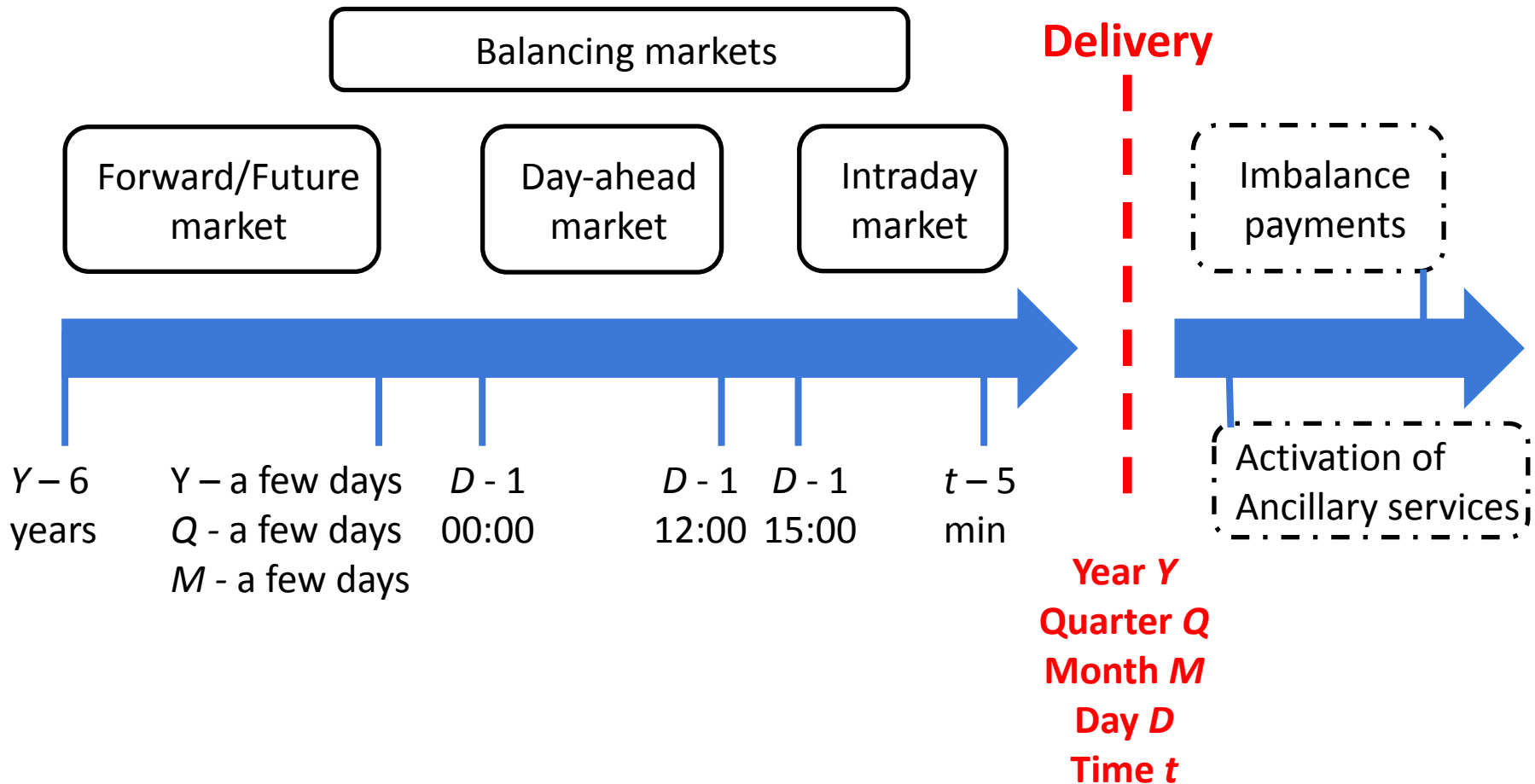


Types of markets

- **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

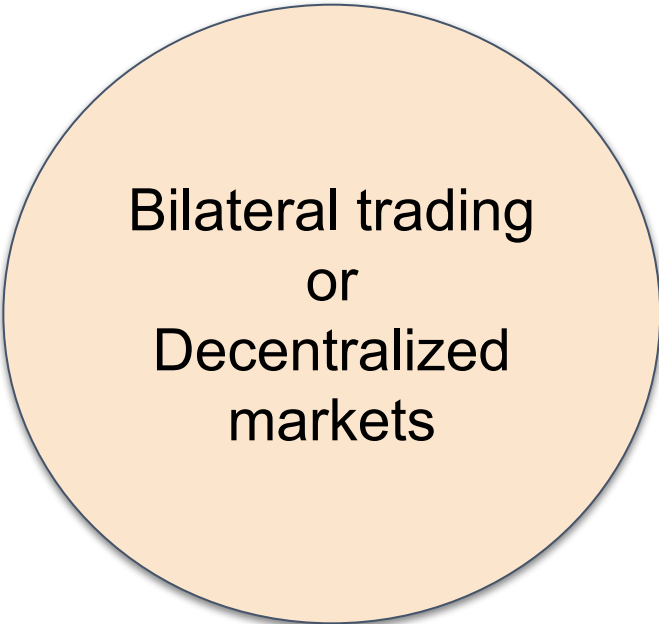


Chronology of markets





Two families of markets



Bilateral trading
or
Decentralized
markets



Electricity pools
or
Centralized
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 \Rightarrow 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	Price
		(MWh)	(\$/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

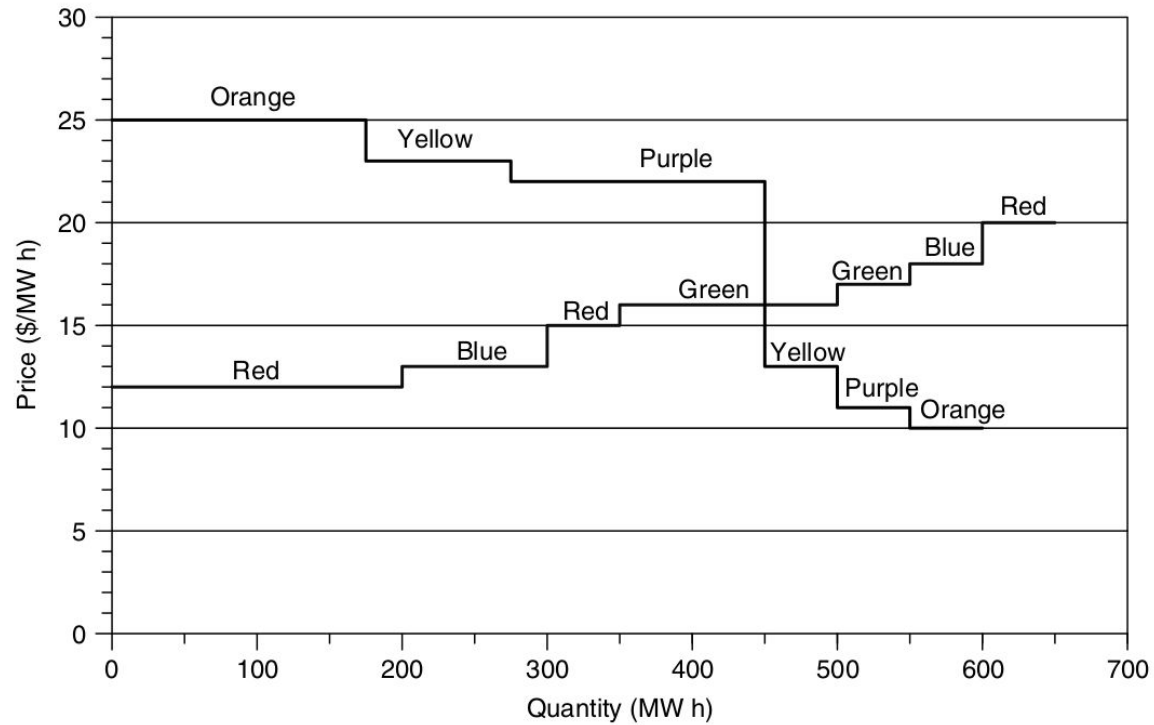


Figure 3.1 Stacks of bids and offers of Example 3.2



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?

$$\begin{aligned} &\rightarrow 10 \text{ MWh} * 0\text{€/MWh} \\ &+ 10 \text{ MWh} * 5\text{€/MWh} = 50\text{€} \end{aligned}$$

What is the cost of the last unit of energy?
 $\rightarrow 5\text{€}$

Marginal cost of energy for a consumer

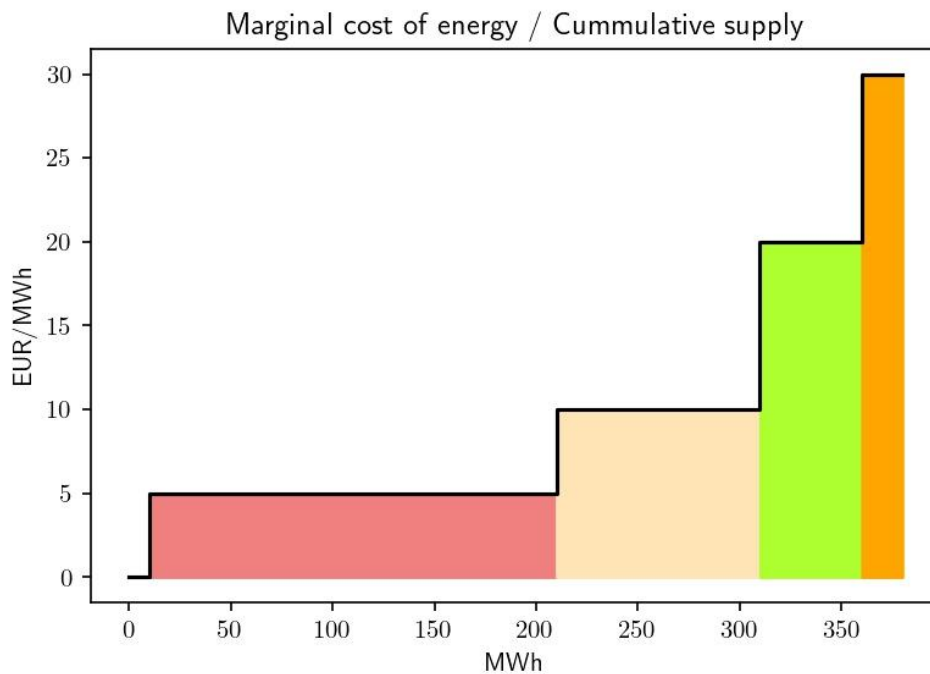
\Rightarrow Marginal cost for x MWh?

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



Merit-order - Exercise

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
	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?

→ $20 \text{ MWh} * 30\text{€/MWh} = 600\text{€}$

What is the cost of the last unit of energy?
→ 30€

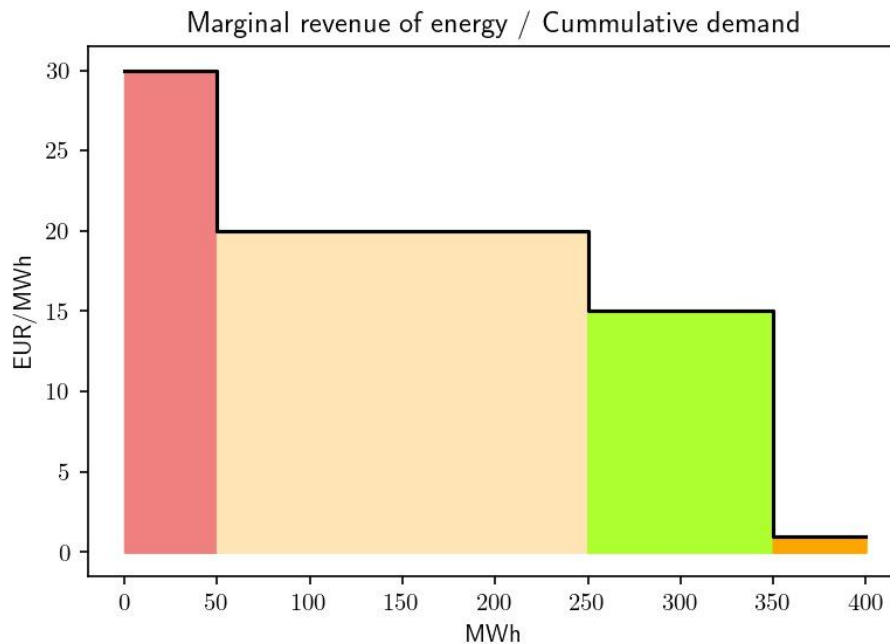
Marginal revenue of energy for a producer

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

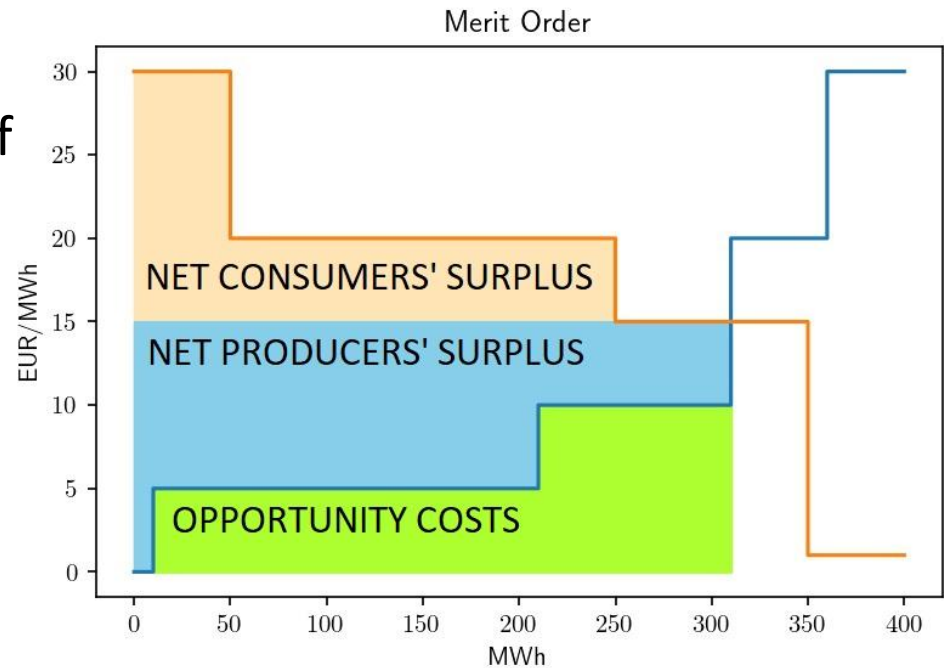
Marginal revenue for x MWh?



Sell	50 MWh	20 €/MWh
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	20 MWh	30 €/MWh
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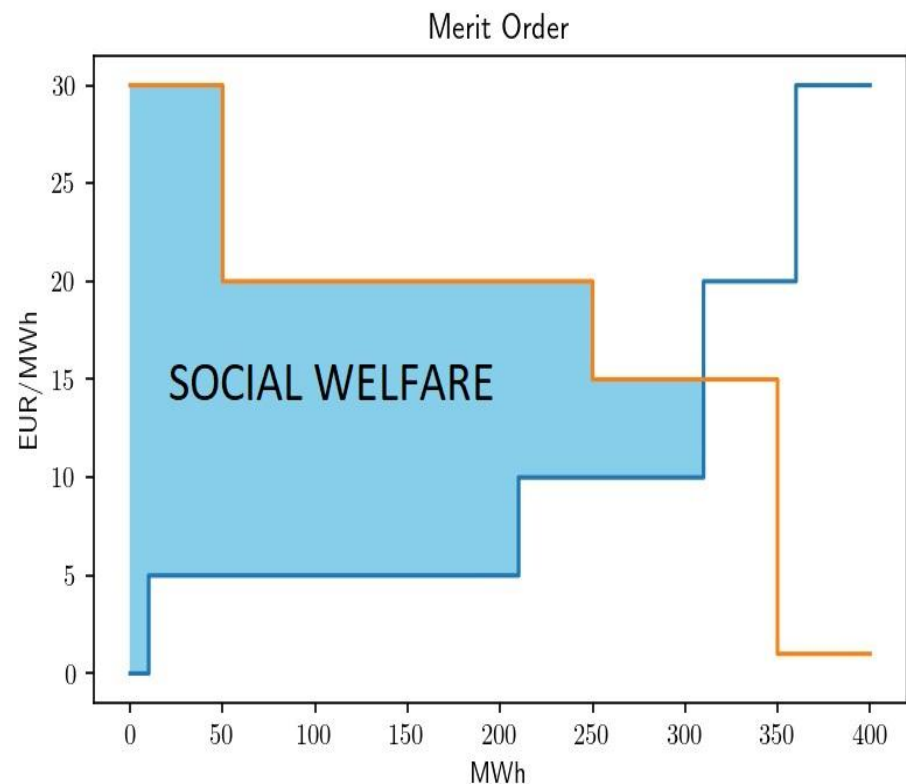
Merit Order

- **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.



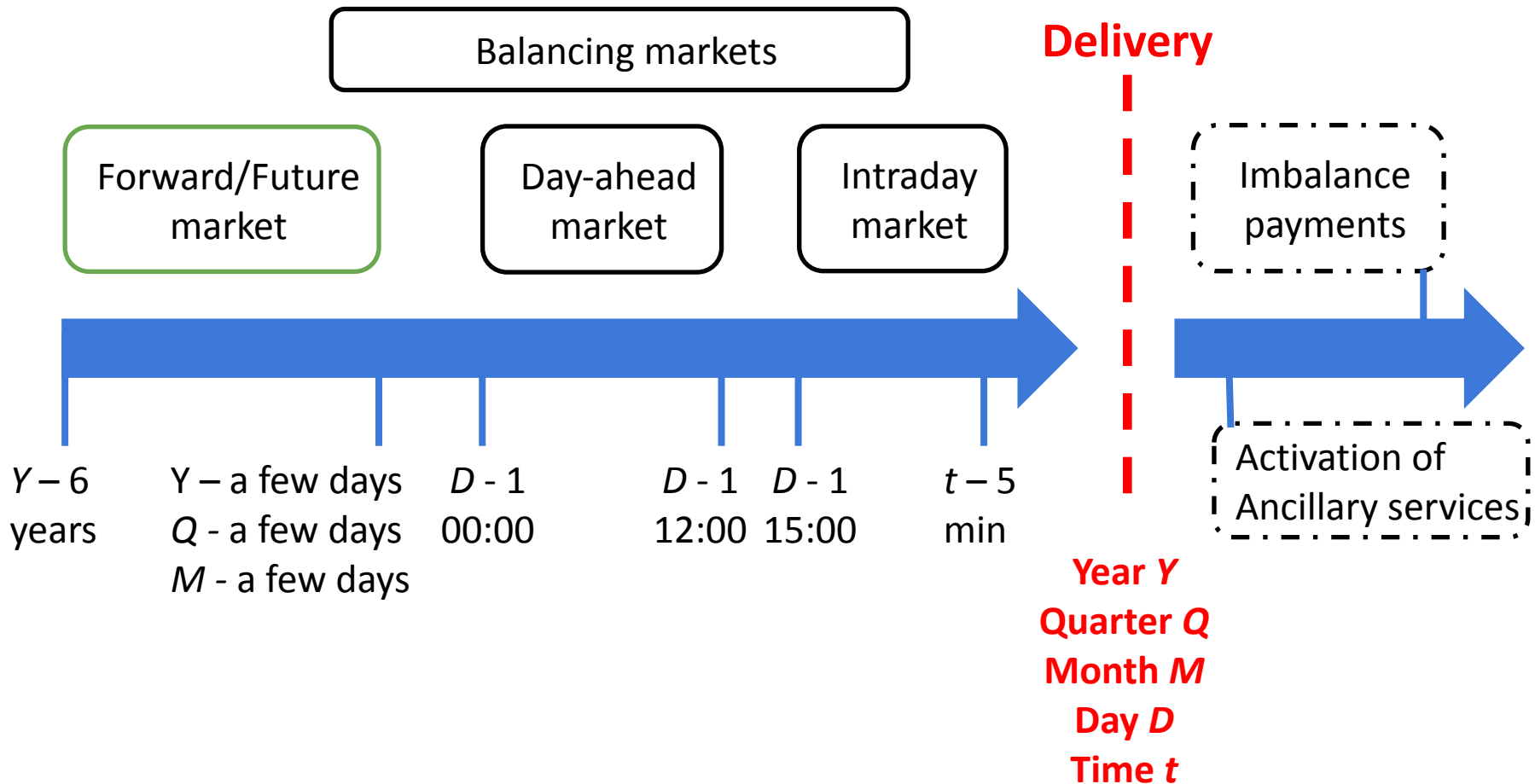


Remarks on electricity pools

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).

Chronology of markets

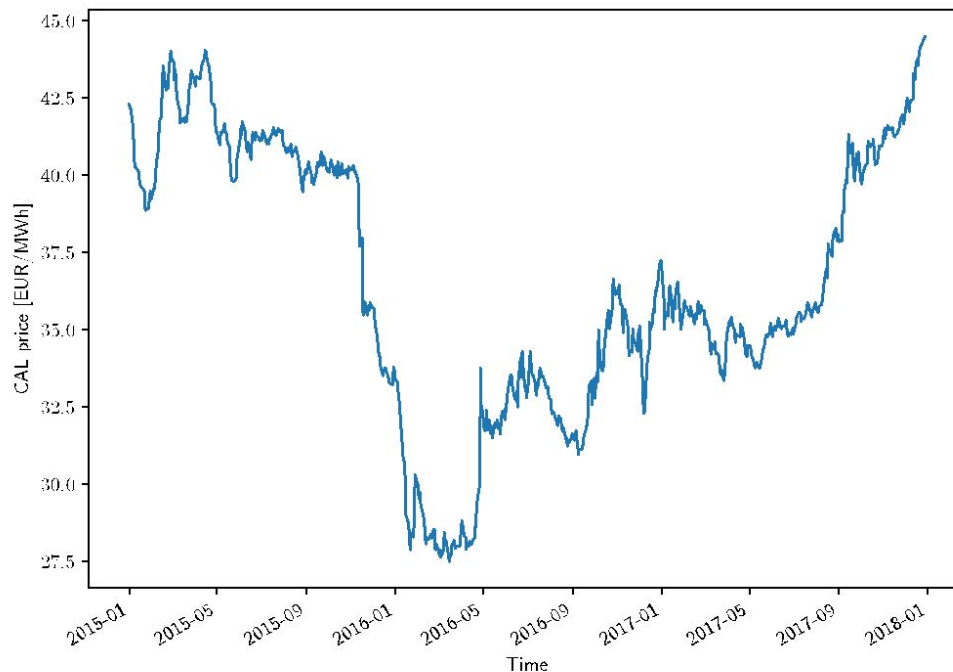


Forward/Future market - Presentation

- Electricity market based on **long-term financial bilateral contracts** between producers and consumers (generally retailers) of electricity.
- **Diverse products** available: yearly, quarterly or monthly base-load products.
- **Fixed amount** of energy for the given period
- Trading horizon from **6 years up to a few days ahead** of the product first delivery day.
- Opportunity for the market participants to perform **price hedging and risk management**, to avoid the short-term higher price volatility.
- Market operator: EEX, ICE Endex.

Forward/Future market – Product example

CAL 2018 product

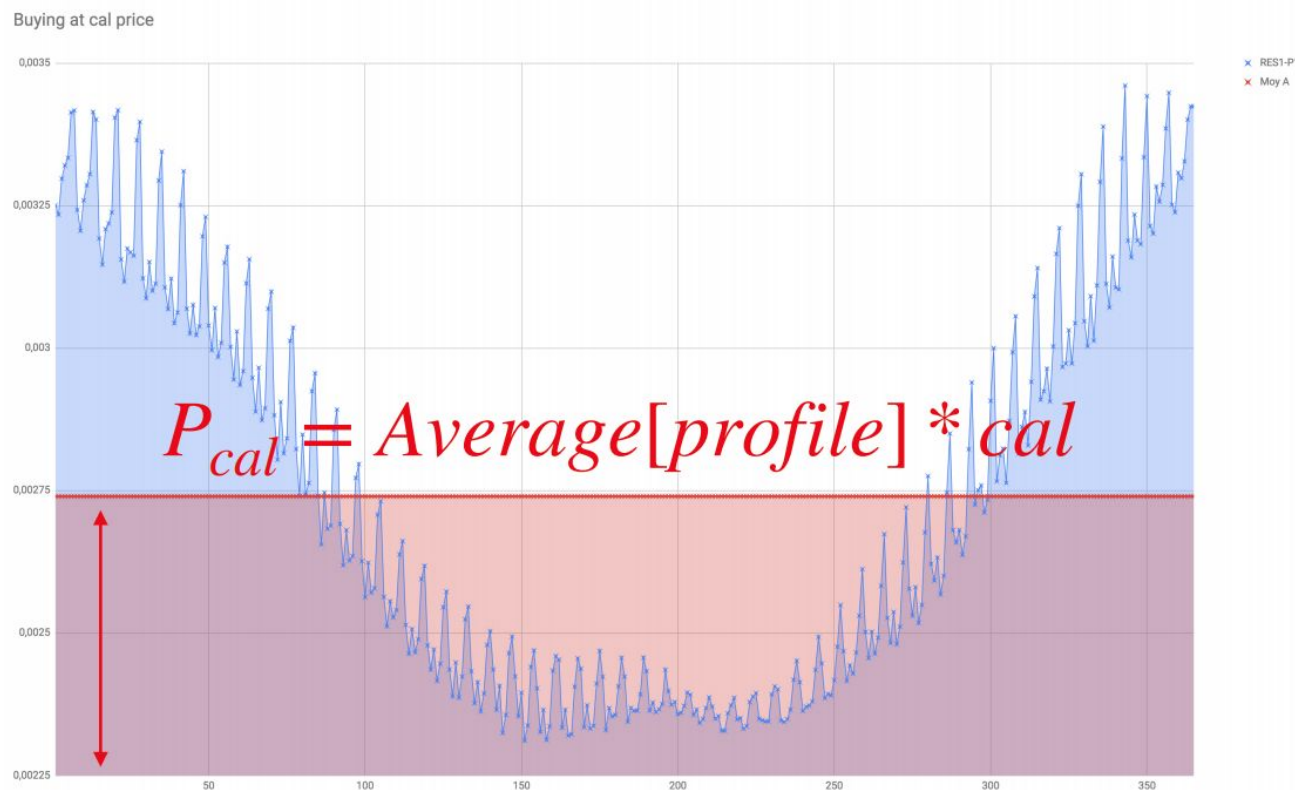


Calendar (CAL) product:

- Yearly base-load product (delivery of **constant electric power** for the entire year).
- Starting 3 years ahead of the delivery year.
- Ending a few days before the first day of the delivery year.

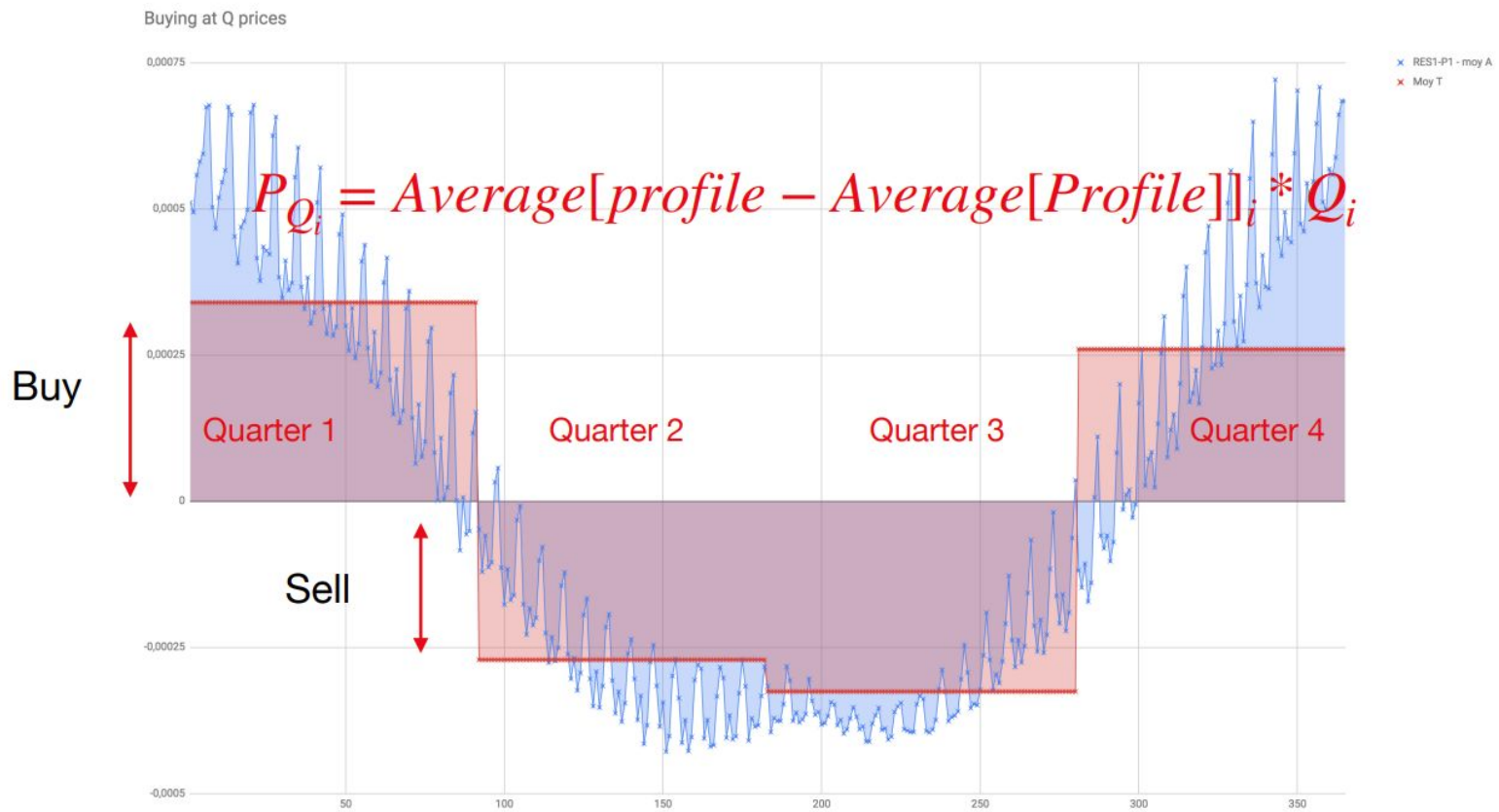
Forward/Future market – Supplier example

- How does a supplier buy energy in advance?



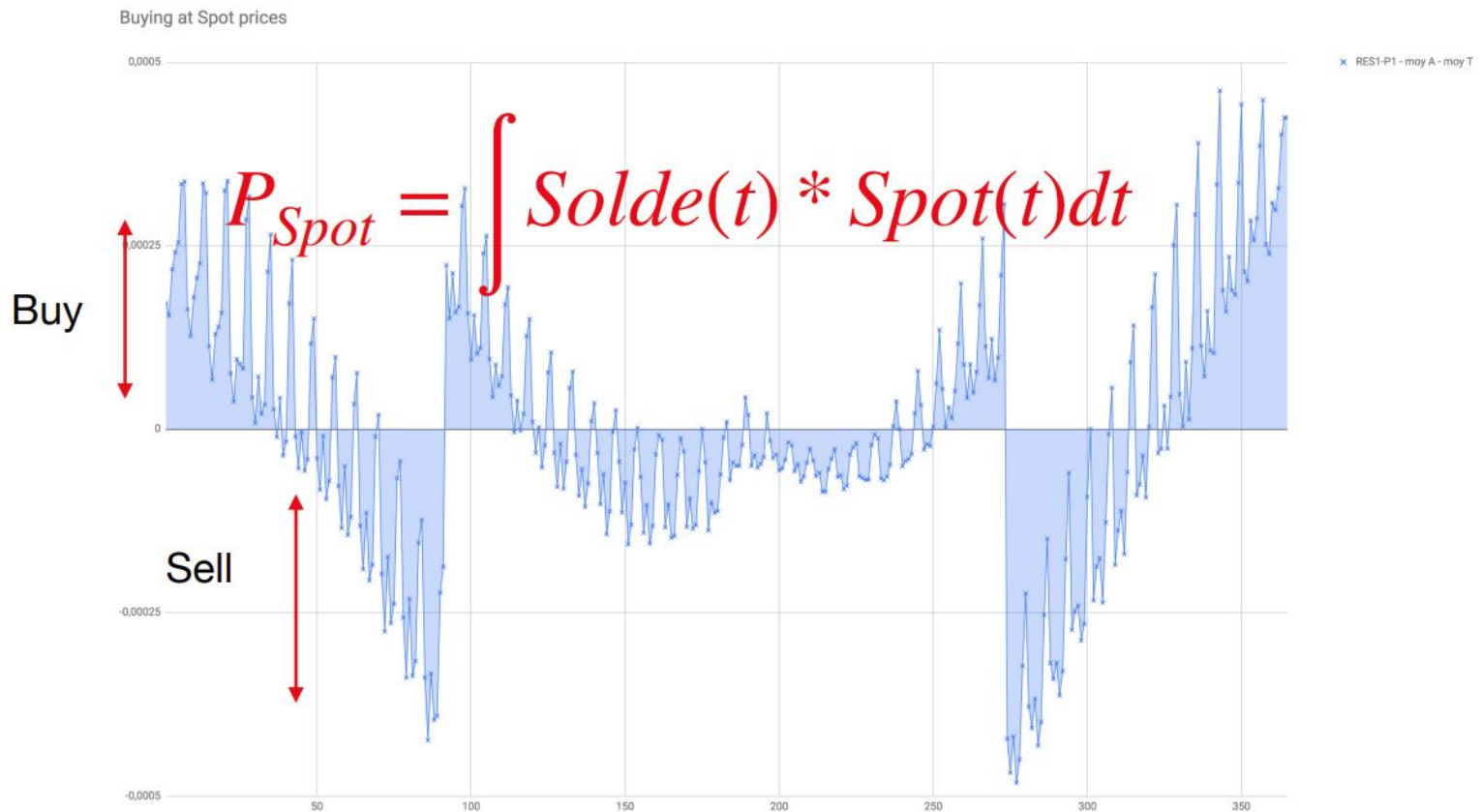
Forward/Future market – Supplier example

- How does a supplier buy energy in advance?

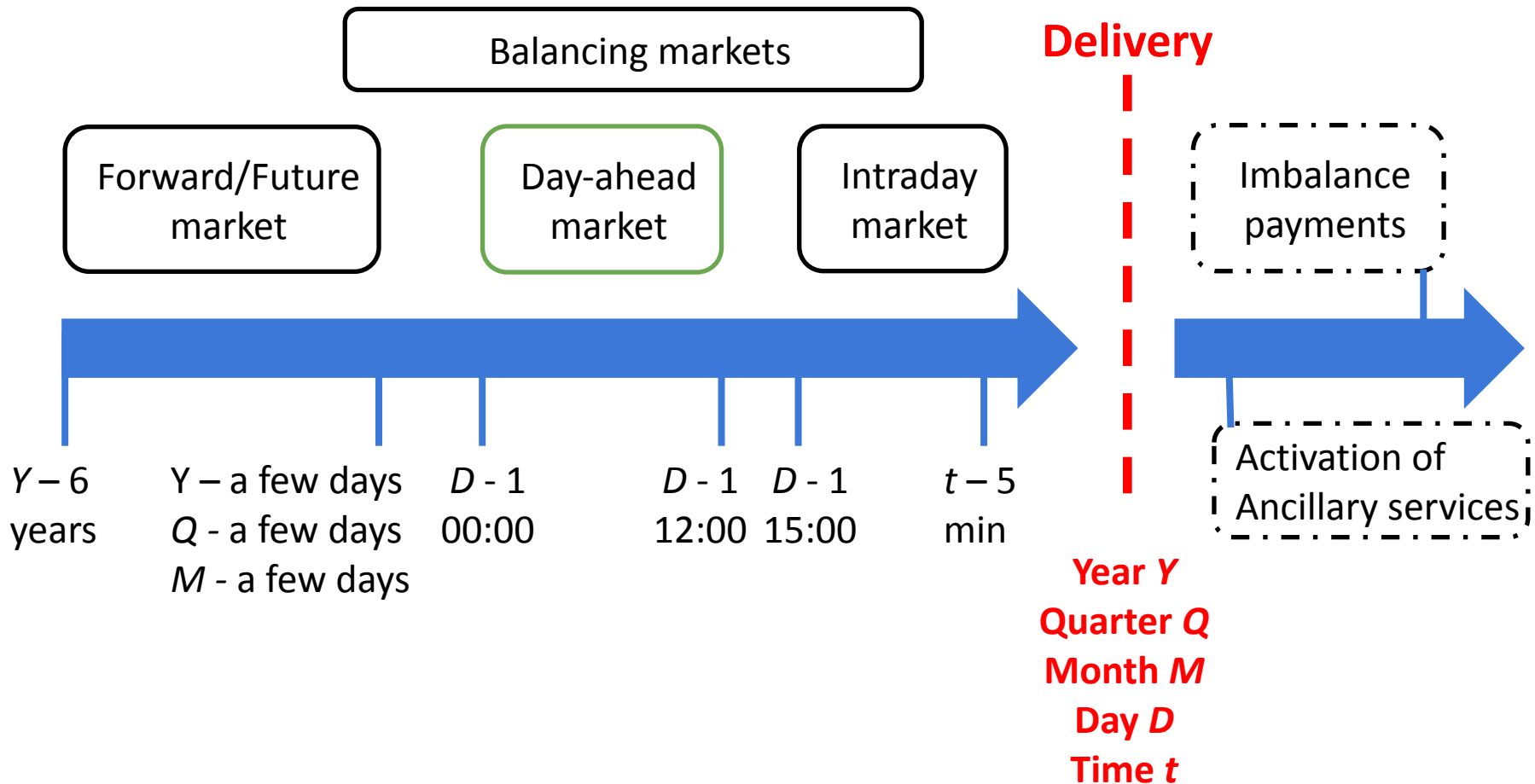


Forward/Future market – Supplier example

- How does a supplier buy energy in advance?



Chronology of markets



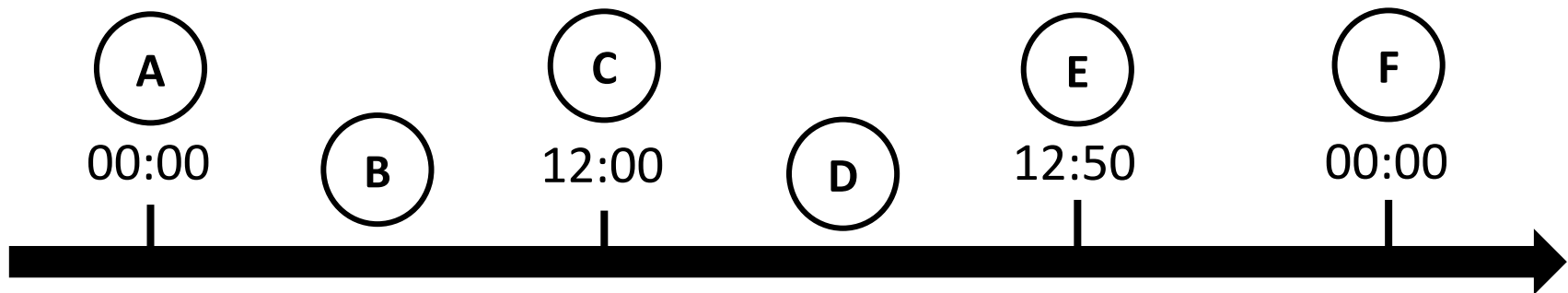


Day-ahead market

⇒ Based on a **centralized trading** platform cleared by the **market operator**.

- The day-ahead market is organized as a **pool**.
- This electricity market is operated once a day for all hours of the following day through a **single blind auction** (**hourly resolution**).
- Market operator: EPEX SPOT

Day-ahead market – Timeline

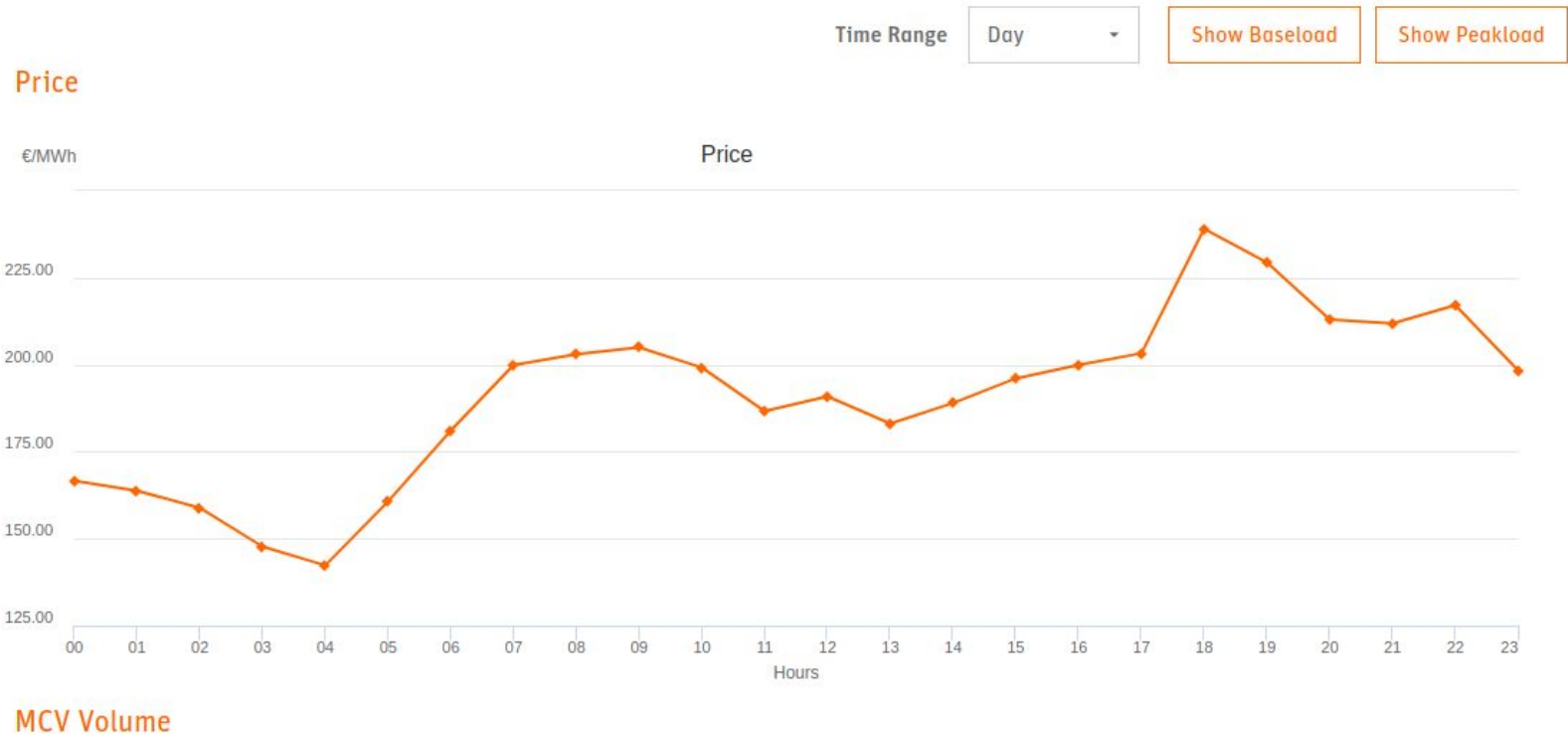


- A. Opening of the day-ahead market for all hours of the following day.
- B. Market participants submit their bids and asks to the order book (simple orders, block orders, exclusive orders, curtailable orders, ...).
- C. Closing of the day-ahead market for all hours of the following day.
- D. Execution 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.

Day-ahead market - Price per hour

Auction > Day-Ahead > 60min > BE > 05 November 2021

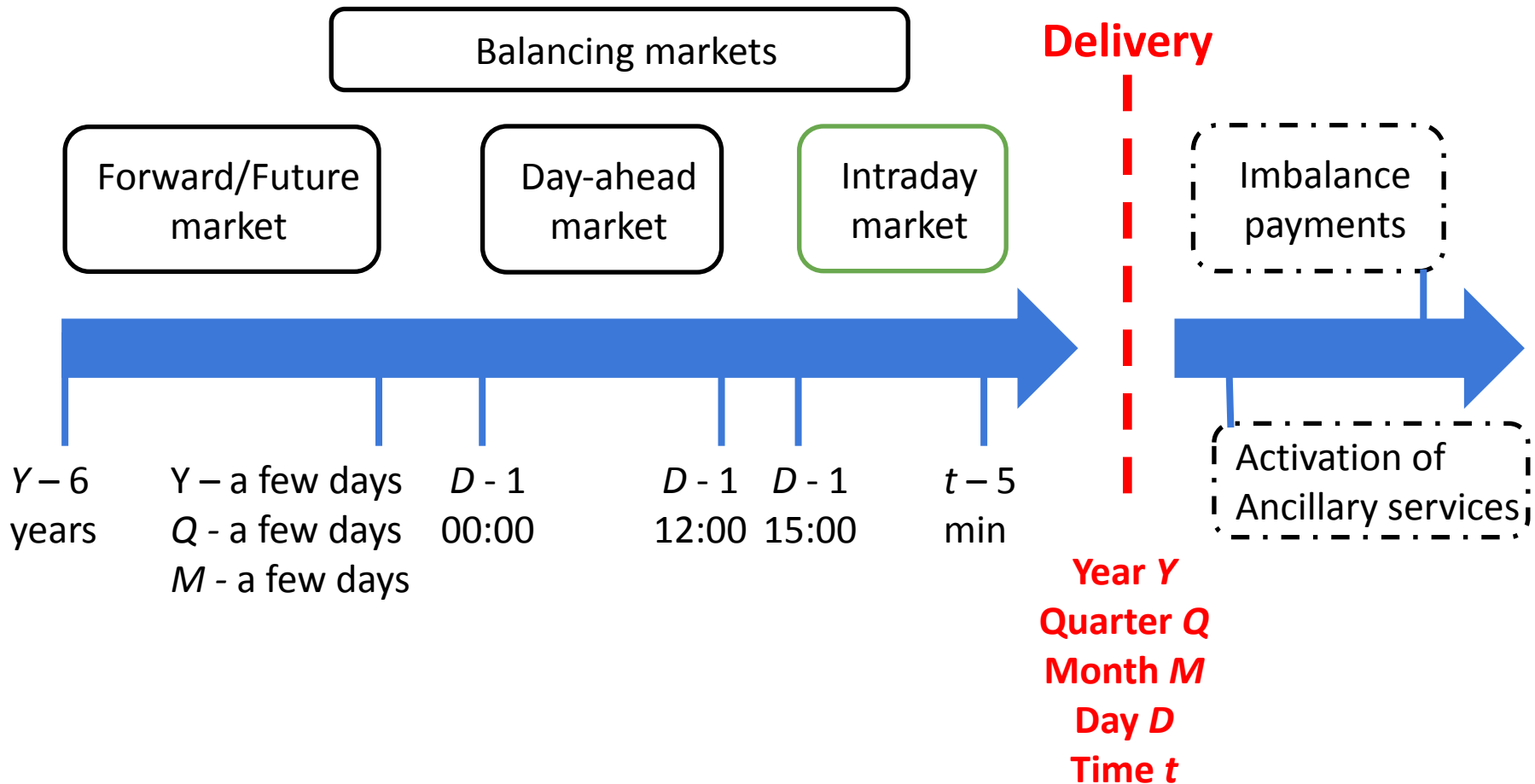
Last update: 04 November 2021 (12:49:12 CET/CEST)



Day-ahead market – Remarks

1. Why is it taking so long to solve the market clearing algorithm?
 - 24 time periods
 - Offers coming from all over Europe
 - Special orders to be respected:
 - E.g.: Block Orders encompass several hours at the **same price**.
A block order is executed at the **same ratio on all its hours**.
 - Transmission constraints or '**cross-border capacities**' set by the TSO **to be respected**
 - EUPHEMIA
2. The day-ahead market is cleared a fairly long time before actual operations (between 12 and 36 hours) **⇒ risk of imbalances**

Chronology of markets





Intra-day market overview

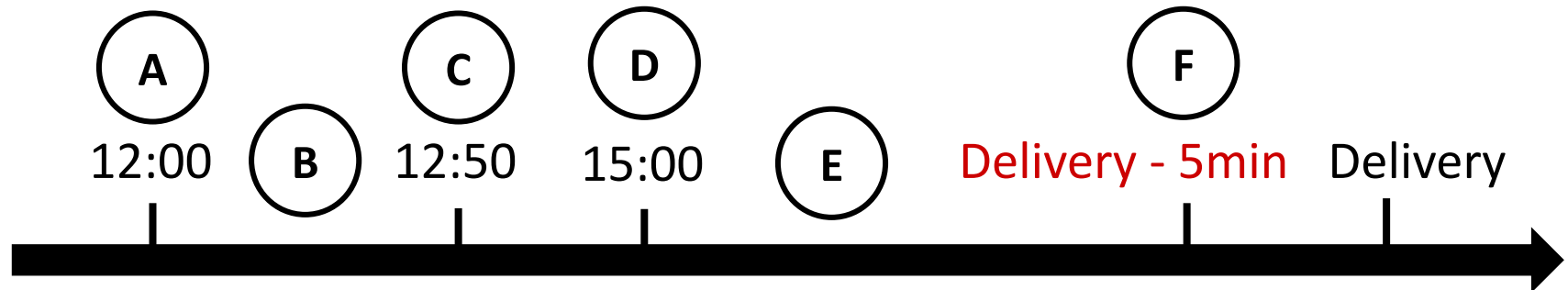
While the **day-ahead** market is

1. a **pool**,
2. based on an auction mechanism,

the **intraday** market is based on **bilateral contracts**, even though **centrally organized (!)**.

- This electricity market authorizes **continuous trading**, meaning that a trade is executed as soon as two orders match (different constraints have to be met depending on the orders types).
- **Multiple contracts** are available: hourly, half-hourly and quarter-hourly.
- Market operator: EPEX SPOT

Intraday market – Timeline



- A. Closing of the day-ahead market for all hours of the following day.
- B. Market clearing algorithm execution.
- C. Notification of the market participants and system operators about the market clearing outcomes.
- D. Opening of the intraday market for the delivery on the following day.
- E. Continuous trading on the intraday market.
- F. Closing of the intraday market for the delivery period considered.

Intraday market – Fictive example (1)

Context: There is a last minute update in the wind forecast, and the predicted wind power generation associated with the portfolio of a producer is suddenly **decreased by 50 MWh** for the time period 10:00-11:00. This wind power generator intends to adapt its position on the intraday market, whose state is represented hereafter for that specific time period.

Question: Which actions could be performed by this supplier to avoid any imbalance?

ID	Side	Quantity (MWh)	Price (€/MWh)
G1	Sell	100	35
G2	Sell	80	40
G3	Sell	50	50
G4	Sell	20	65
C1	Buy	10	55
C2	Buy	20	60
C3	Buy	35	65
C4	Buy	110	70

} Curtailable orders
(All or None)

Intraday market – Fictive example (2)

1. A **first possibility** is to buy 50 MWh to G3 and pay $50 \times 50 = 2500$ €.
2. A **second possibility** is to buy 80 MWh to G2 and sell respectively 10 MWh and 20 MWh to C1 and C2, thus paying $80 \times 40 - 10 \times 55 - 20 \times 60 = 1450$ €.
3. Other possibilities?

ID	Side	Quantity (MWh)	Price (€/MWh)
G1	Sell	100	35
G2	Sell	80	40
G3	Sell	50	50
G4	Sell	20	65
C1	Buy	10	55
C2	Buy	20	60
C3	Buy	35	65
C4	Buy	110	70

Curtable orders
(All or None)



From financial market to physical operation

Forward/future, day-ahead and intra-day markets are **financial** markets!

1. These are only transactions - **No one is “forced”** to generate or consume...
2. Both market participants and **system operator** are informed about market clearing outcomes (price and volumes for each market time unit)
3. In the European set-up, the market participants will then **self-dispatch**, i.e., determine themselves how they will generate or consume depending on volumes and prices

However, **imbalances may still arise** (i.e. amount contracted by a party to buy or sell **different** from the amount that it actually needs or can produce)



From financial market to physical operation

⇒ **Managed markets** are essential for balancing the load and generation and should **supersede** the open energy market (where most of the trading would occur) as time of delivery approaches.

ISO is given the responsibility to maintain the system balance.

Such a setup relies on the crucial concepts of

1. Balance Responsible Parties (BRP)
2. Ancillary services provided by Balance System Providers (BSP)



Balance Responsible Party (BRP)

‘Balance Responsible Party’ (BRP) in the electricity market is a market participant or its chosen representative **responsible for its imbalances**.

The BRP may be a producer, major customer, energy supplier or trader.

As a result, each BRP is responsible for a portfolio of **access points** and must develop and take all reasonable measures to maintain the balance between injections, offtakes and commercial power trades within their portfolio.

A list of Belgian BRPs is available at:
http://publications.elia.be/upload/List_Arp.html



BRP - Daily balance schedule

One day before the period in question, the BRP must submit to Elia a daily balance schedule for their portfolio for day D, which consists of:

- Expected injections and offtakes at each access point;
- Commercial power trades, i.e. purchases and sales, with other BRPs and/or related to imports and exports on the borders.

In Belgium, the daily balance schedule must be balanced on a **quarter-hourly basis**: the sum of injections and purchases must equal the sum of offtakes and sales.

To maintain balance at portfolio level, a BRP can use a hub or a power exchange to exchange energy with other BRPs for the following day (day-ahead) or for the same day (intraday).



BRP - Imbalance tariffs

Elia uses the ex-post measurement data of the access points and the commercial trade schedules to **verify whether a BRP has remained balanced**.

If a BRP incurs an imbalance on a quarter-hourly basis, the BRP is subject to the **imbalance tariffs**.

The imbalance tariff **incentivises the BRP to keep their portfolio balanced** or, in certain conditions, to help Elia keep the grid secure and reliable.



BSP - Balance Service Providers

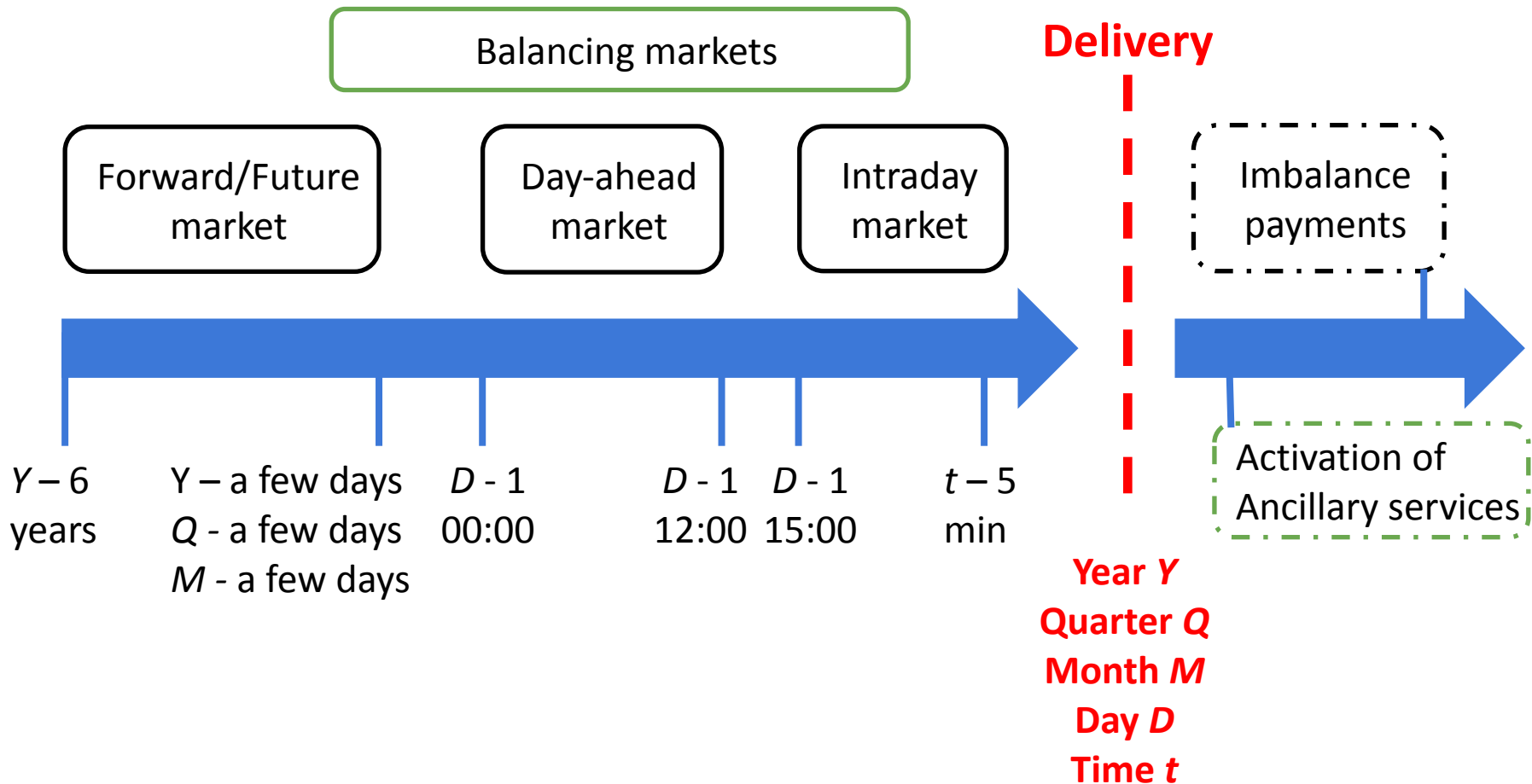
To **correct the imbalances** created by BRPs

⇒ the ISO organises **balancing markets**

These markets offer flexibility:

- in the form of **ancillary services**
- provided by **Balance Service Providers** or BSPs

Chronology of markets





Ancillary services

An important aspect of balancing is the approach to procuring **ancillary services**.

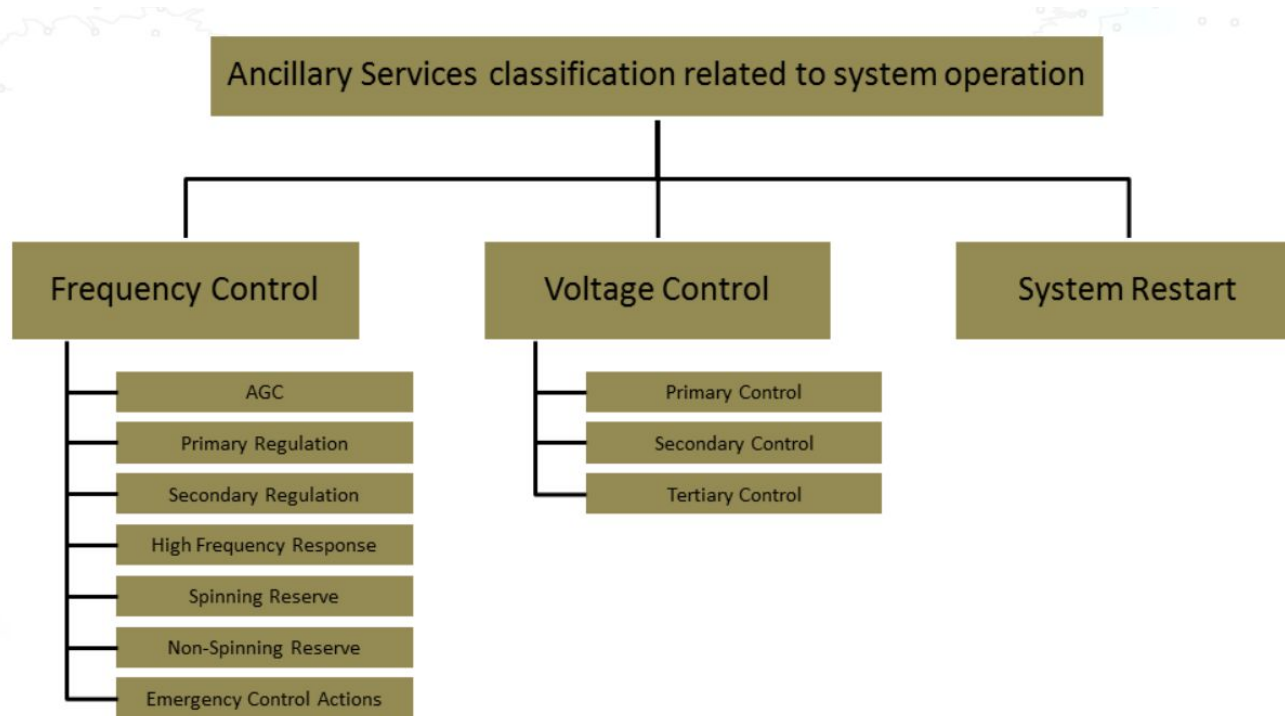
‘Ancillary services’ refers to a range of functions which ISOs contract so that they can guarantee system security.

These include:

- black start capability (the ability to restart a grid following a blackout);
- **frequency response** (to maintain system frequency with automatic and very fast responses);
- fast reserve (which can provide additional energy when needed);
- the provision of reactive power
- and various other services.



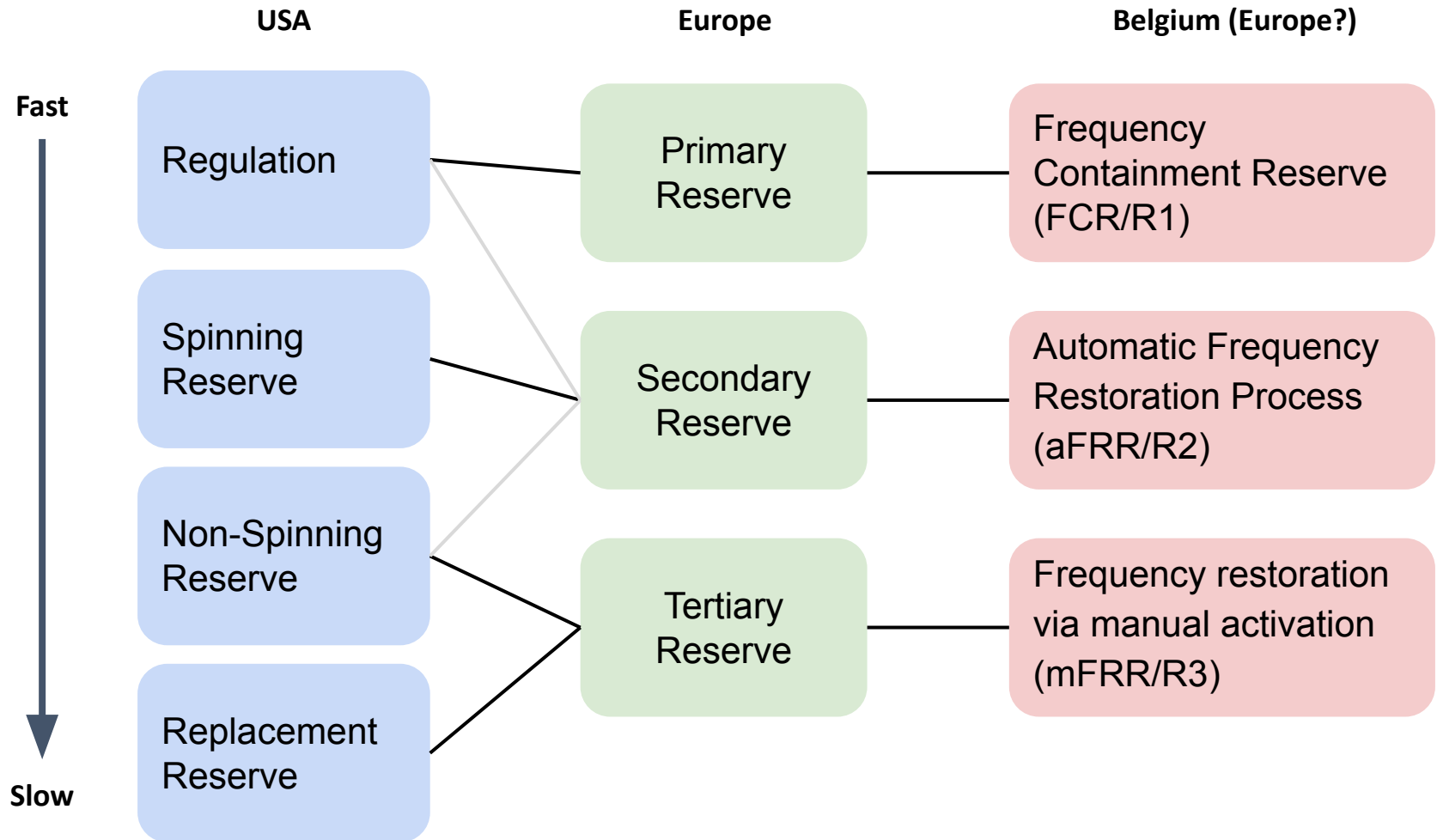
Various types of ancillary services



We will focus on frequency-related services in the following, as they directly relate to system balance



Reserves - Beware of naming conventions





Ancillary services – Reserves

Primary reserve:

- Automatically activated within **30 seconds**
- Goal: stabilizing frequency by equilibrating generation and consumption

Secondary reserve:

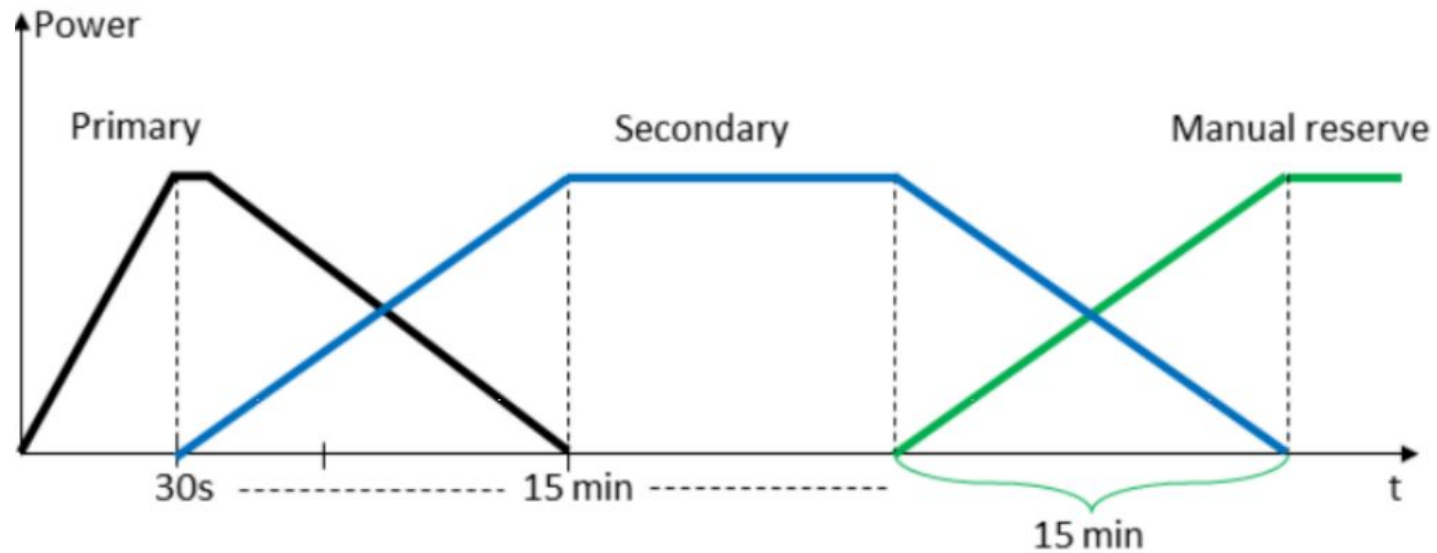
- Automatically activated within **15 minutes**
- Goal: get the power grid back to its target frequency

Tertiary reserve:

- **Manually activated**
- Goal: backup for the secondary reserve



Ancillary services – Reserves





What for and how is the system operator paying ?

Depending on the reserve, the ISO might be paying for:

Capacity and/or energy

For example, primary reserves are 'energy-neutral services' in the sense that the BSP are only paid for the capacity they provide.

Based on the acquired reserves, the ISO will set an **imbalance price** or **imbalance tariff**.

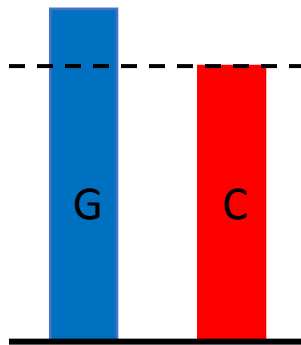
⇒ BRP in imbalance need to pay their imbalance times this tariff.

System vs participant imbalance

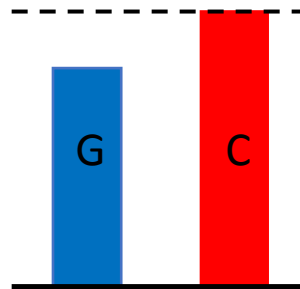
There exist 3 possible situations for the system as a whole:

- **Positive imbalance:** $\text{Generation} > \text{Consumption}$ (downward regulation required).
- **Negative imbalance:** $\text{Generation} < \text{Consumption}$ (upward regulation required).
- **No imbalance:** $\text{Generation} \sim \text{Consumption}$ (no regulation required).

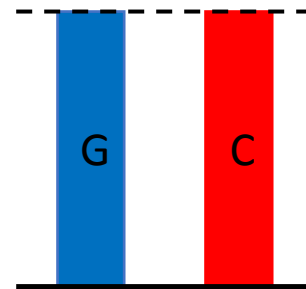
The same reasoning is also valid for a producer/consumer considered individually (contracted production/consumption vs actual production/consumption).



Positive imbalance



Negative imbalance



No imbalance

Imbalance payment – Simple example (1)

Context:

- A generator is scheduled to produce 100 MWh for 40€/MWh of electricity with wind turbines during the time period 10:00-11:00.
- Inaccurate wind forecasts at the time of delivery \Rightarrow deviation of the actual production from its original schedule.
- The whole system also in *negative imbalance* ($G < C$) and the ISO activates reserves for 50€/MWh.

Questions:

1. What is the revenue of this generator if its actual production is 80 MWh? (*negative imbalance*)
2. What is the revenue of this generator if its forecast was correct?
3. What is the revenue of this generator if its actual production is 120 MWh? (*positive imbalance*)

Imbalance payment – Simple example (2)

Answers:

1. Day-ahead market revenue: $100 \times 40 = 4000\text{€}$.
Imbalance revenue: $-20 \times 50 = -1000\text{€}$.
Eventually, the generator's revenue is equal to 3000€ .
2. Day-ahead market revenue: $100 \times 40 = 4000\text{€}$.
Imbalance revenue: $0 \times 50 = 0\text{€}$.
Eventually, the generator's revenue is equal to 4000€ .
3. Day-ahead market revenue: $100 \times 40 = 4000\text{€}$.
Imbalance revenue: $20 \times 50 = 1000\text{€}$.
Eventually, the generator's revenue is equal to 5000€ .

Imbalance payment – Simple example (3)

Remarks:

In the 3rd situation, the positive imbalance of the producer (partially) counters the negative imbalance of the entire power system, resulting in a revenue surplus.

⇒ This may lead to speculation on the imbalance side, which is undesired for the sake of safety.

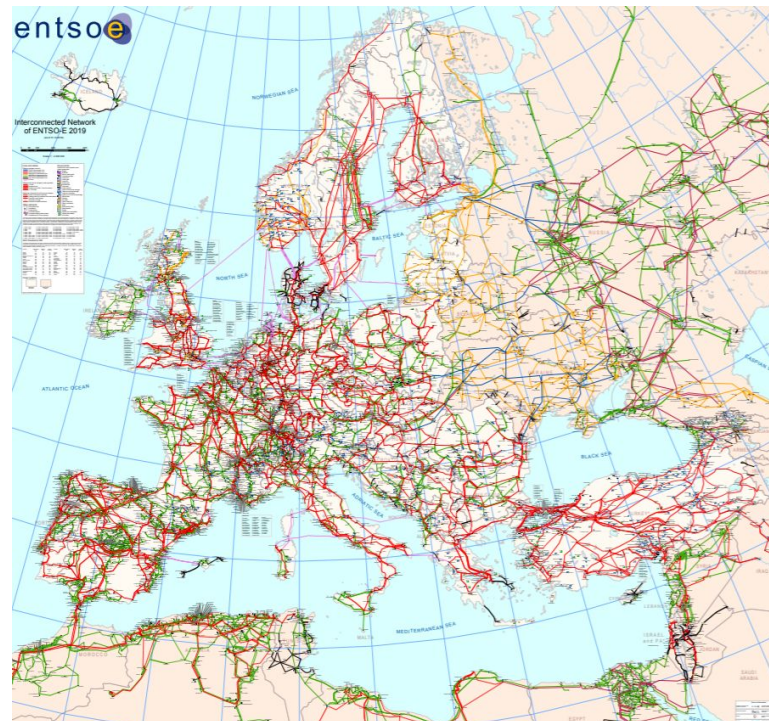
One price settlement VS **two prices** settlement



Part 4. Including the transmission network limits

Transmission networks

- So far, in our market discussion, we have not talked much about physical limits.
- To illustrate, we will briefly introduce the impact of transmission capacity on the day-ahead market.



Transmission networks

- The **network** is divided into **nodes**. The nodes are interconnected with **transmission lines**. It is possible to transmit a **limited amount of power** from one node to the other through these lines.
- How to take these constraints into account in the day-ahead auction?



Let's exemplify

- *Deadline for offers:* 29th of January, 12:00 - *Delivery period:* 30th of January, 11:00-12:00
- Supply and demand offers include:

Demand: (for a total of 1065 MWh)

Company	Supply/Demand	id	Amount (MWh)	Price (€/MWh)
CleanRetail	Demand	D_1	250	200
El4You	Demand	D_2	300	110
EVcharge	Demand	D_3	120	100
QualiWatt	Demand	D_4	80	90
IntelliWatt	Demand	D_5	40	85
El4You	Demand	D_6	70	75
CleanRetail	Demand	D_7	60	65
IntelliWatt	Demand	D_8	45	40
QualiWatt	Demand	D_9	30	38
IntelliWatt	Demand	D_{10}	35	31
CleanRetail	Demand	D_{11}	25	24
El4You	Demand	D_{12}	10	16



And supply...

Supply: (for a total of 1435 MWh)

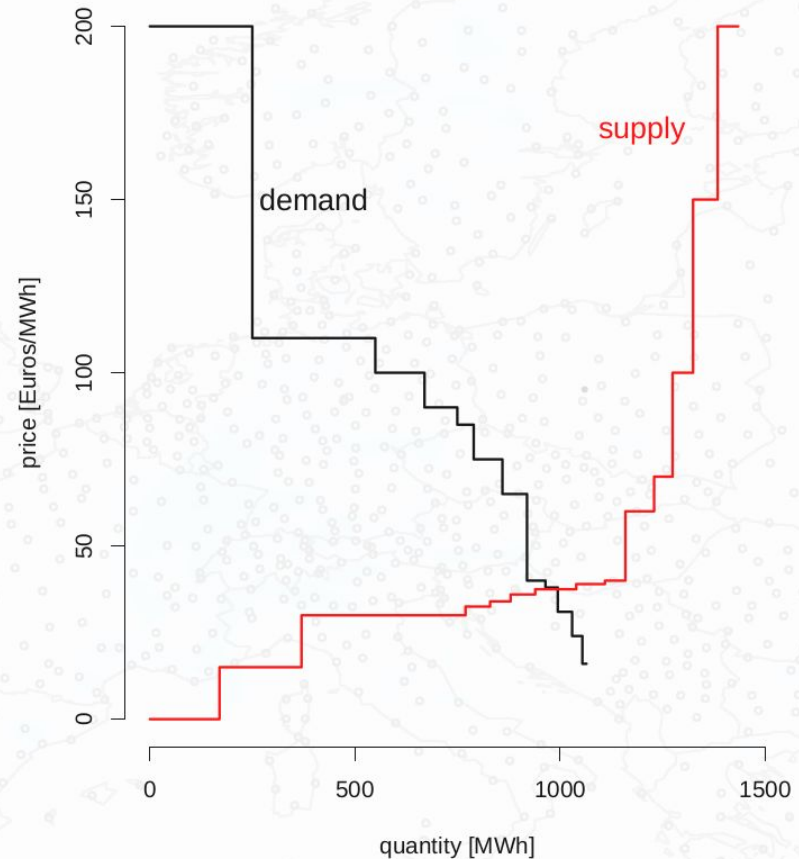
Company	Supply/Demand	id	Amount (MWh)	Price (€/MWh)
RT [®]	Supply	G ₁	120	0
WeTrustInWind	Supply	G ₂	50	0
BlueHydro	Supply	G ₃	200	15
RT [®]	Supply	G ₄	400	30
KøbenhavnCHP	Supply	G ₅	60	32.5
KøbenhavnCHP	Supply	G ₆	50	34
KøbenhavnCHP	Supply	G ₇	60	36
DirtyPower	Supply	G ₈	100	37.5
DirtyPower	Supply	G ₉	70	39
DirtyPower	Supply	G ₁₀	50	40
RT [®]	Supply	G ₁₁	70	60
RT [®]	Supply	G ₁₂	45	70
SafePeak	Supply	G ₁₃	50	100
SafePeak	Supply	G ₁₄	60	150
SafePeak	Supply	G ₁₅	50	200

That is a lot of offers to match... but how?



Merit-order

- Consumption offers are ranked in *decreasing price order*
- Supply offers are ranked in *increasing price order*
- This defines the **merit order**
- A “magic” point appears: the equilibrium point between supply and demand...





Market-clearing results

1. Total energy: 995 MWh
2. Supply side - accepted: $\{G1, \dots, G8\}$ (but only 55 MWh for G8)
3. Supply side - rejected: $\{G9, \dots, G15\}$
4. Demand side - accepted: $\{D1, \dots, D9\}$
5. Demand side - rejected: $\{D10, \dots, D12\}$
6. System price: 37.5 €/MWh



From system to area prices

Let's now split the system into two areas DTU-West and DTU-East with a transmission **capacity of 40 MW**.

Demand: (for a total of 1065 MWh)

Company	id	Amount (MWh)	Price (€/MWh)	Area
CleanRetail	D ₁	250	200	DTU-West
El4You	D ₂	300	110	DTU-East
EVcharge	D ₃	120	100	DTU-West
QualiWatt	D ₄	80	90	DTU-East
IntelliWatt	D ₅	40	85	DTU-West
El4You	D ₆	70	75	DTU-West
CleanRetail	D ₇	60	65	DTU-East
IntelliWatt	D ₈	45	40	DTU-West
QualiWatt	D ₉	30	38	DTU-West
IntelliWatt	D ₁₀	35	31	DTU-East
CleanRetail	D ₁₁	25	24	DTU-East
El4You	D ₁₂	10	16	DTU-East



And supply...

Supply: (for a total of 1435 MWh)

Company	id	Amount (MWh)	Price (€/MWh)	Area
RT [®]	G ₁	120	0	DTU-West
WeTrustInWind	G ₂	50	0	DTU-East
BlueHydro	G ₃	200	15	DTU-West
RT [®]	G ₄	400	30	DTU-East
KøbenhavnCHP	G ₅	60	32.5	DTU-West
KøbenhavnCHP	G ₆	50	34	DTU-East
KøbenhavnCHP	G ₇	60	36	DTU-West
DirtyPower	G ₈	100	37.5	DTU-West
DirtyPower	G ₉	70	39	DTU-West
DirtyPower	G ₁₀	50	40	DTU-West
RT [®]	G ₁₁	70	60	DTU-East
RT [®]	G ₁₂	45	70	DTU-West
SafePeak	G ₁₃	50	100	DTU-East
SafePeak	G ₁₄	60	150	DTU-East
SafePeak	G ₁₅	50	200	DTU-East



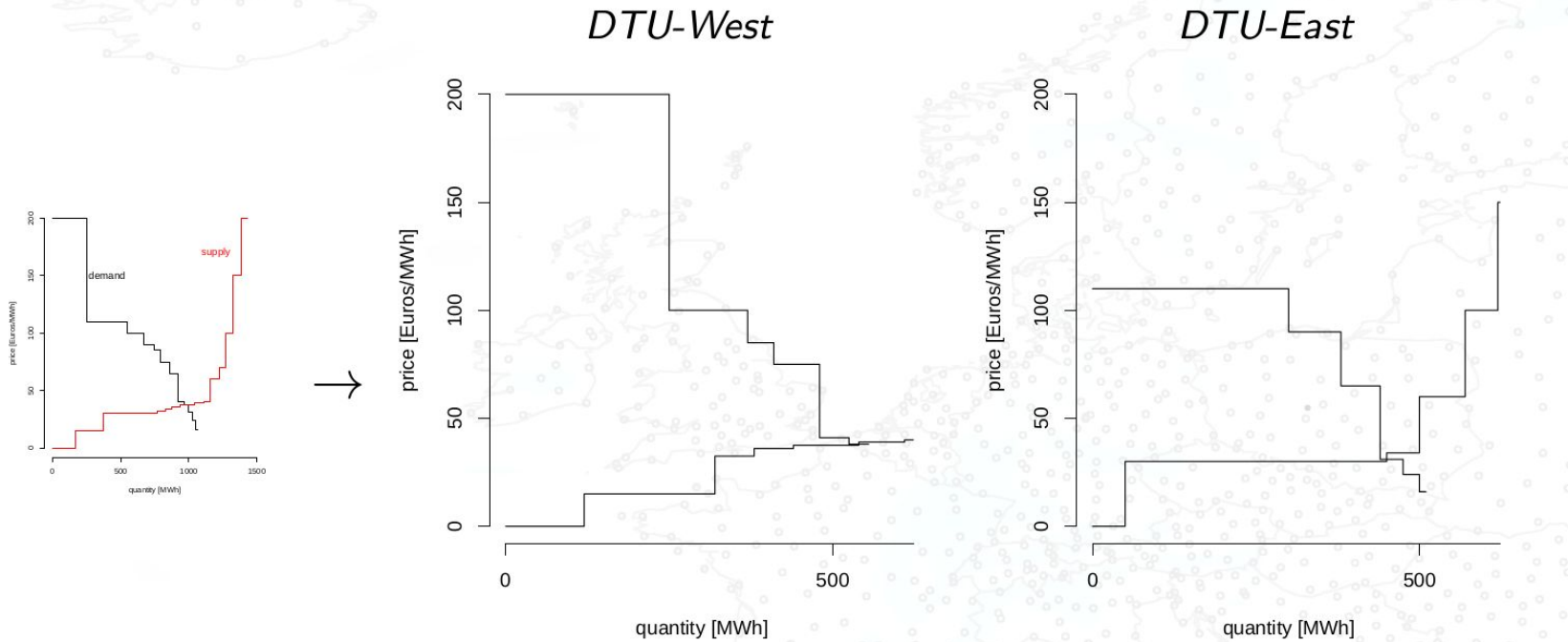
Localizing the previous market results

- Following previous market clearing results, one obtains
 - DTU-West:
 - Supply side: $\{G_1, G_3, G_5, G_7, G_8\}$ (but only 55 MWh for G_8) - Total: 495 MWh
 - Demand side: $\{D_1, D_3, D_5, D_6, D_8, D_9\}$ - Total: 555 MWh
 - Deficit of 60 MWh
 - DTU-East:
 - Supply side: $\{G_2, G_4, G_6\}$ - Total: 500 MWh
 - Demand side: $\{D_2, D_4, D_7\}$ - Total: 440 MWh
 - Surplus of 60 MWh

BUT, only 40 MWh can flow through the interconnection!

Market split: Import-Export approach

- Due to transmission constraints, the market has to split and becomes two markets

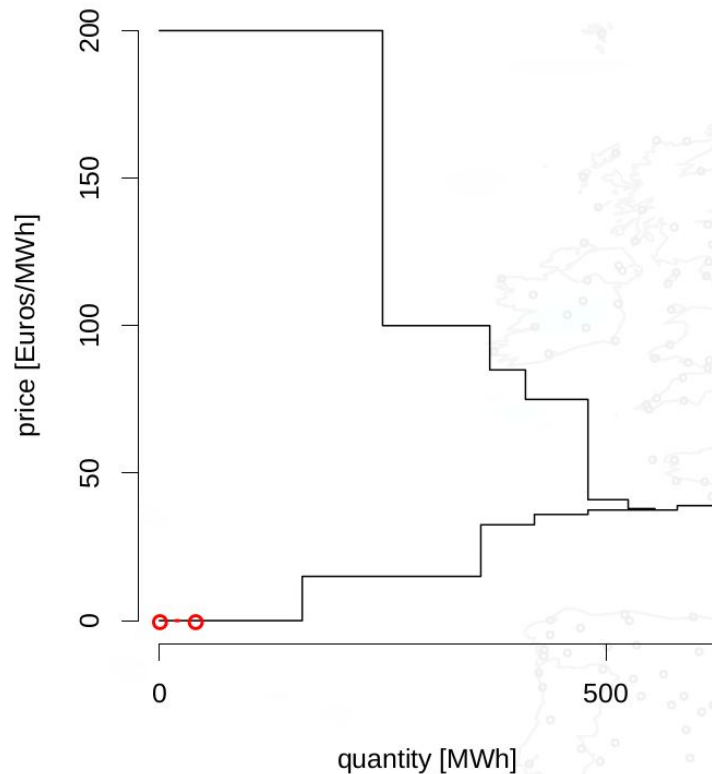


- In practice:
 - 2 market zones with their own supply-demand equilibrium
 - extra (price-independent) consumption/generation offers representing the transmission from one zone to the next to be added

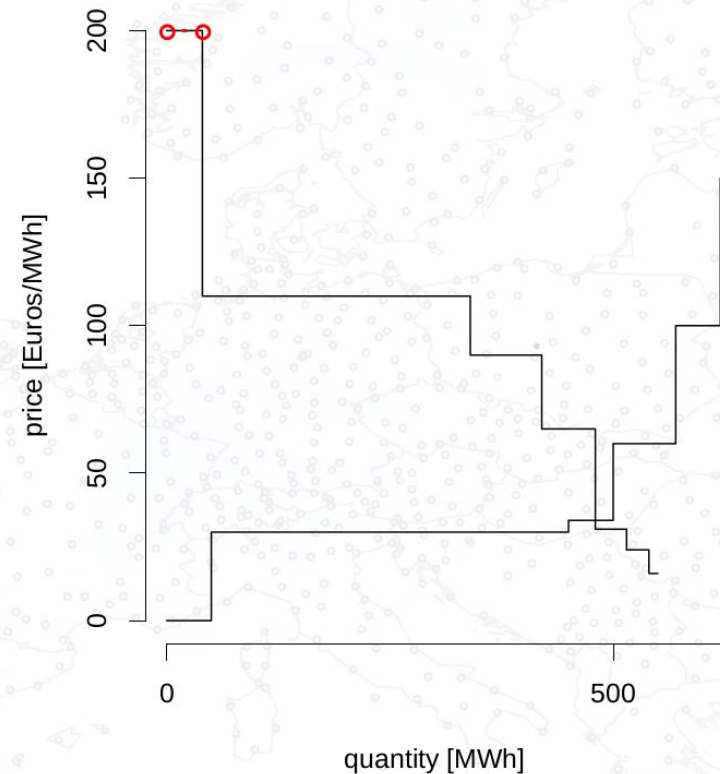


Adding transmission-related offers

- Extra supply in the high price area (40 MWh coming from DTU-East)



- Extra consumption in the low price area (40 MWh for DTU-West)



- Power ought to flow from a low price area to a high price area



Results for each zone

- That eventually yields
 - DTU-West:
 - Supply side: $\{G_1, G_3, G_5, G_7, G_8\}$ (but only 75 MWh for G_8) - Total: 515 MWh
 - Demand side: $\{D_1, D_3, D_5, D_6, D_8, D_9\}$ - Total: 555 MWh
 - Zonal price: 37.5 €
 - DTU-East:
 - Supply side: $\{G_2, G_4, G_6\}$ (but only 30 MWh for G_6) - Total: 480 MWh
 - Demand side: $\{D_2, D_4, D_7\}$ - Total: 440 MWh
 - Zonal price: 34 €

A few questions at this stage:

- What is the impact on the settlement?
- Do you think it would generalize well for more than 2 zones?

Settlement - Congestion surplus

- If we subtract consumer payments from producer revenues, it is not 0:

$$\Rightarrow 37.5 * 555 + 34 * 440 - (515 * 37.5 + 480 * 34) = 140 \text{ €}$$

- **Congestion surplus** : difference between the payments made by the loads and the revenues of the generator.
- Congestion surplus only arises when the transmission line is saturated/congested.



Approaches to representing network constraints

- There are basically two philosophies, developed on both sides of the Atlantic:
 - US
 - Europe

	Europe	US
System Operator	TSO	ISO
Market Operator	Ind. Market Operator	ISO
Offers	Market products	Unit capabilities
Clearing	Supply-demand equilibrium	UCED problem
Prices	Zonal	Nodal

TSO: Transmission System Operator

ISO: Independent System Operator

UCED: Unit Commitment and Economic Dispatch



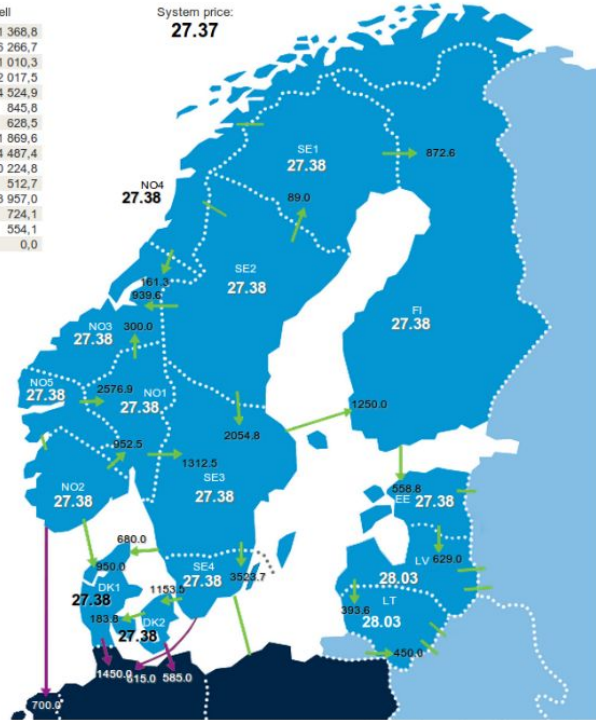
Illustration of zonal and nodal pricing

Scandinavia (Zonal):

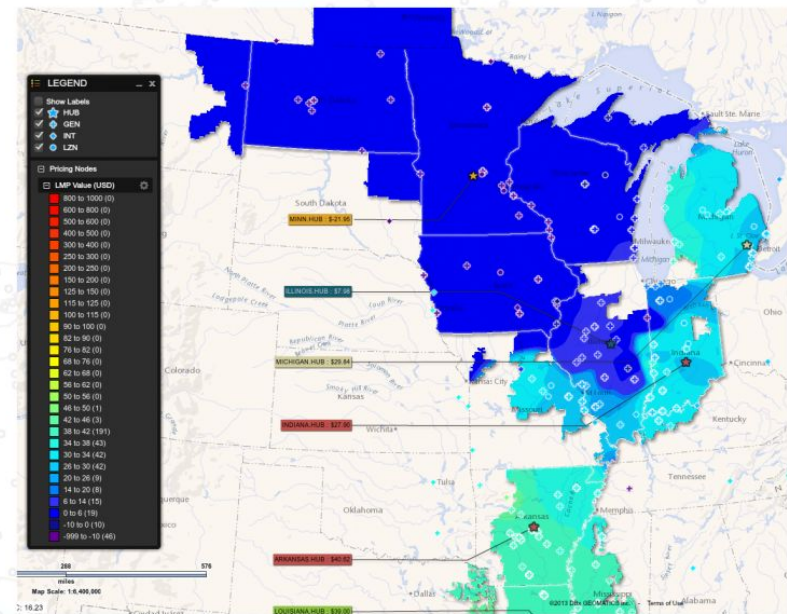
Eislot volumes

	Buy	Sell
NO1	3 285,7	1 368,8
NO2	4 364,2	6 266,7
NO3	2 411,2	1 010,3
NO4	1 856,2	2 017,5
NO5	1 948,0	4 524,9
DK1	2 659,6	845,8
DK2	1 598,2	628,5
SE1	1 086,0	1 869,6
SE2	1 404,0	4 487,4
SE3	8 138,4	10 224,8
SE4	2 882,9	512,7
FI	5 520,8	3 957,0
EE	653,9	724,1
LT	947,7	554,1
LV	235,4	0,0

System price:
27.37



Midwest US (Nodal):



Go visit: <http://nordpoolgroup.com> (market data, map)

Go visit: <https://www.misoenergy.org>



A word about losses in transmission networks

Losses occur in electricity networks (e.g. copper losses, eddy currents, ...)

Since one or more generators must produce this lost energy and since these generators expect to be paid for all the energy they produce, a mechanism must be devised to take losses and their cost into account in electricity networks.

Allocating the losses or their costs between all the market participants is a problem that does not have a rigorous solution.

A fair mechanism is one in which the participants that contribute more to losses pay a larger share than the others.



Part 5. Influence of renewable integration

Regulation in the electricity system

- Until the 1980s, the electricity system was mainly treated as a physical infrastructure system. It should primarily supply the required services.
- In the 1980's and 1990's, energy was treated more and more as a commodity, which could be left to market forces.
- The electricity system was divided into:
 - a natural monopoly part (--> regulated industry)
 - a commercial part (--> market competition)
- Until 2000, most European countries had newly established commercial markets for the electricity system.
- In the view of many economists, the liberalised supply and trade area should operate in an efficient way when left alone.
- From the 2000s, the view on the markets became more pluralistic: New objectives started to become more important and regulation became more important again.

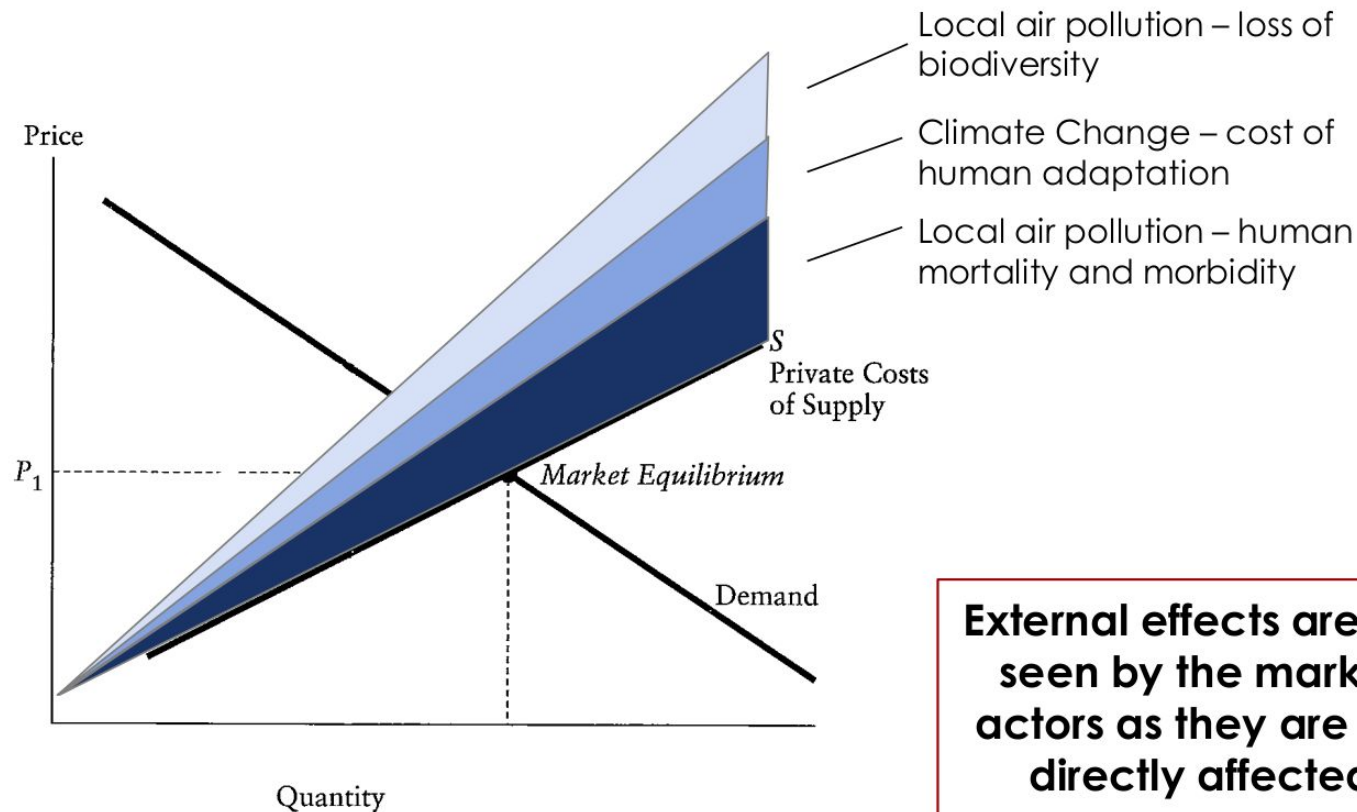
Different approaches:
Consumer cooperatives
and state-owned
monopolies (Denmark)
or private-owned
monopolies (USA), or a
mixture of both
(Germany).

New objectives:

1. Security of supply
(independence from
fossil fuels)
2. Climate change

Sources: Helm 2007

Efficient Markets: Marginal cost and benefits



External effects are not seen by the market actors as they are not directly affected

Market failures and need for regulation

1. **Complementarity** to the rest of the economy
 - societal costs of scarcity (excess demand) are higher than those of excess supply
2. **Just-in-time** requirements: Storage options are extremely limited
 - supply and demand must be kept balanced at all times for technical reasons, economic cycles to adjust demand/supply may become problematic
3. **Natural monopoly** in the network/grid segment
 - shared pool, i.e. a public good to the system as a whole – undersupplied by markets
4. **Positive externalities**, such as innovation processes, job creation, security of supply, social and equity issues,...)
5. **Negative environmental externalities** (emissions from fossil fuels)
 - if not adequately internalised, they cause wrong incentives

**Regulation is needed to govern sufficient, stable supply
in the interest of society and to internalise externalities**

Setting the right incentives

- So, regulation is necessary. How to do it?



- How to deal with external cost?

1. Collect fees from the polluters (Tax, Emissions trading,...)
2. Pay subsidy to alternative (non-polluting) technologies

Generation-based RES support

EXERCISE
Part 1

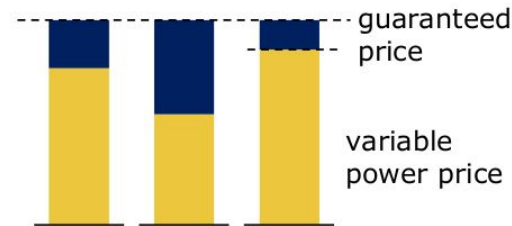
(1) Price-based

'Traditional' Feed-in Tariff (FIT)

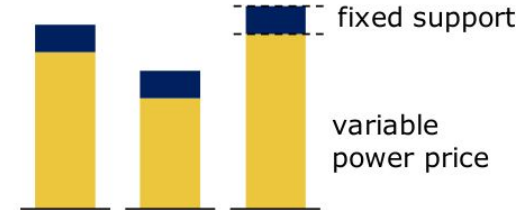


'Modern' Feed-in Tariff (FIT)

Sliding Premium / Contract for Difference (CfD)

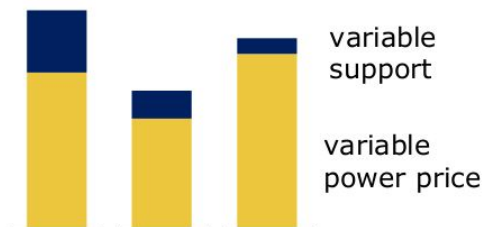


Fixed Feed-in Premium (FIP)



(2) Quantity-based

Tradable Green Certificates Scheme (TGC) / Quota Obligation

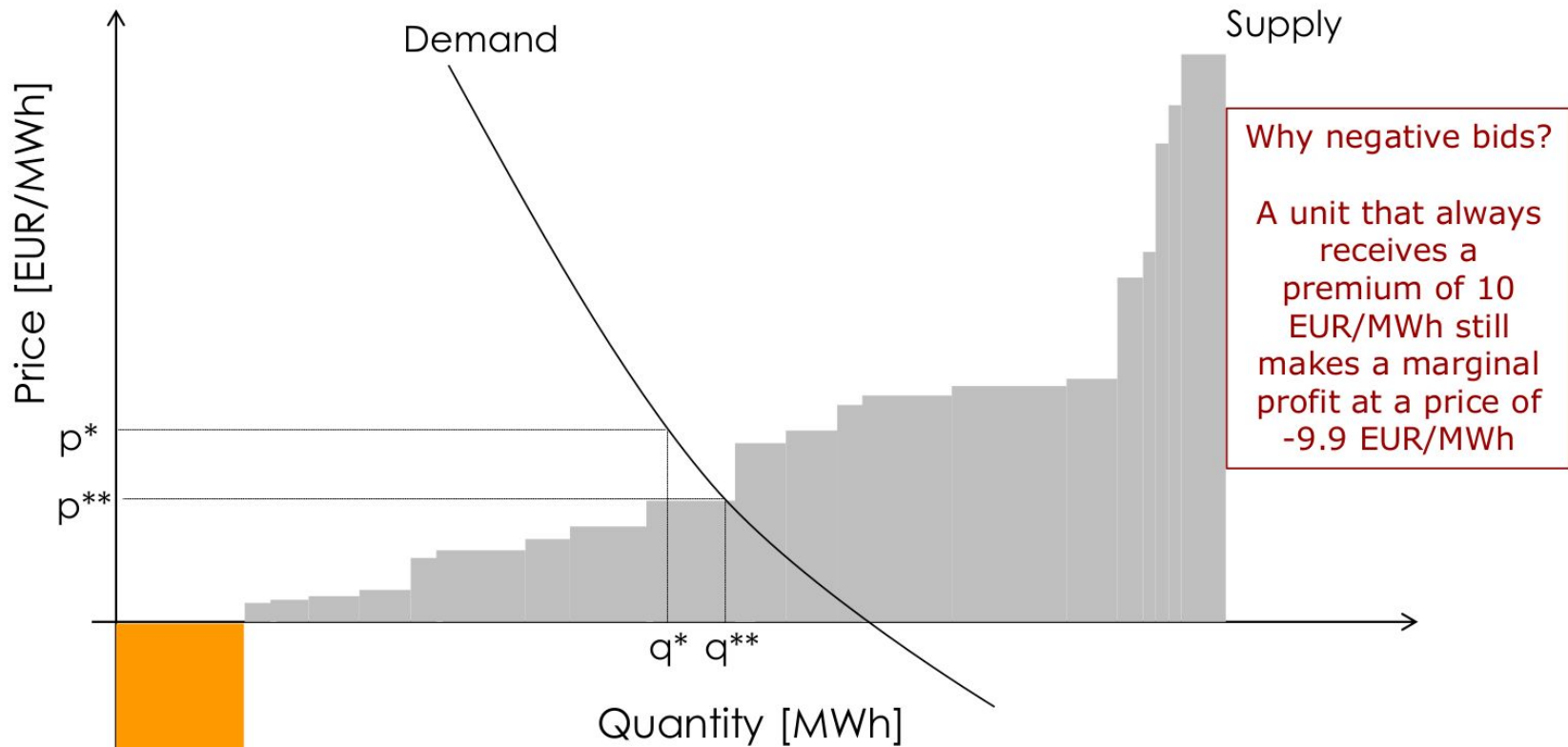


How would a supported wind park bid into the spot market – and what is the effect on market price?

'Traditional' Feed-in tariff: *No bidding – production at all prices*

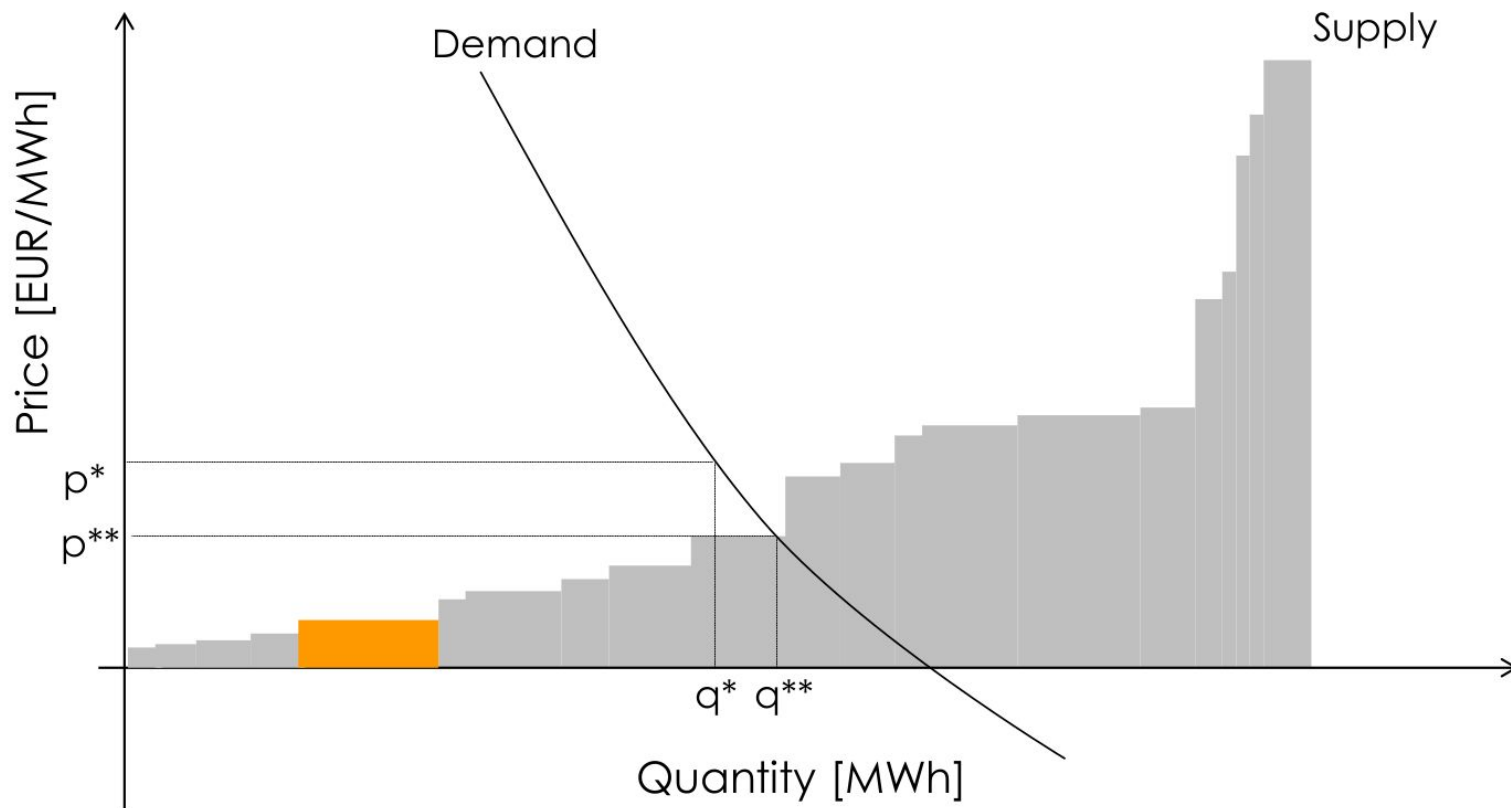
'Fixed' Feed-in premium: *Bidding at minus the premium*

'Sliding premium' Feed-in tariff: *Bidding at minus the tariff (strike price)**



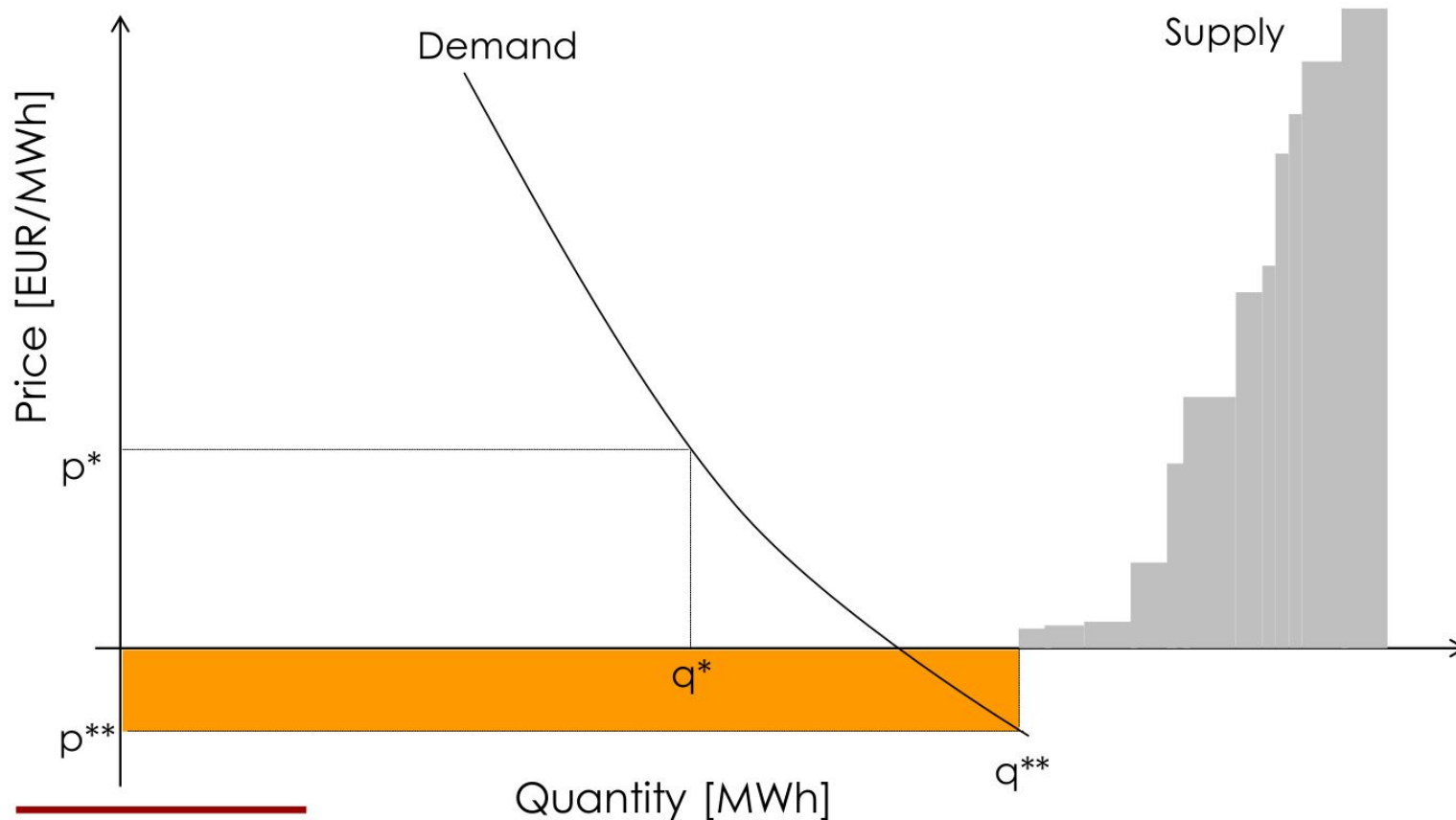
And what is the effect on market price if the park bid at marginal cost?

The negative bidding incentives are not problematic when supported units are pure price takers (= at low market shares)



How would a supported wind park bid into the spot market – and what is the effect on market price?

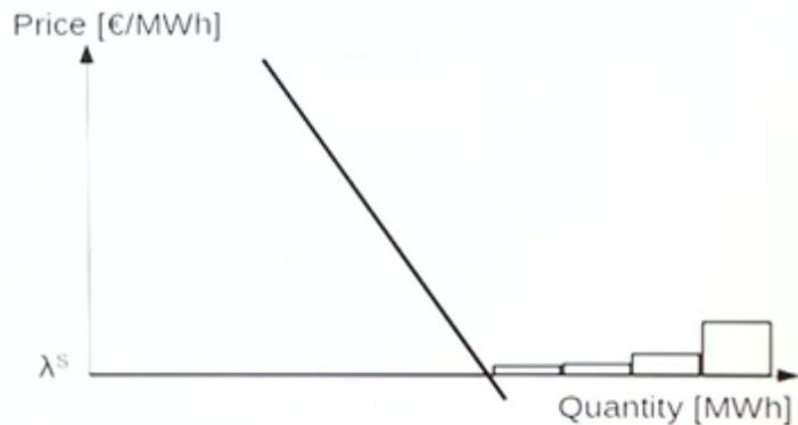
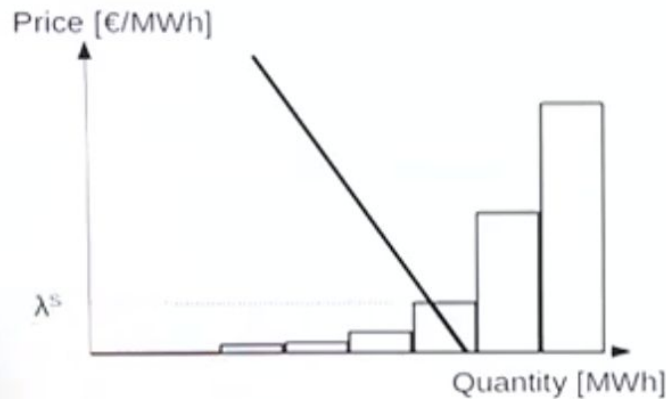
As soon as supported units become price setters (= at high market shares), we need adjustments of support scheme design





How to deal with negative prices?

- The regulator states that if clearing prices are negative, market participants lose their support (C/D and FIP)
- For both support scheme, the optimal strategy is then to offer at 0 €/MWh
- Only a few of them
- Quite many more



- Clearing prices still decrease, but they never become negative



Effects of renewable introduction

Increase introduction of renewables:

- reduce prices on energy markets
- increase system cost

Let's analyze that for two different kinds of renewable generation:

- industrial production level
- prosumer level

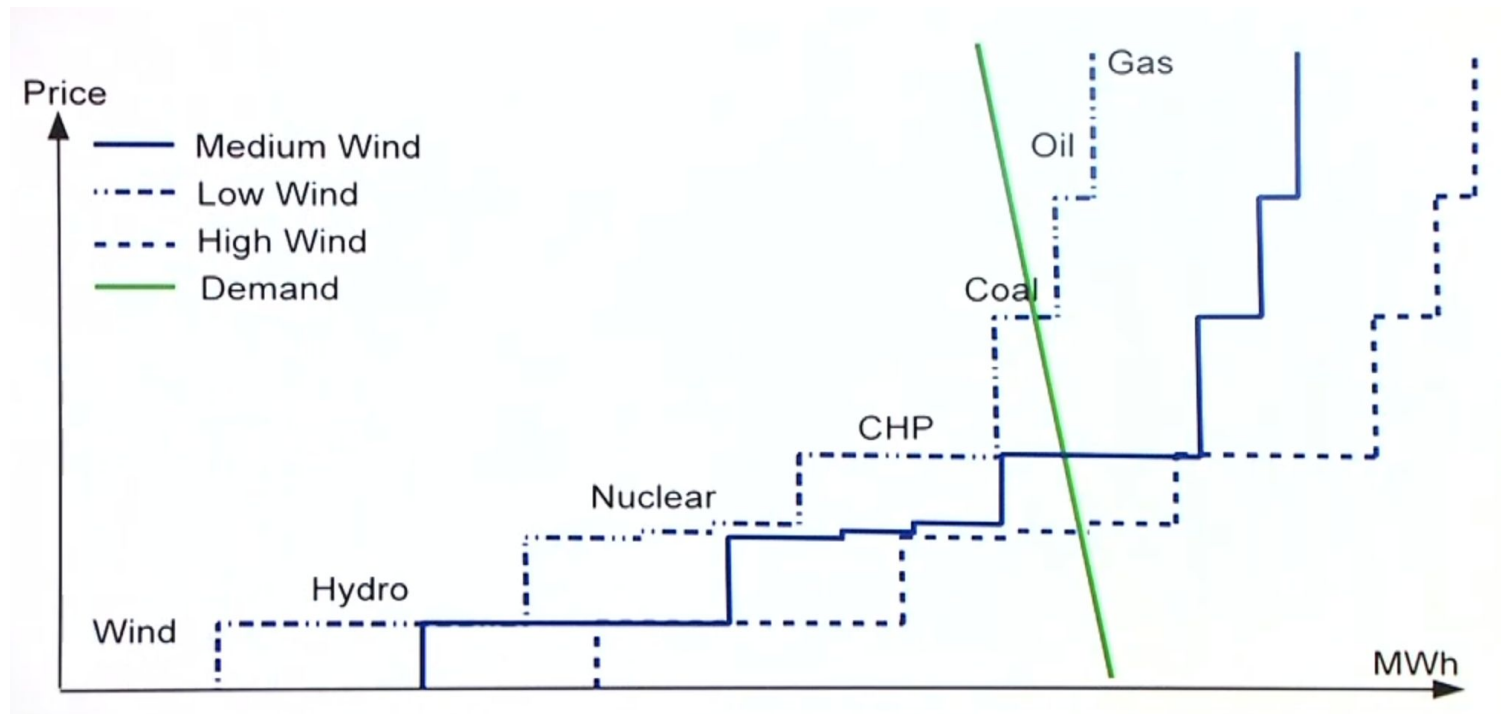


Industrial level

Renewable energy generally bid at 0.

Impact on the merit-order curve:

1. High renewable generation → low prices
2. Low renewable generation → high prices

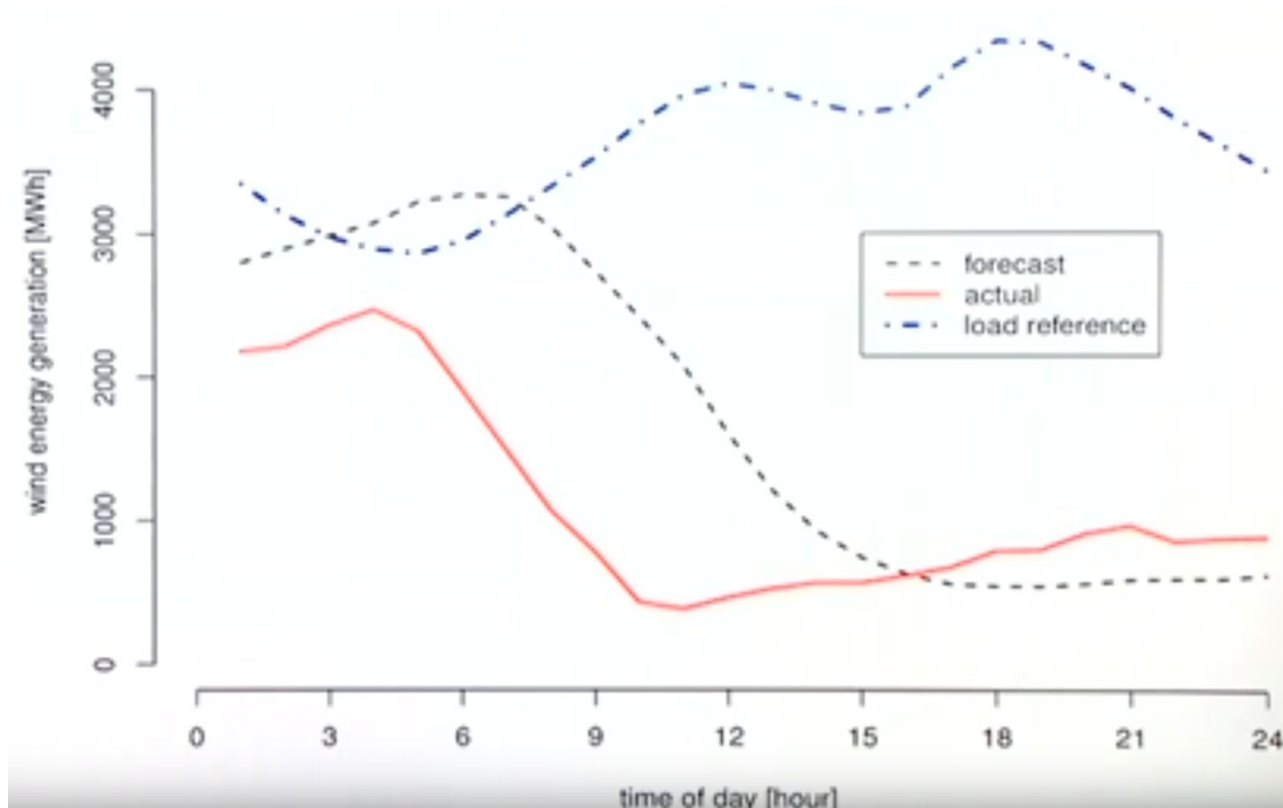




A rising need for reserve

Fluctuations of renewables and forecast errors lead to:

1. increase need for balancing reserves
2. impacts the system costs





Prosumer level

Typically, company or households possessing solar panels

→ Initial investment but reduce the electricity bill

→ Can generate overvoltages on the network and damage it

Currently, PV owners do not pay for the service of the network.

→ Might change rapidly in the future e.g. tax on capacity installed

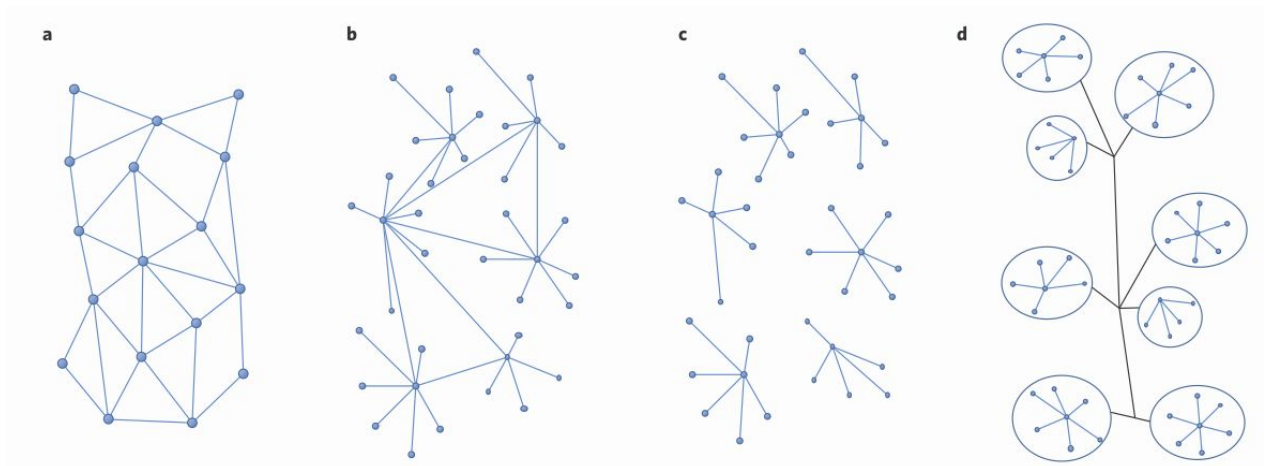




Impacts on the markets

We are seeing the increase of new alternative markets:

Read “*Electricity market design for the prosumer era*”

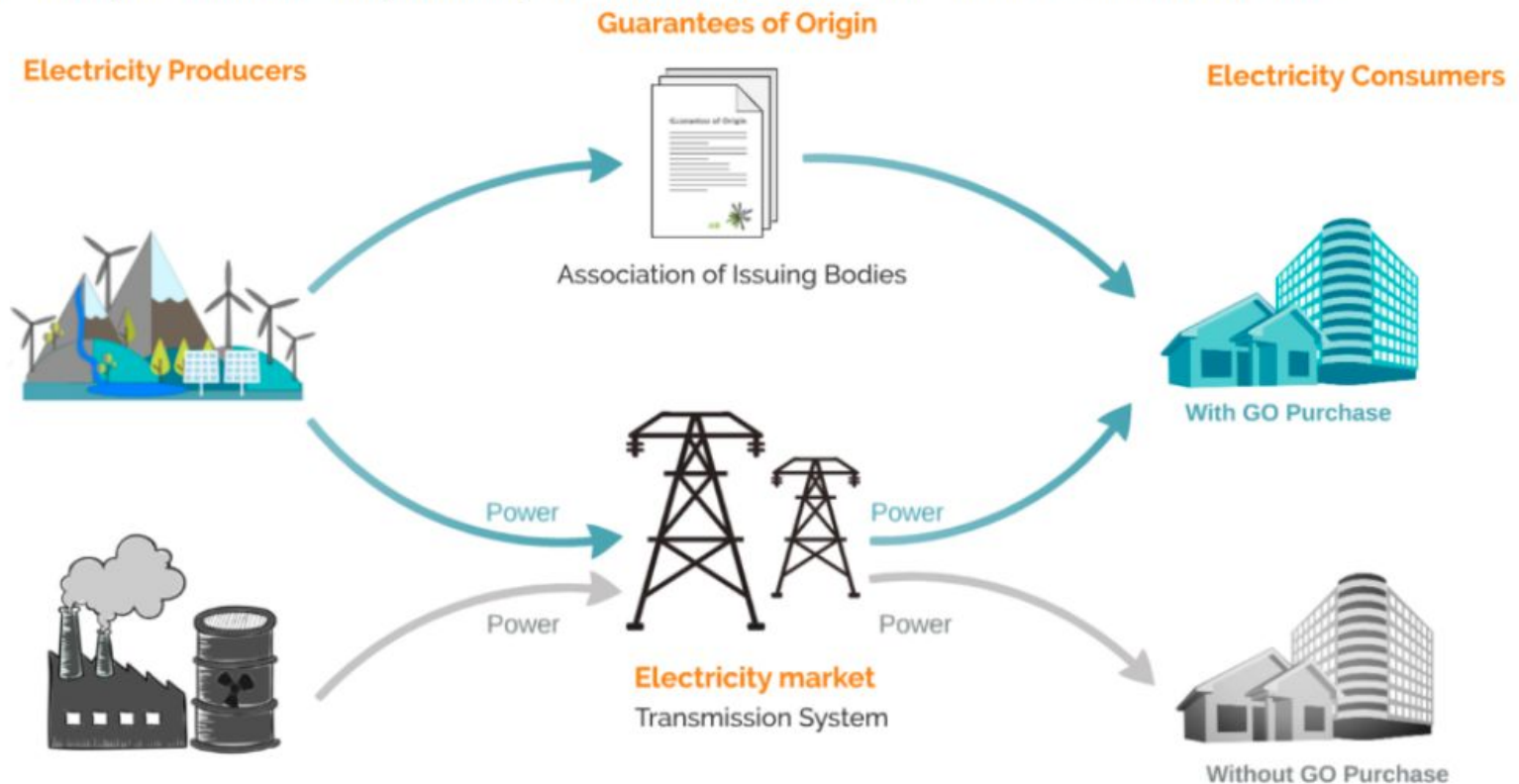




« Green » energy ? -> Guarantees of Origin (GO)

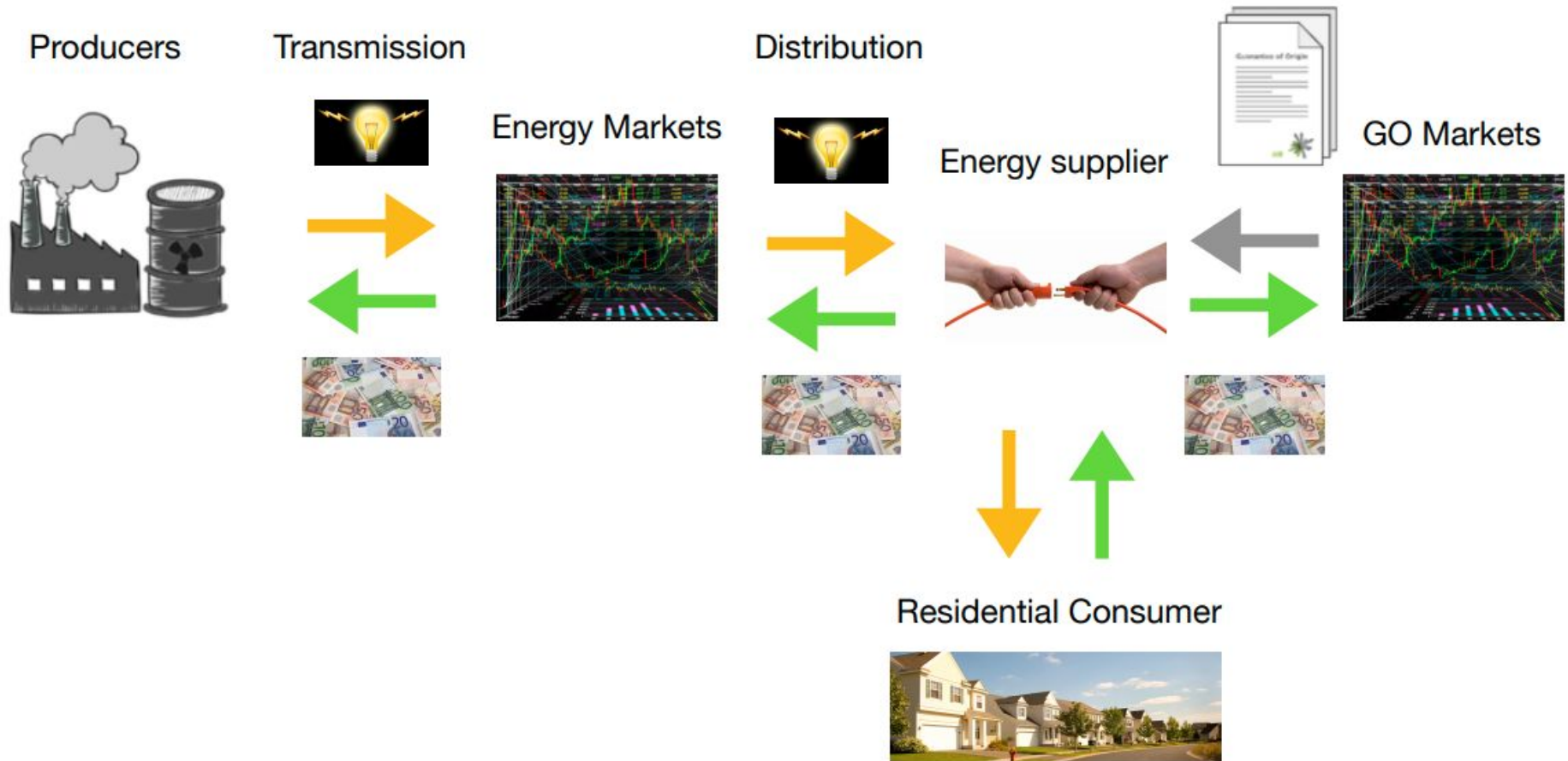
A Guarantee of Origin (GO or GoO) is a **tracking instrument** defined in article 15 of the **European Directive 2009/28/EC**

Source: <https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32009L0028>



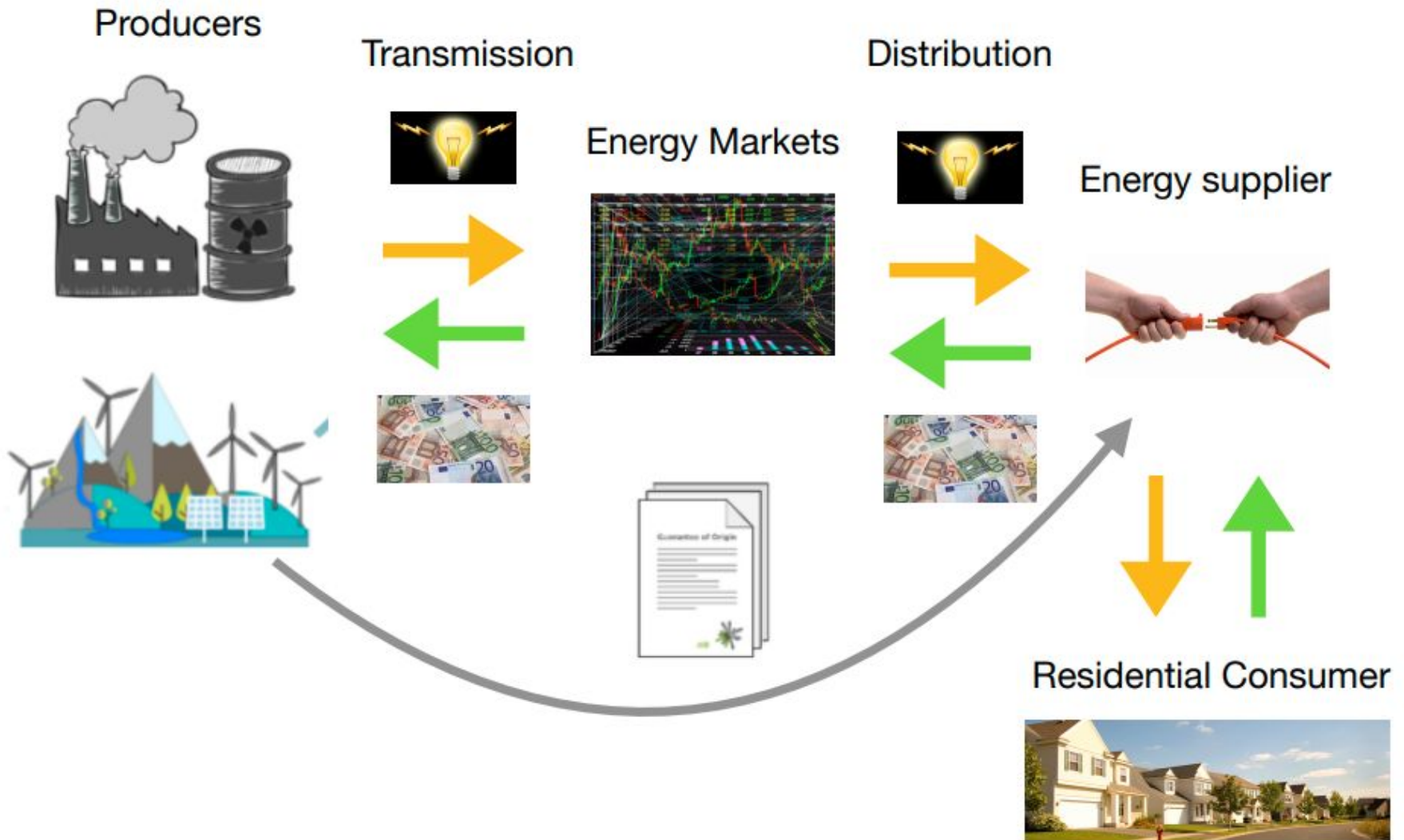


Non-« green » to « green » market offer



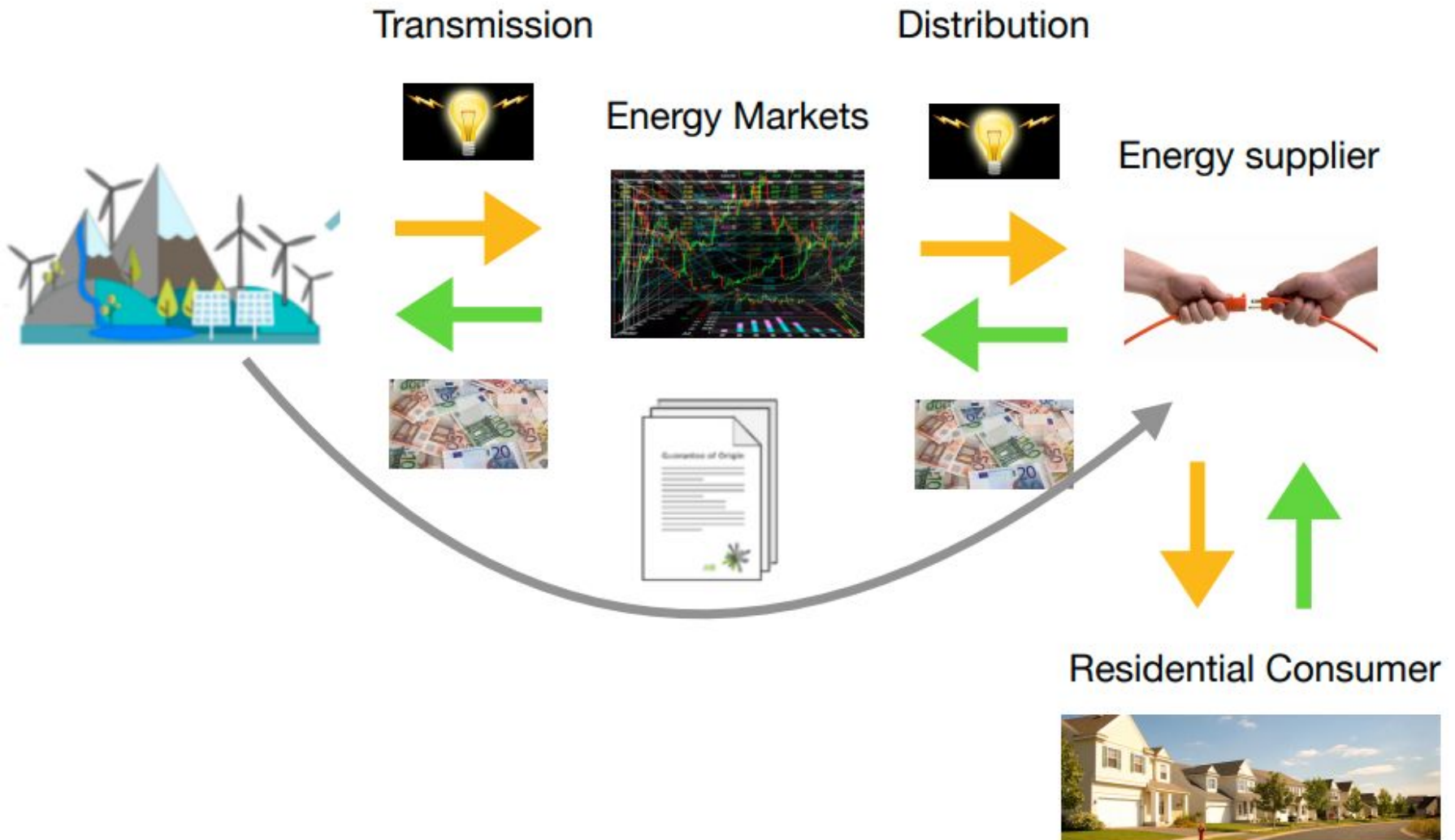


Mix « green » to « green » market offer



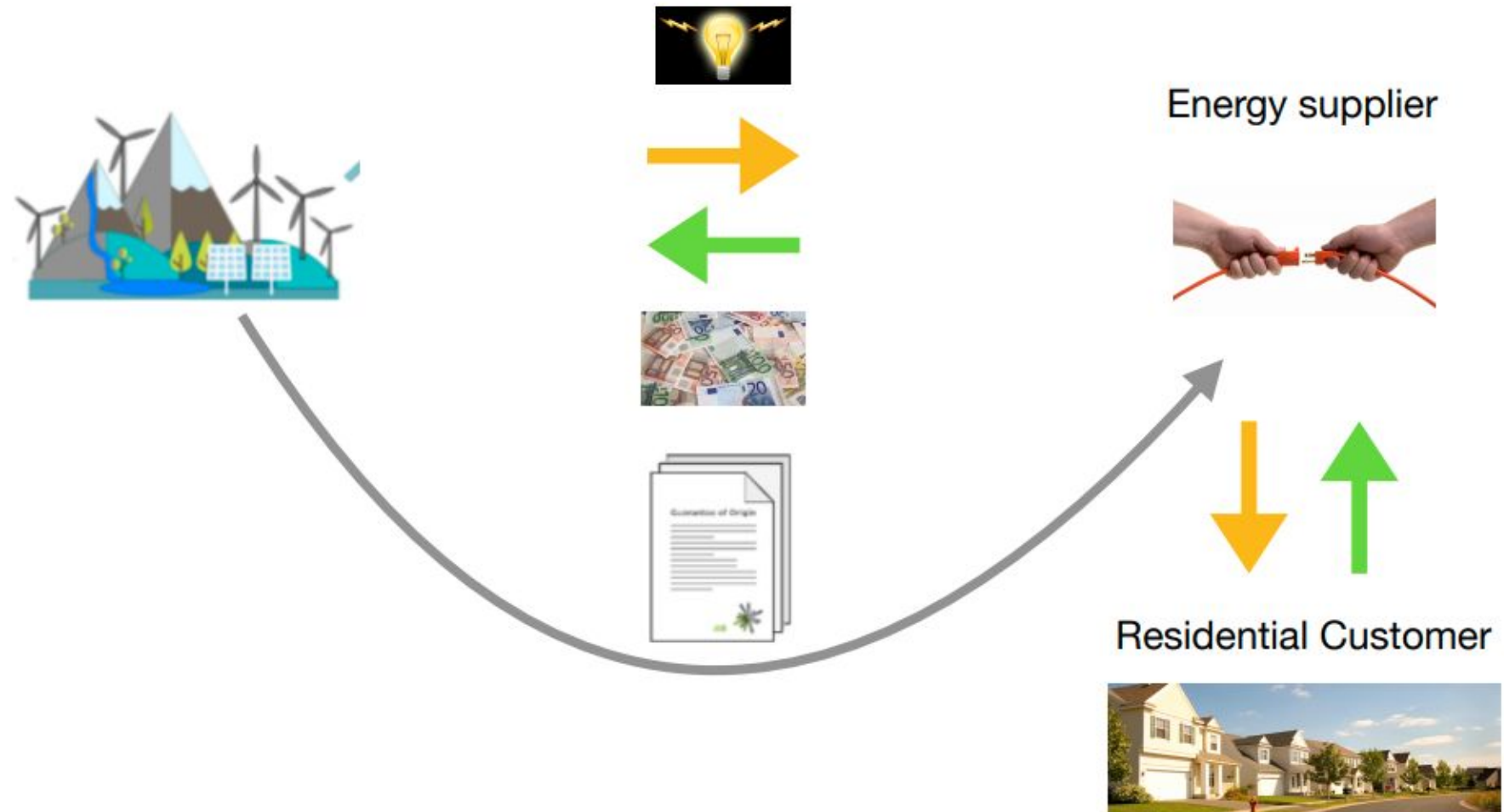


« Green » market offer





Direct « green » offer





Small recap

How an **energy supplier builds** a **residential electricity offer** ?

- **direct** to the producer -> money into the pockets of the producer
- **market** based offer -> money to a lot of market players
- **mix direct - market** based offer

What is a « **green** » energy offer ?

- **Guarantees of Origin** (GO)



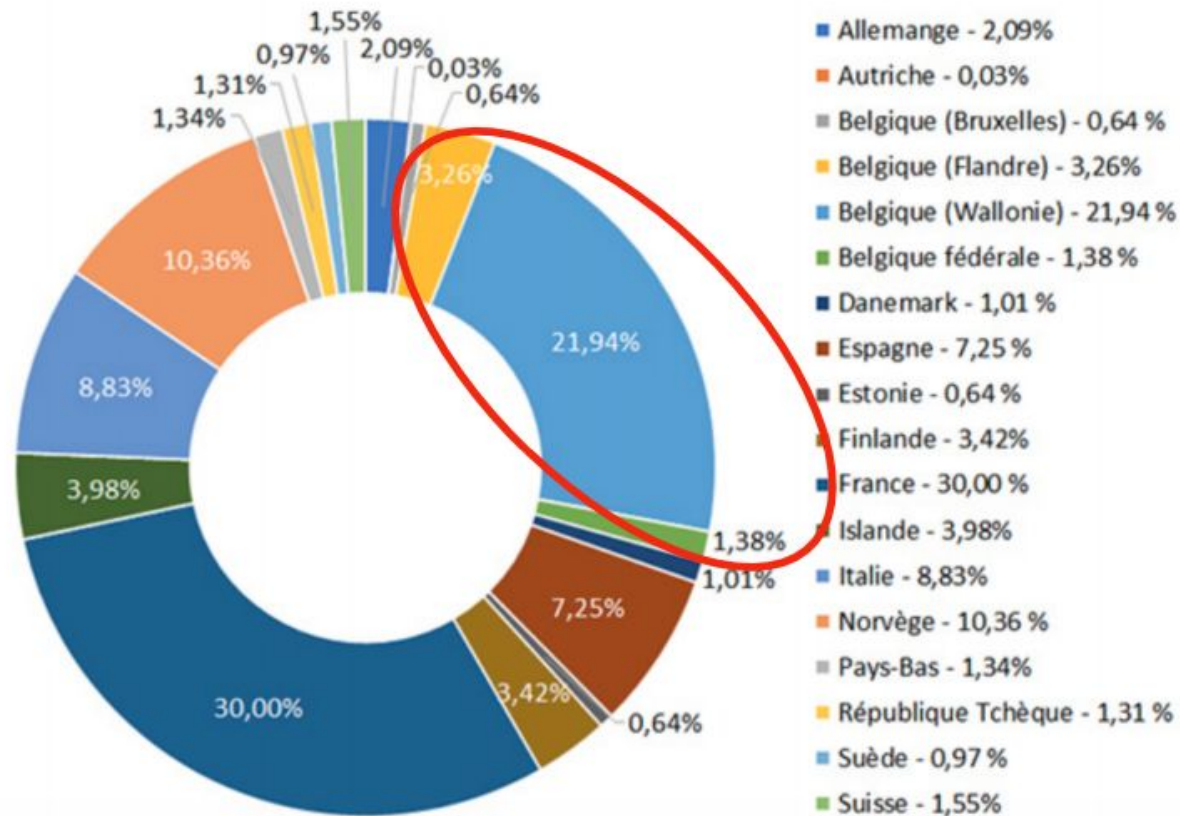
« **green** » does not mean low carbon footprint !!!



Residential energy supplier

Walloon 2019 GO distribution per country

30% GO from Belgium



Source: <https://www.cwape.be/?dir=4.12.1>



Conclusion

It is impossible to compare energy suppliers on GOs ...

Some possible criteria:

- energy mix
- **carbon footprint** of the energy mix
- financial **transparency**
- **Belgian GO** vs GO from other countries, etc
- direct, market-based offer ?
- Etc



« green » does not mean low carbon footprint !!!



Conclusion

- Electricity is special commodity.
- A plethora of markets and financial security mechanisms have been created to ensure that production always equals demand.
- These markets are evolving rapidly as our society tend towards a more decarbonate future.