Artelys | OPTIMIZATION SOLUTIONS

Electricity price formation and interlinkages with gas

Business game

Christopher Andrey

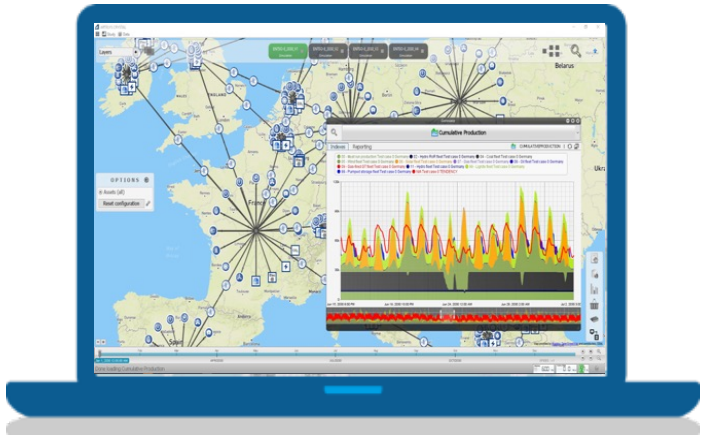
Contribution to the GIE workshop *Energy Crisis* - 25 February 2022

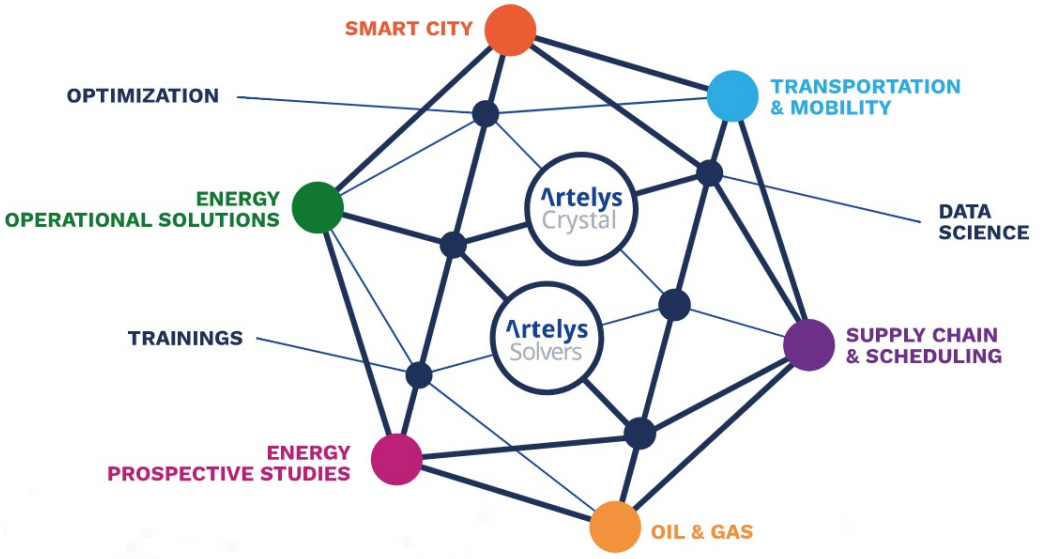
Artelys – An overview

- Artelys is an **independent** software edition and consulting company specialised in decision support, modelling and optimisation
- Founded in **2000** by its current President, Arnaud Renaud
- More than **300 customers** in **40 countries**
- Around **90 members of staff** in Paris, Brussels, Montréal, Los Angeles and Chicago
- Artelys is active in **multiple areas**: energy, resource planning, logistics, transport and mobility

Artelys – Our DNA

- In the energy sector, **three mutually reinforcing dimensions** allow us to provide our clients with state-of-the-art solutions:
  - Consulting activities for clients all along the energy value chain
  - Development and distribution of the Artelys Crystal suite and ad-hoc decision-support tools
  - Development and distribution of numerical solvers
- The continuous **cross-fertilization** between these dimensions is one of the **key strengths** of Artelys





Agenda

1. A primer on wholesale electricity price formation in Europe
    - Pay-as-clear market design
    - Impact of market coupling
2. Relation between gas and electricity prices
3. Quiz

Electricity price formation in Europe

How are European wholesale electricity markets organised?

Electricity price formation in Europe

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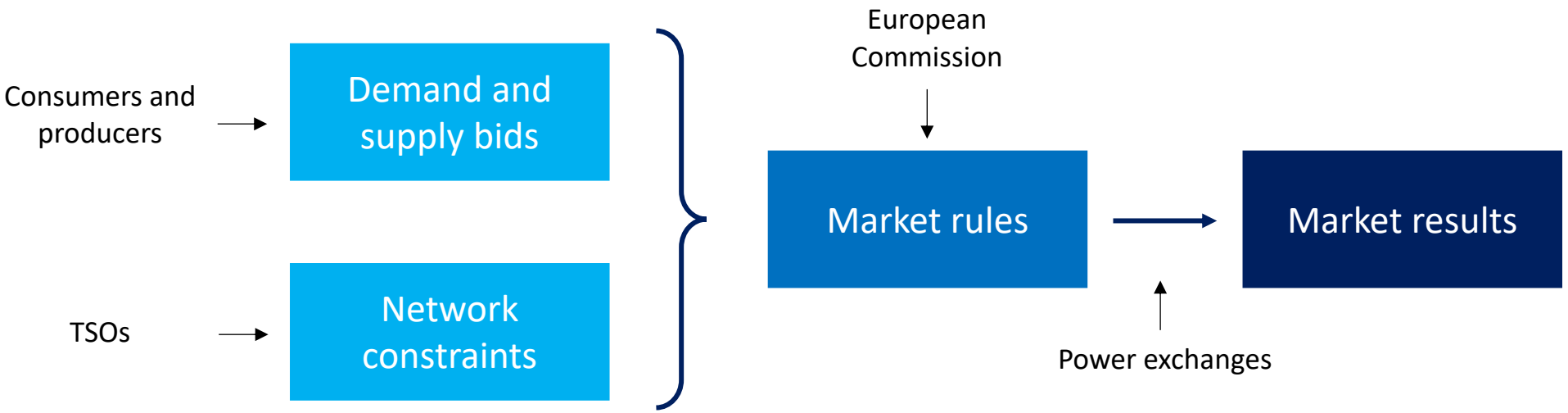
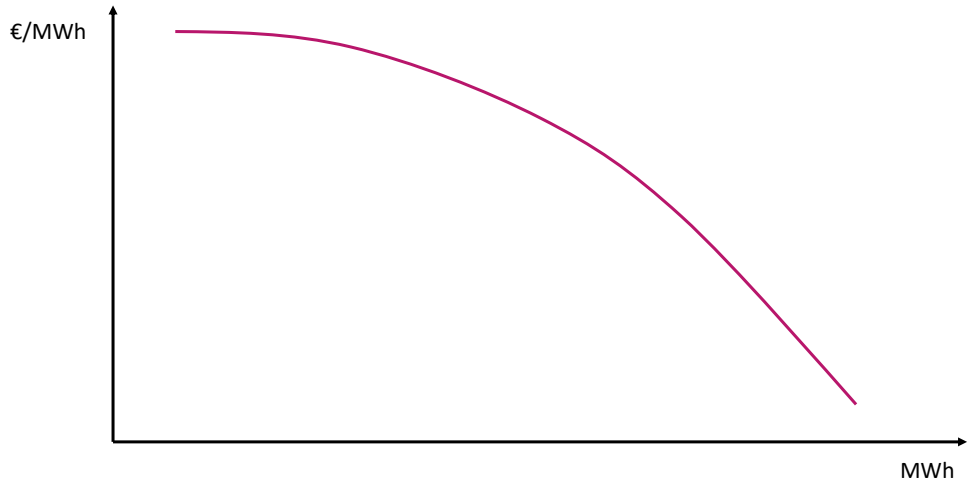


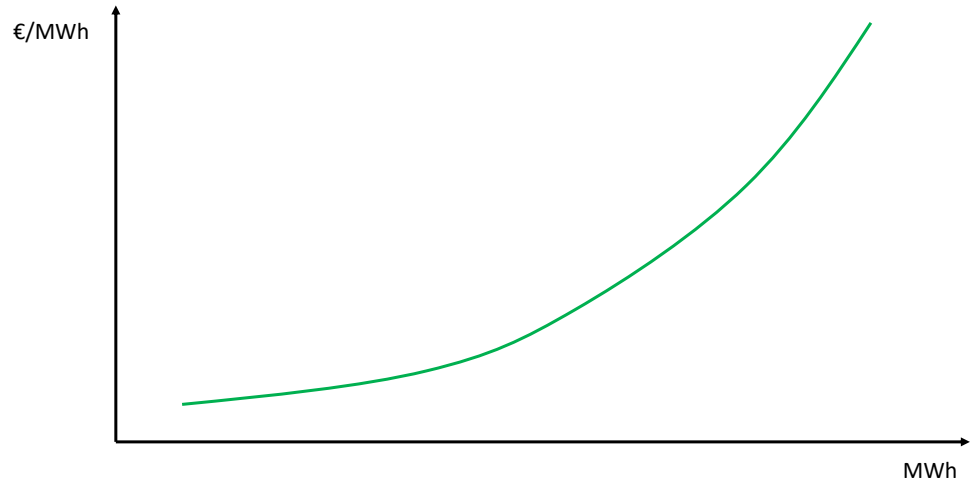
What do bids look like

Bids, in their simplest forms, translate “willingness to pay” and “need to earn” of market participants

Typical consumers’ bids



Typical producers’ bids



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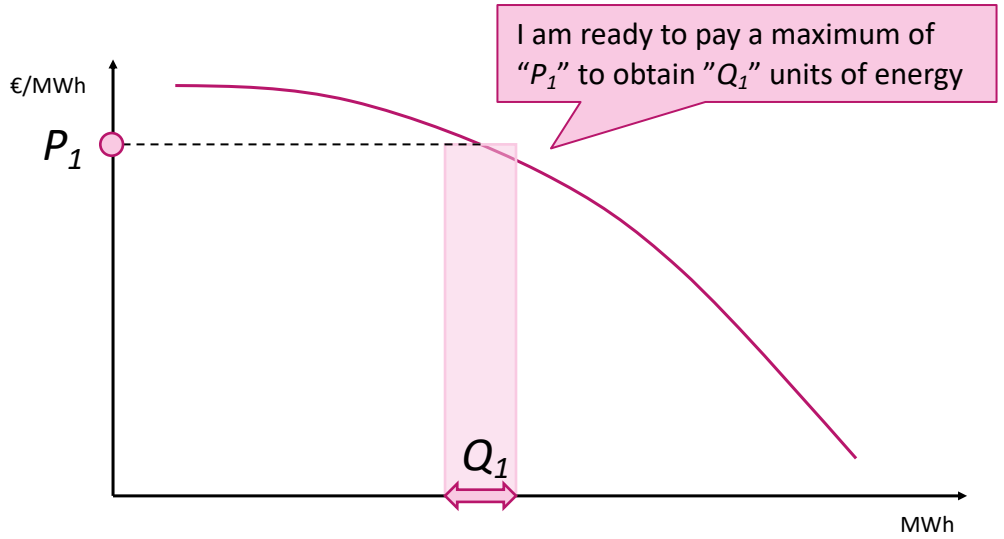
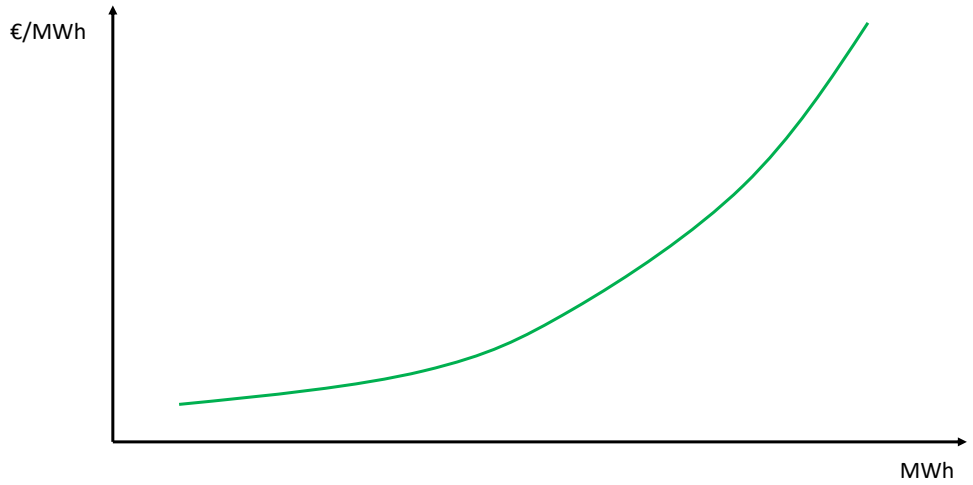


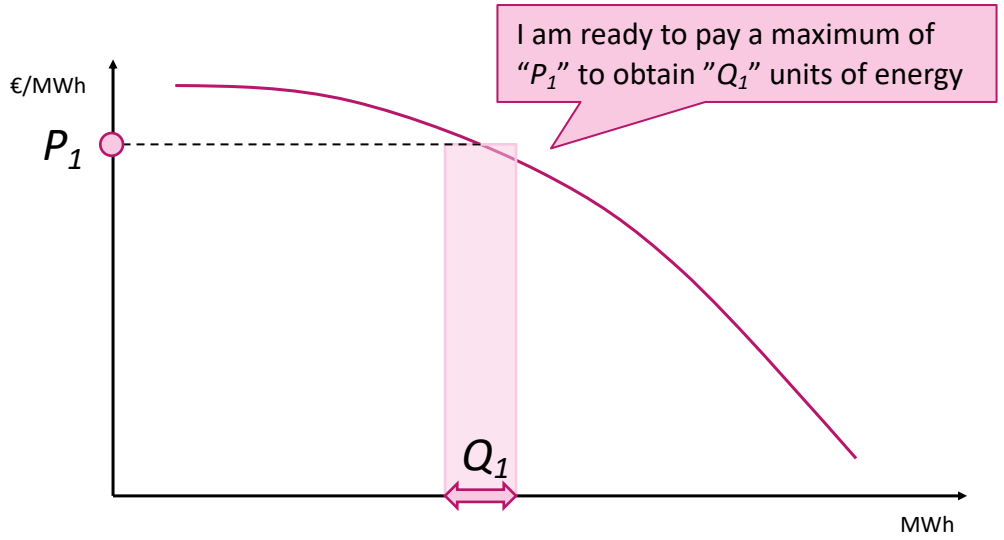
Typical producers’ bids



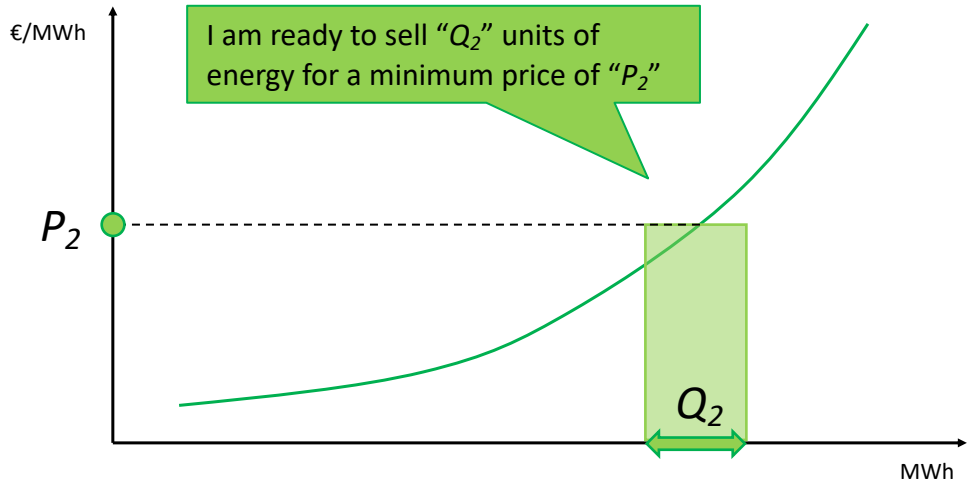
What do bids look like

Bids, in their simplest forms, translate “willingness to pay” and “willingness to sell” of market participants

Typical consumers’ bids



Typical producers’ bids

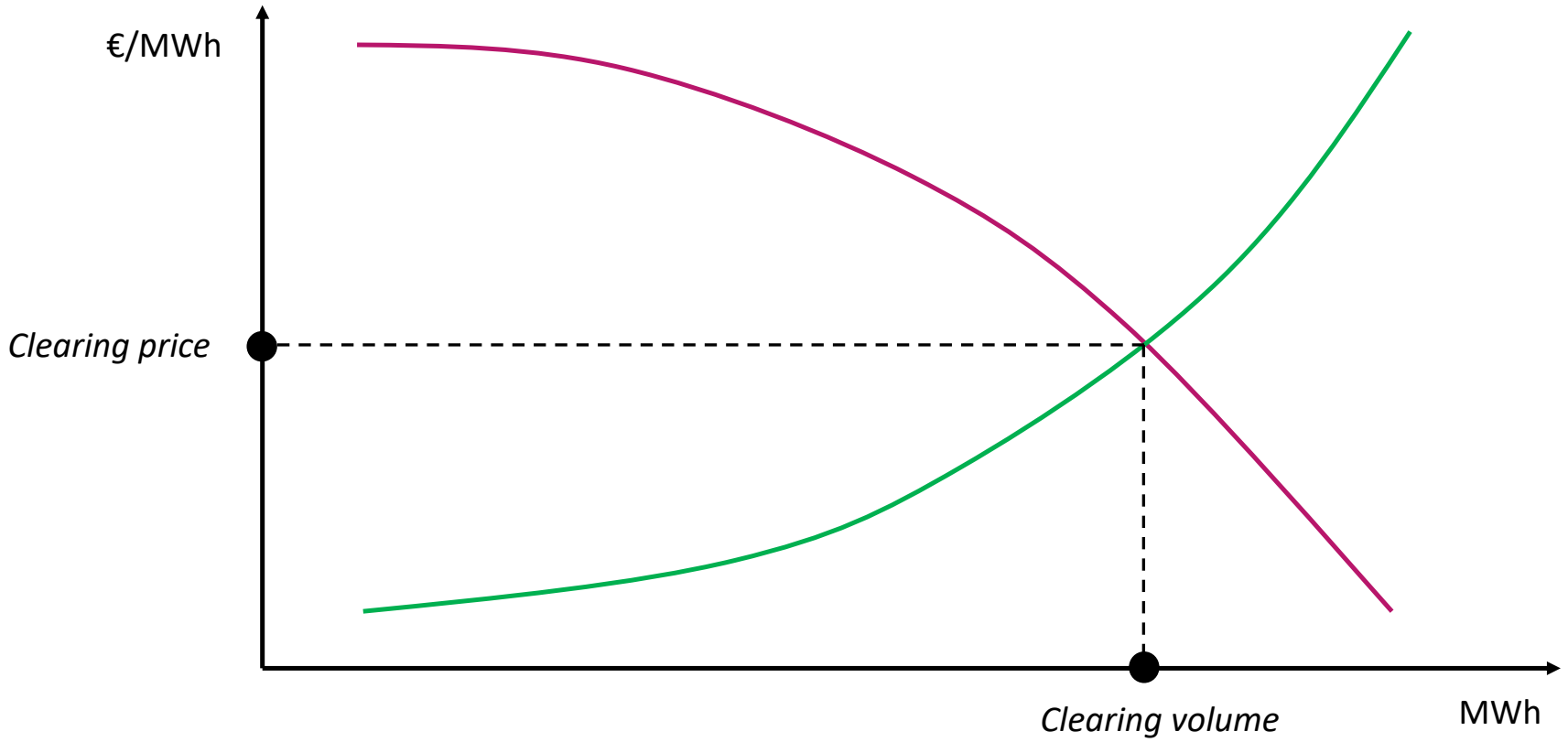


Electricity price formation in Europe

How are European wholesale electricity markets organised?

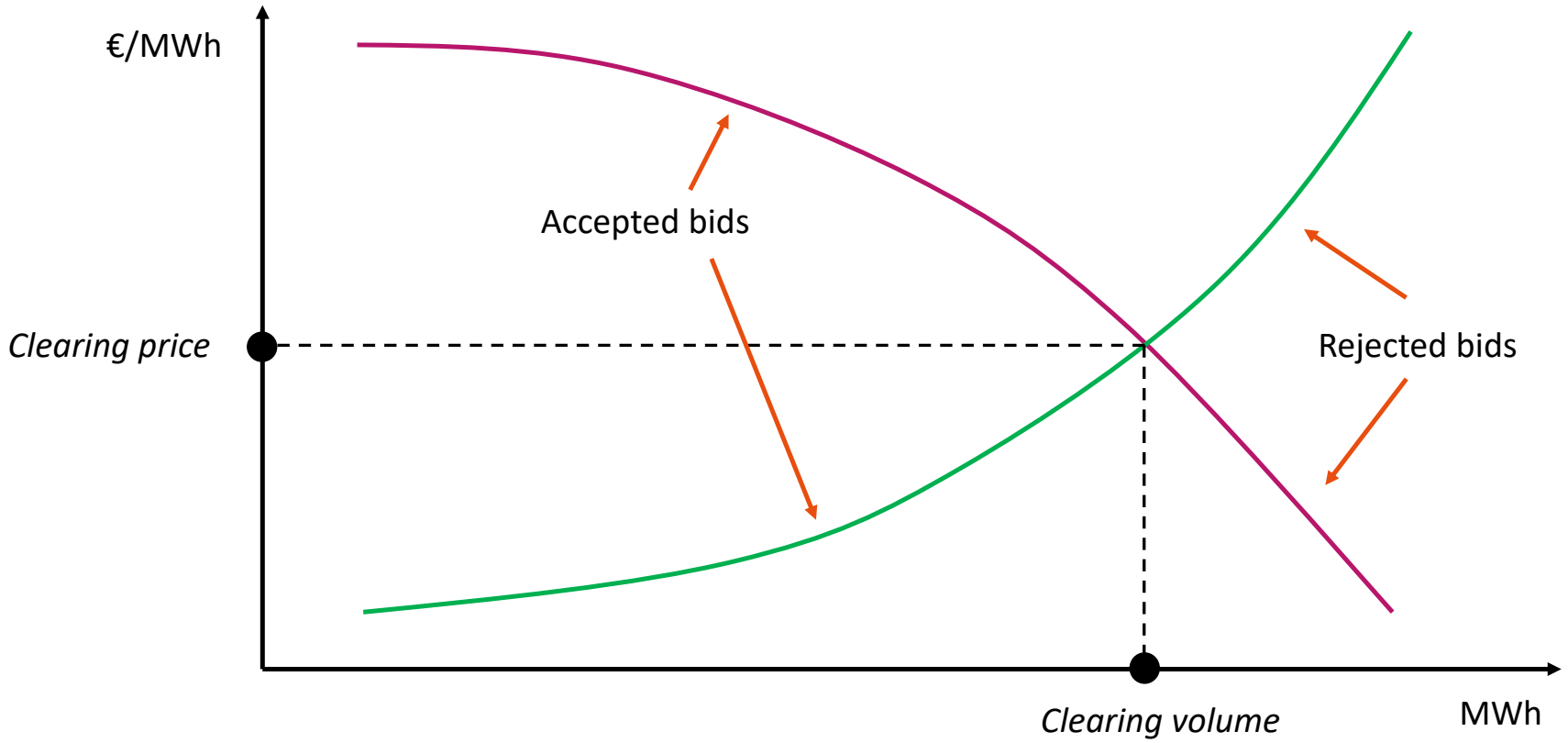
Electricity price formation in Europe

Price formation in European day-ahead electricity markets: marginal pricing (pay-as-clear)



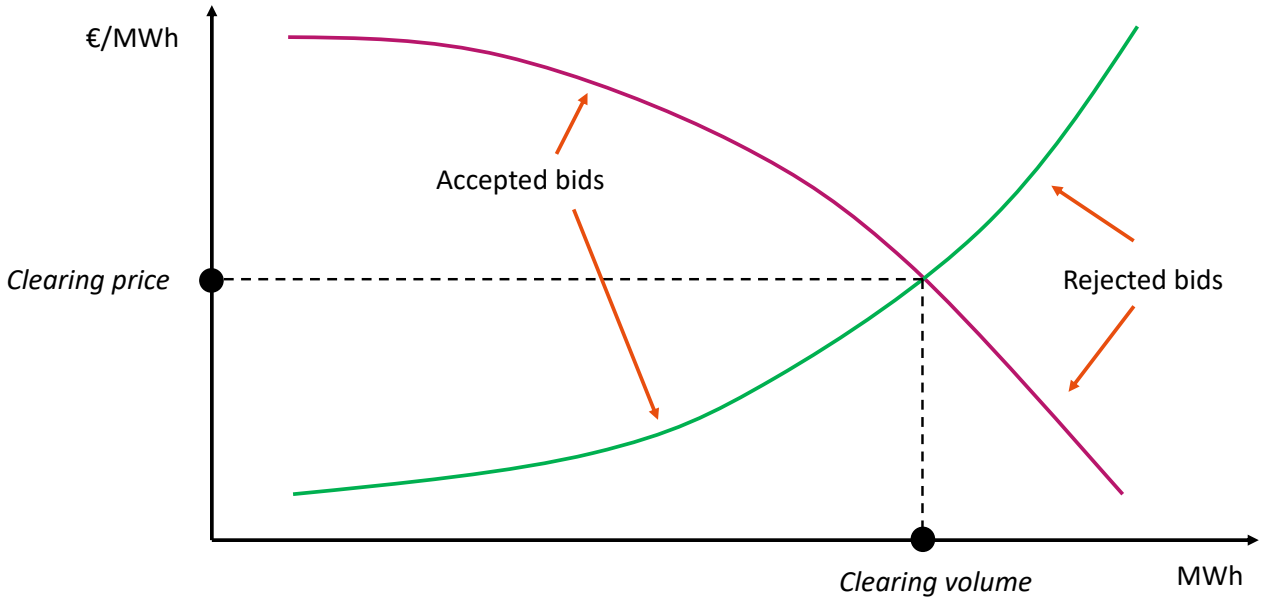
Electricity price formation in Europe

Price formation in European day-ahead electricity markets: marginal pricing (pay-as-clear)



Electricity price formation in Europe

Price formation in European day-ahead electricity markets: marginal pricing (pay-as-clear)



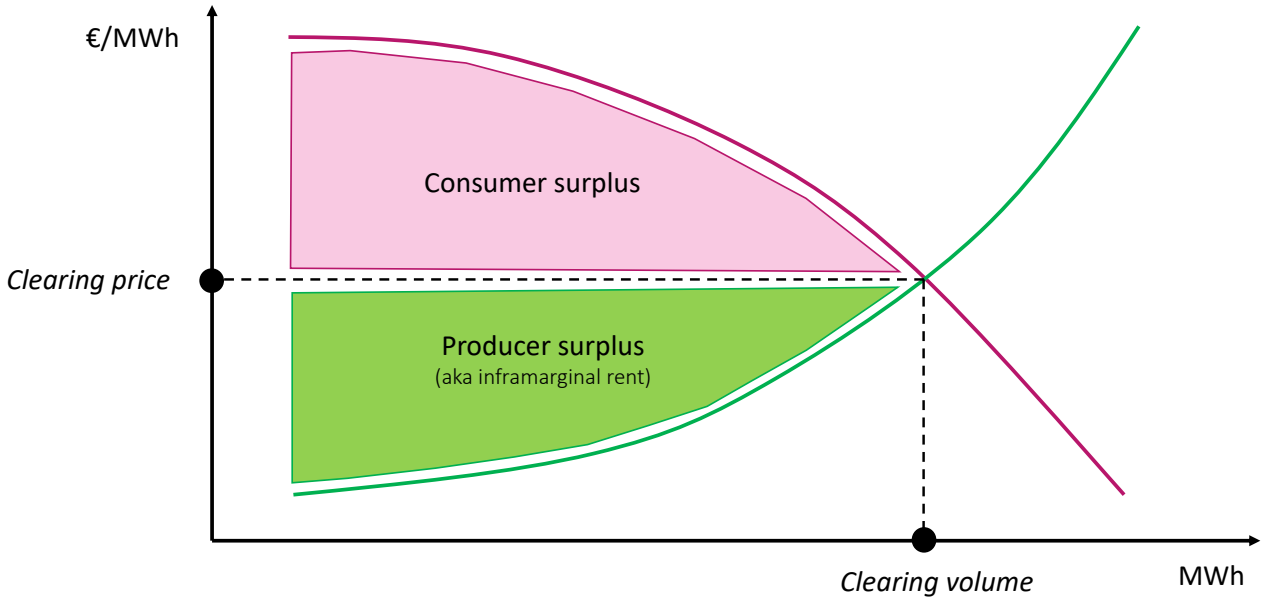
European wholesale electricity markets use a "**pay-as-clear**" approach.

All accepted producers receive the ***clearing price*** per unit of energy produced, even if their bids were lower.

All accepted consumers pay the ***clearing price*** per unit of energy consumed, even if their bids were higher

Electricity price formation in Europe

Price formation in European wholesale electricity markets: marginal pricing (pay-as-clear)



Surpluses

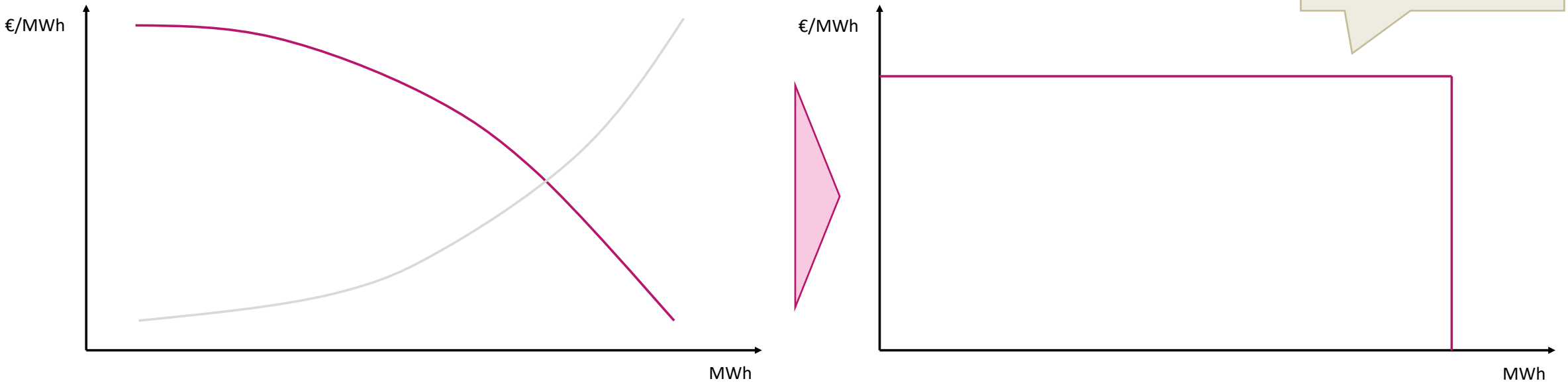
The producer surplus is defined as the difference between the revenues of producers and what they were ready to accept to earn.

The consumer surplus is defined as the difference between what consumers were ready to pay and their actual expenses.

Case of an inelastic demand

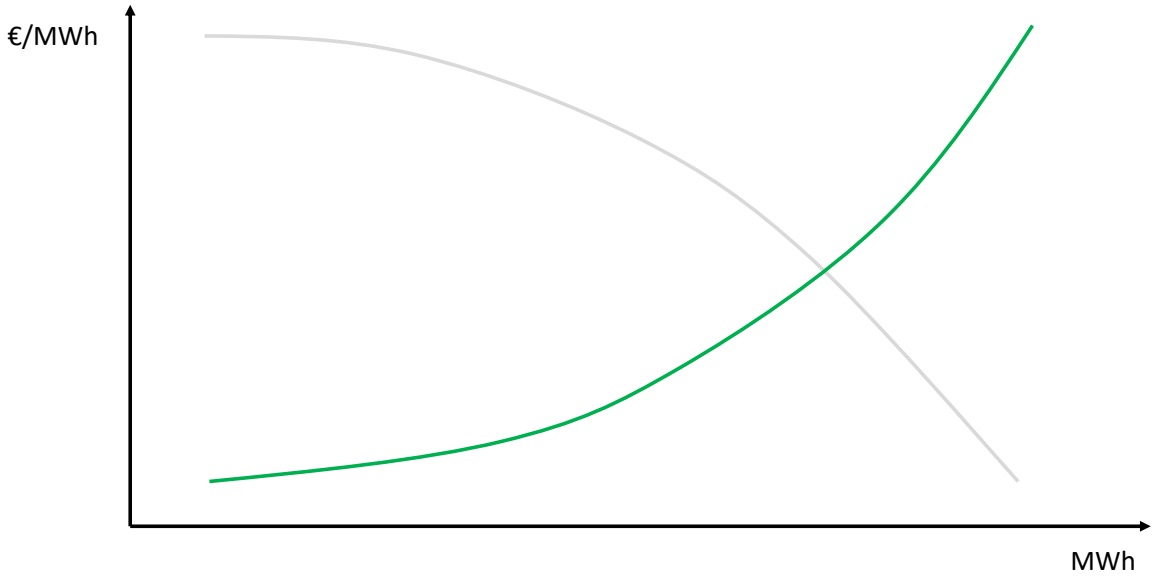
In the following slides we will consider the case of an inelastic demand:

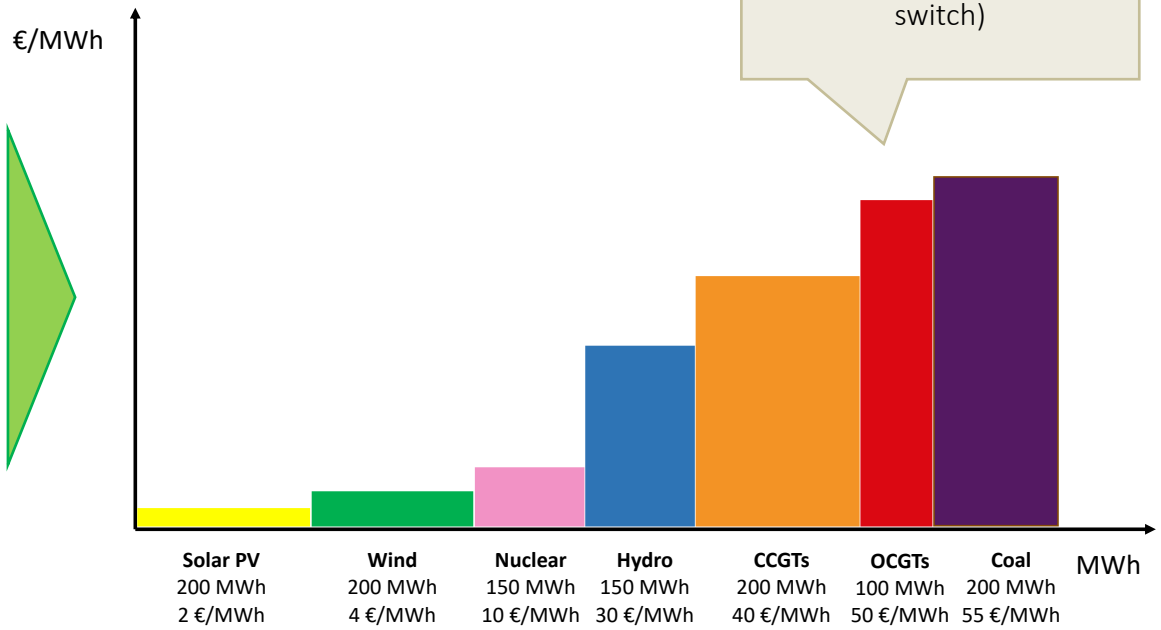
In the case of an inelastic demand, all consumers are willing to pay a high price (e.g. market price cap). In reality, the demand of some consumers is inelastic (i.e. price-dependent)



Introducing the “merit order”

In practice, the supply curve is built by considering bids by different producers:

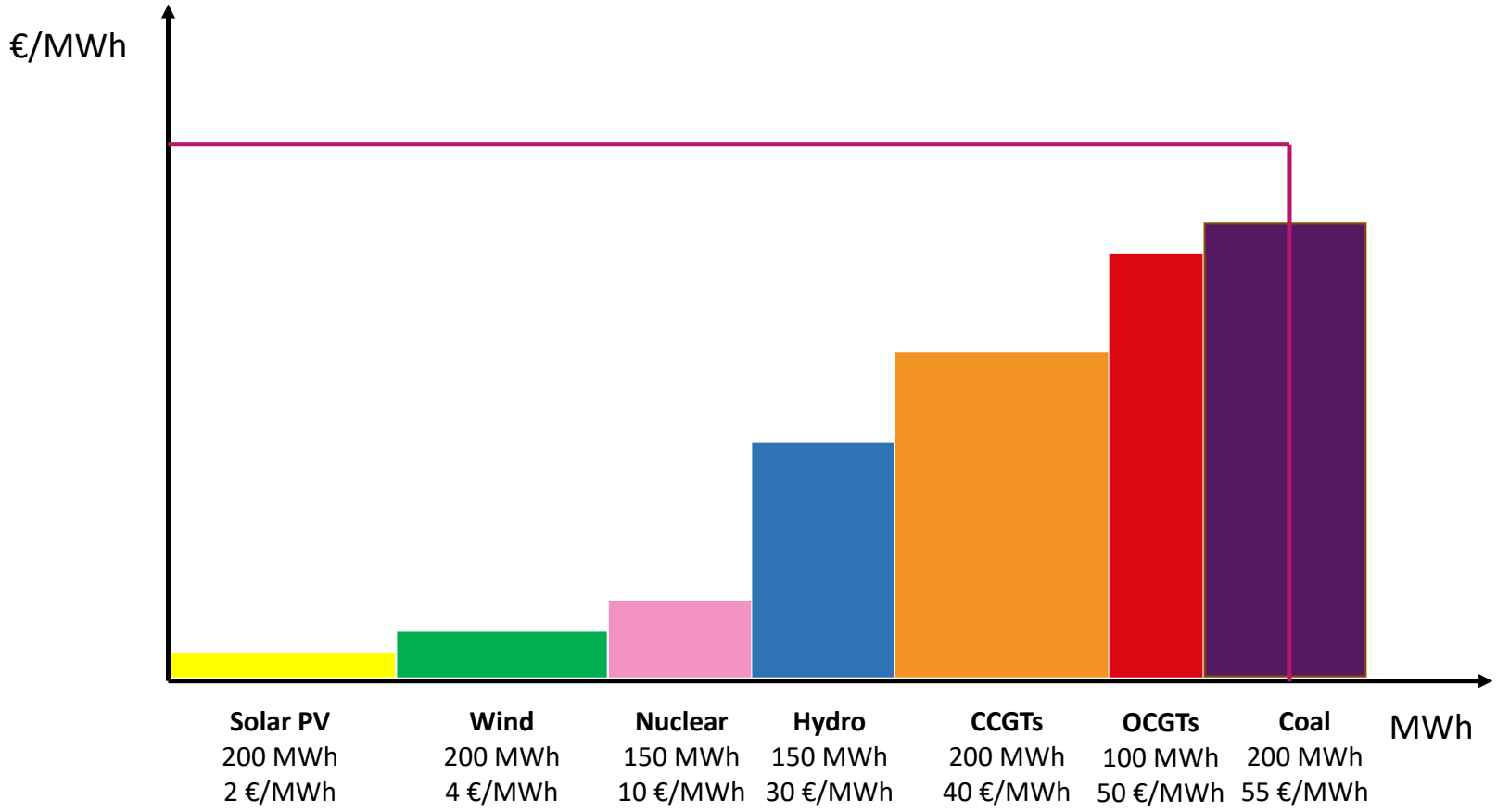




Coal and gas-fired units internalise the CO2 price when establishing their bids. As a consequence the merit order is impacted by the CO2 price (coal-gas switch)

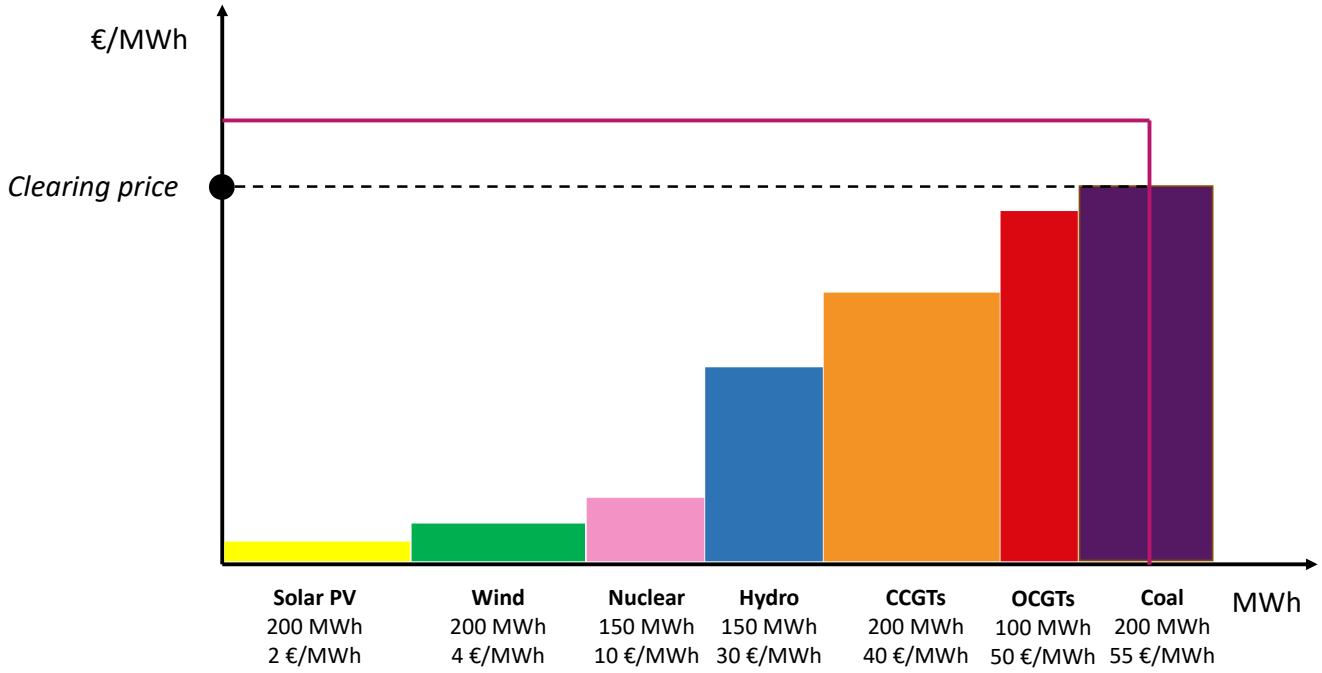
Market clearing in the case of an inelastic demand

When putting both pieces together, we obtain the following situation



Market clearing in the case of an inelastic demand

In this case, the clearing price is set by the marginal cost of a coal power plant: 55€/MWh



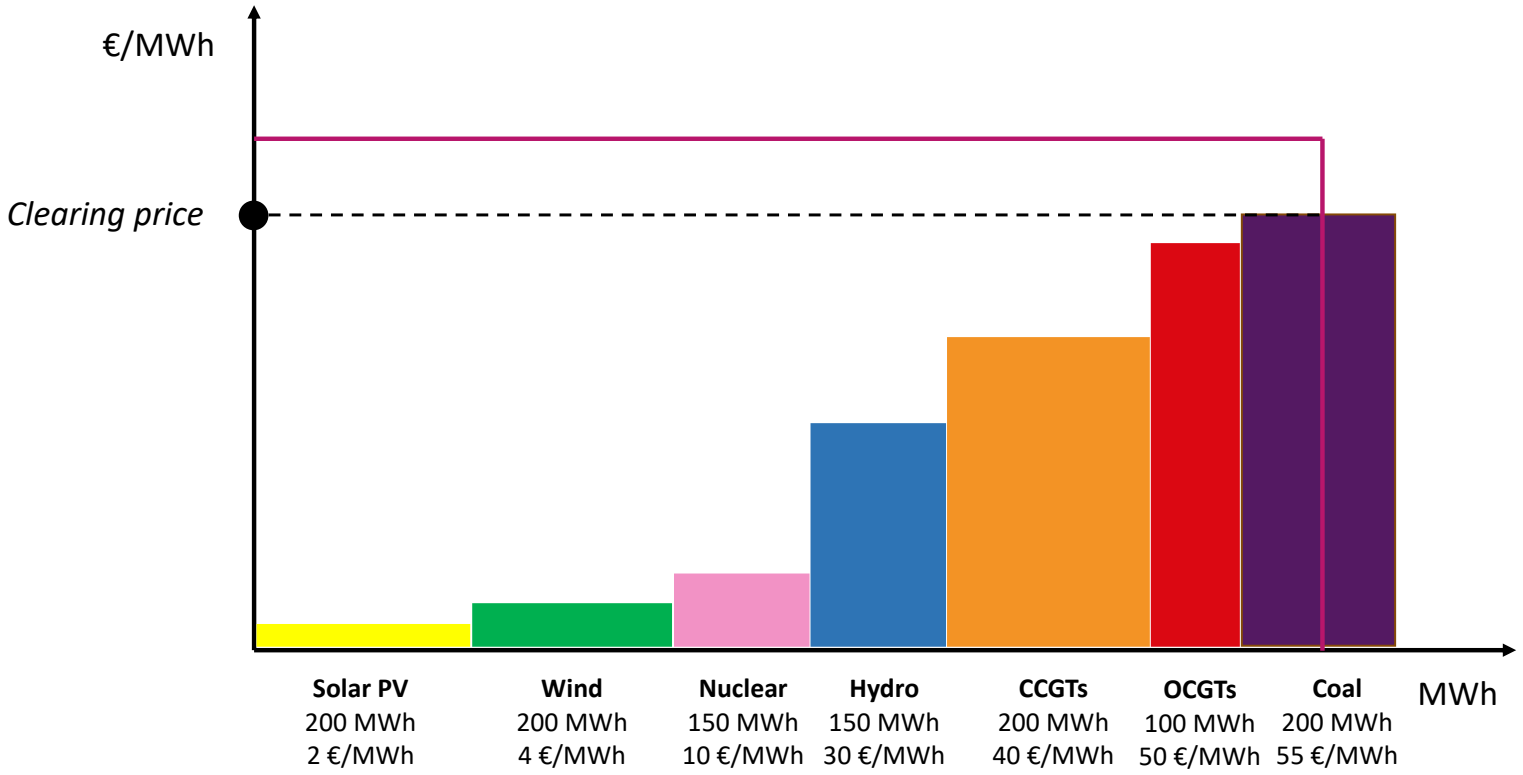
The clearing price, defined as the marginal cost, can be found by considering the following question:

"What would be the additional cost (in €) to meet a demand that is 1 MWh higher?"

In this case, an additional MWh would have to be supplied by a coal unit, therefore the price is 55€/MWh.

Quiz question 1

What would be the clearing price in case the demand reaches 800 MWh instead of 1100 MWh?



a) 55 €/MWh

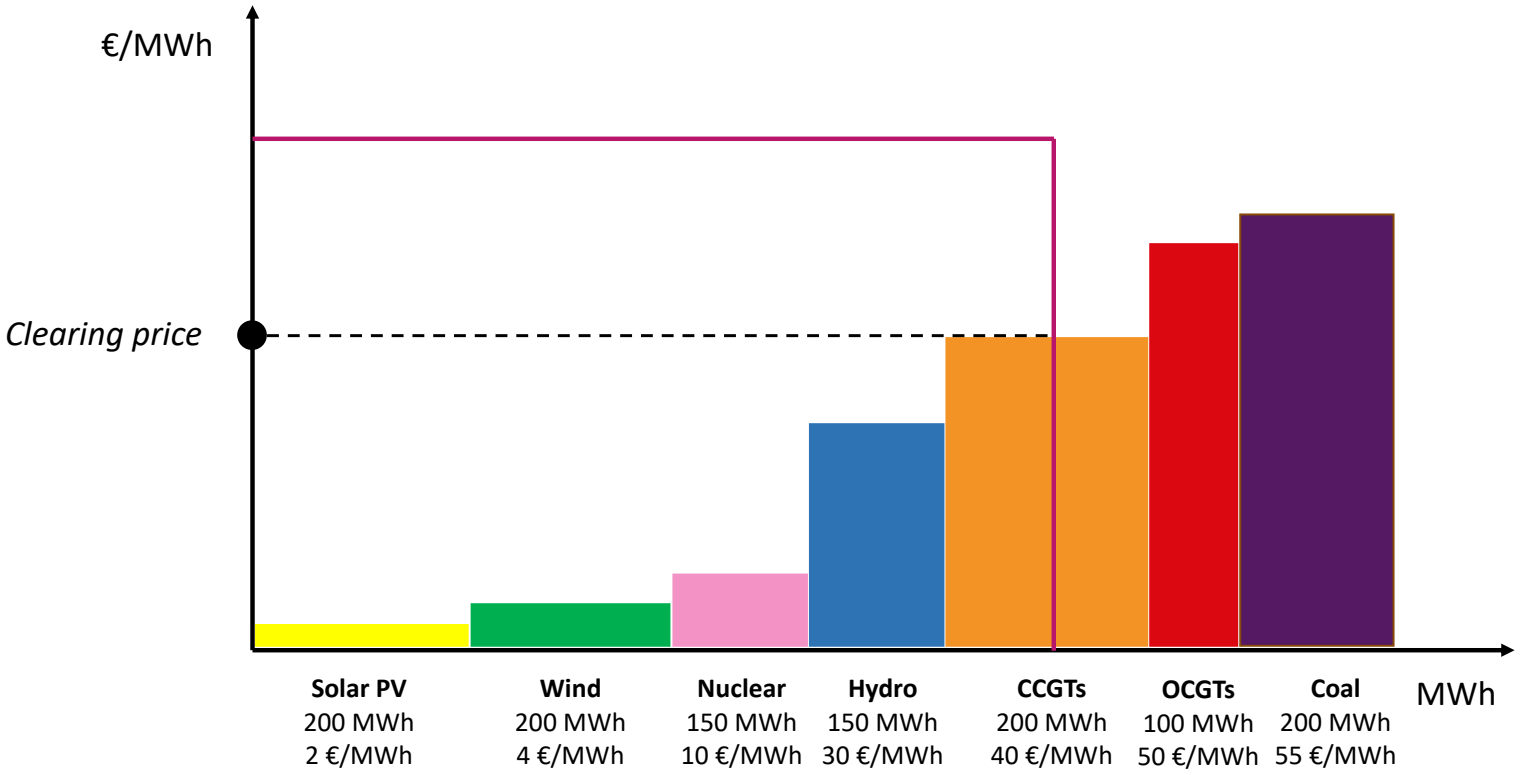
b) More than 55 €/MWh

c) 40 €/MWh

d) 15 €/MWh

Quiz question 1 - Answer

What would be the clearing price in case the demand reaches 800 MWh instead of 1100 MWh?



a) 55 €/MWh

b) More than 55 €/MWh

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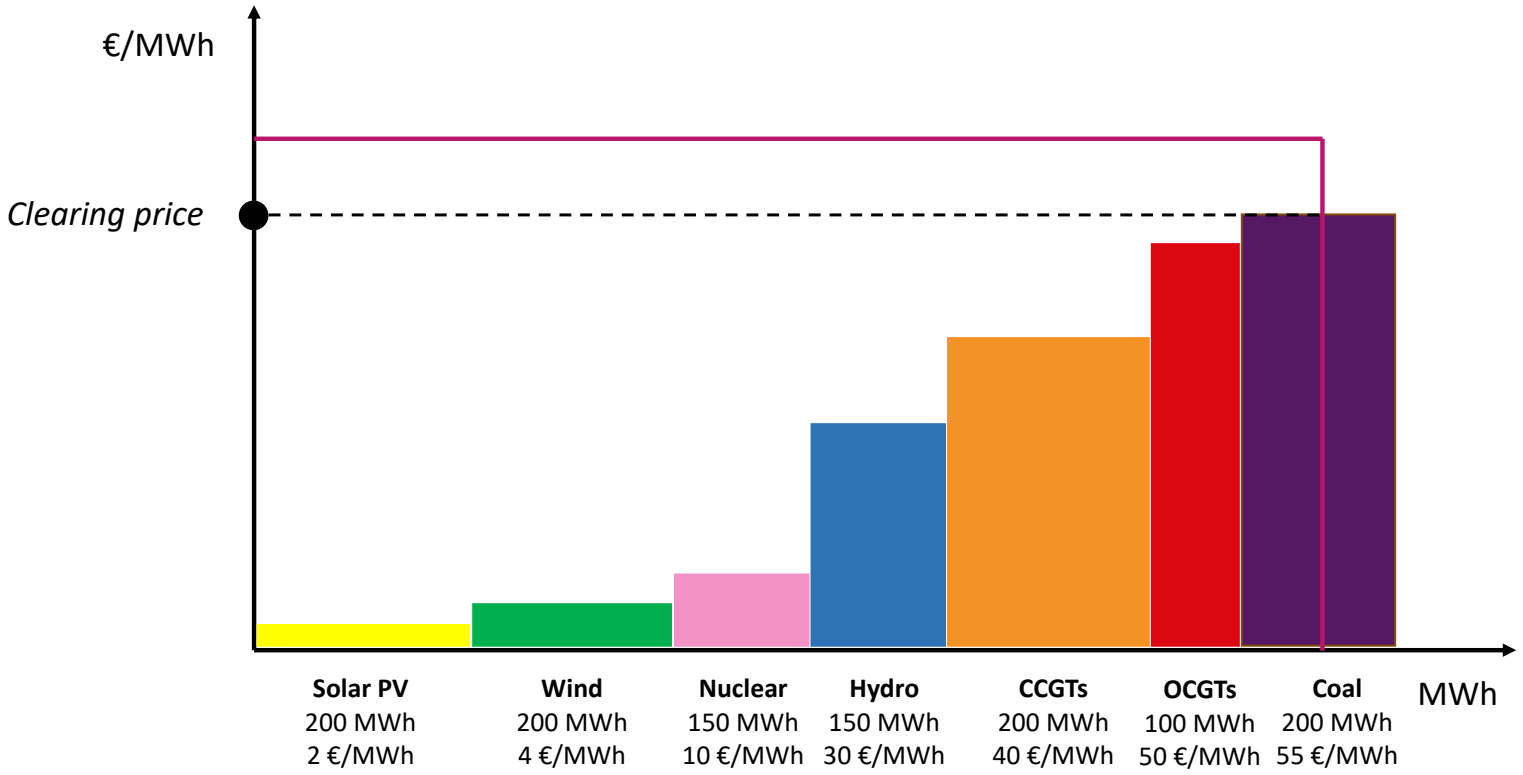
d) 15 €/MWh

Quiz question 2

What is the producer surplus (aka inframarginal rent) of the selected coal units in the situation depicted below?



a) 55 €/MWh

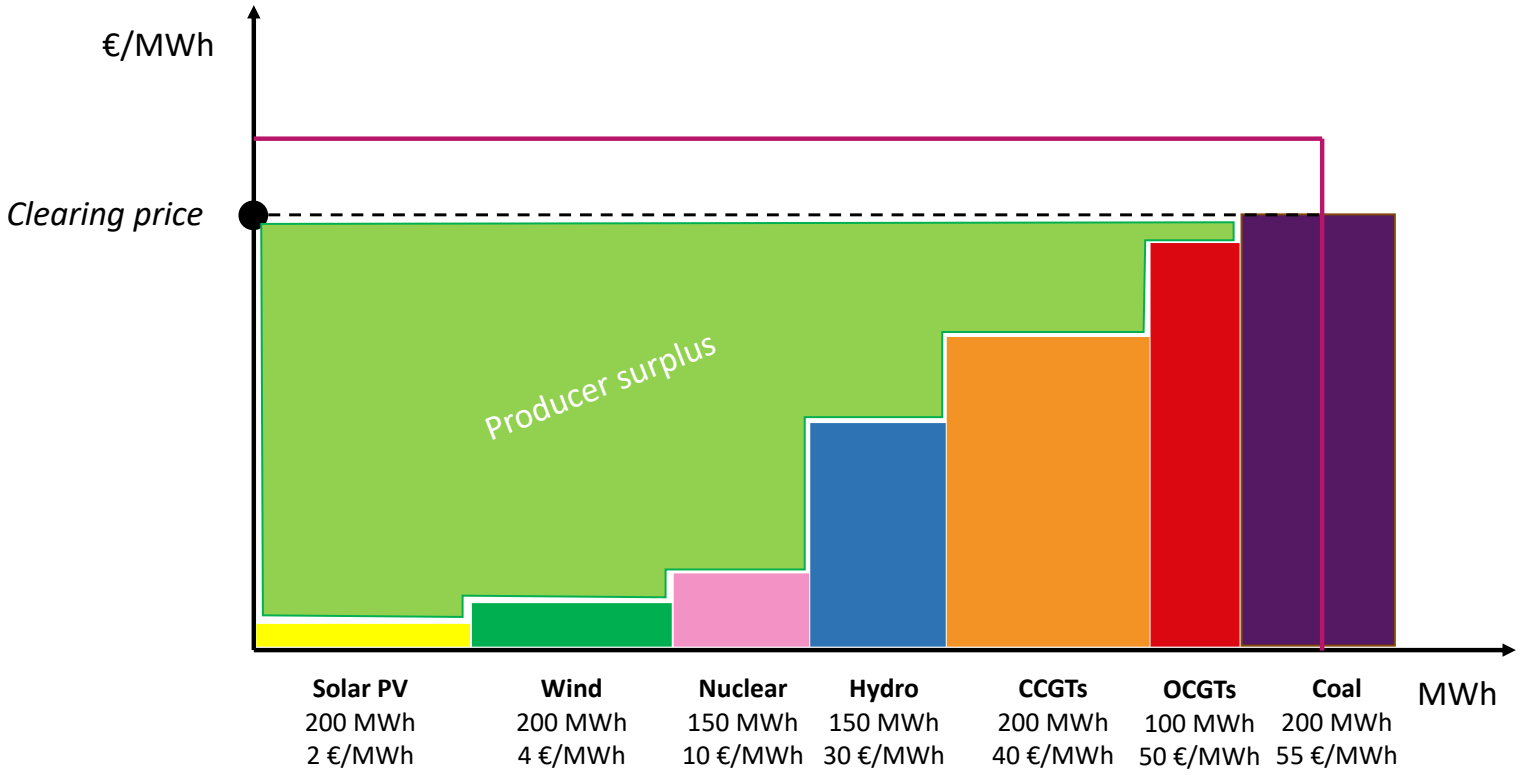
b) 0 €/MWh

c) 5 €/MWh

d) 50 €/MWh

Quiz question 2 - Answer

What is the producer surplus (aka inframarginal rent) of the selected coal units in the situation depicted below?



a) 55 €/MWh

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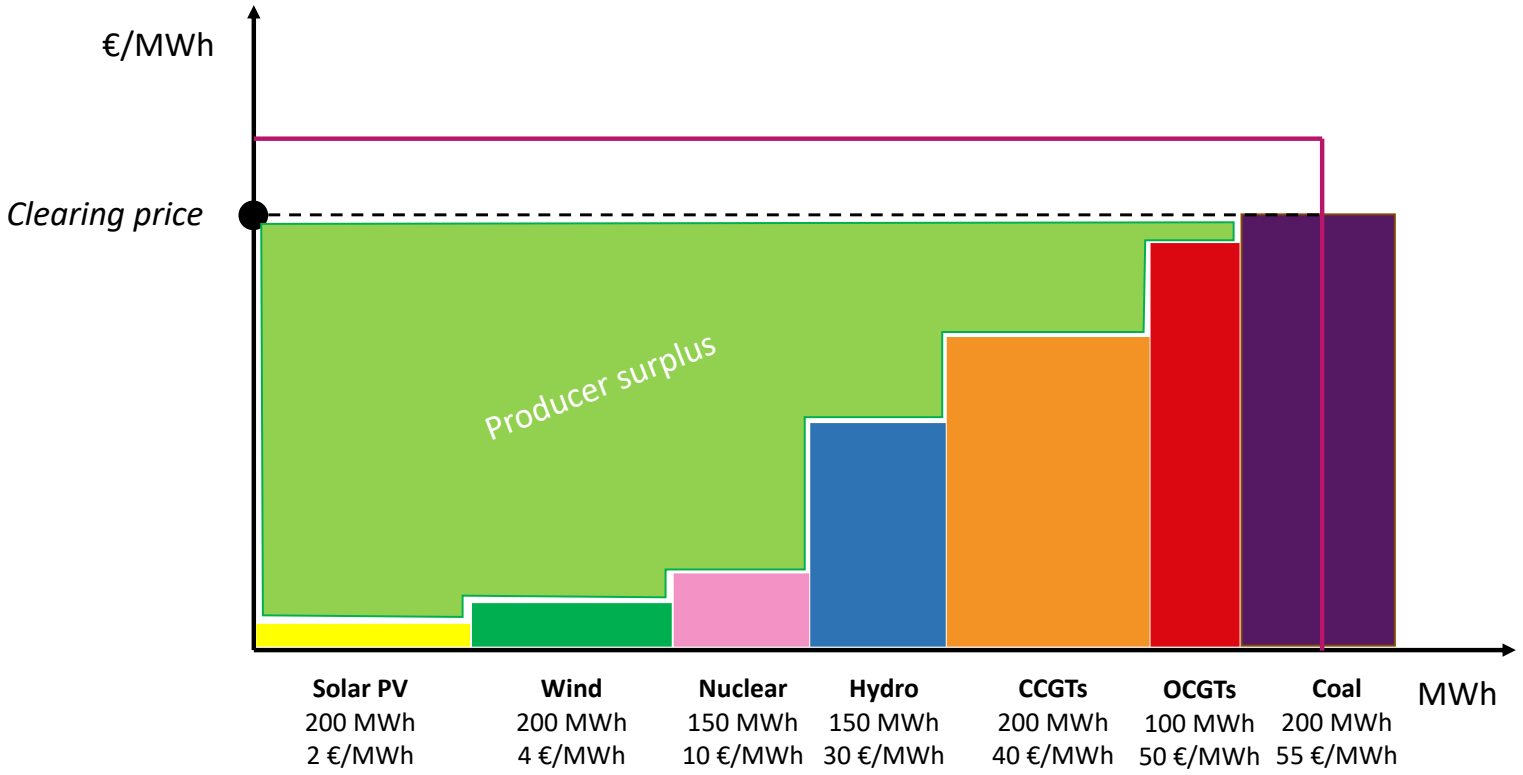
Quiz question 2 - Comment

What is the producer surplus (aka inframarginal rent) of the selected coal units in the situation depicted below?



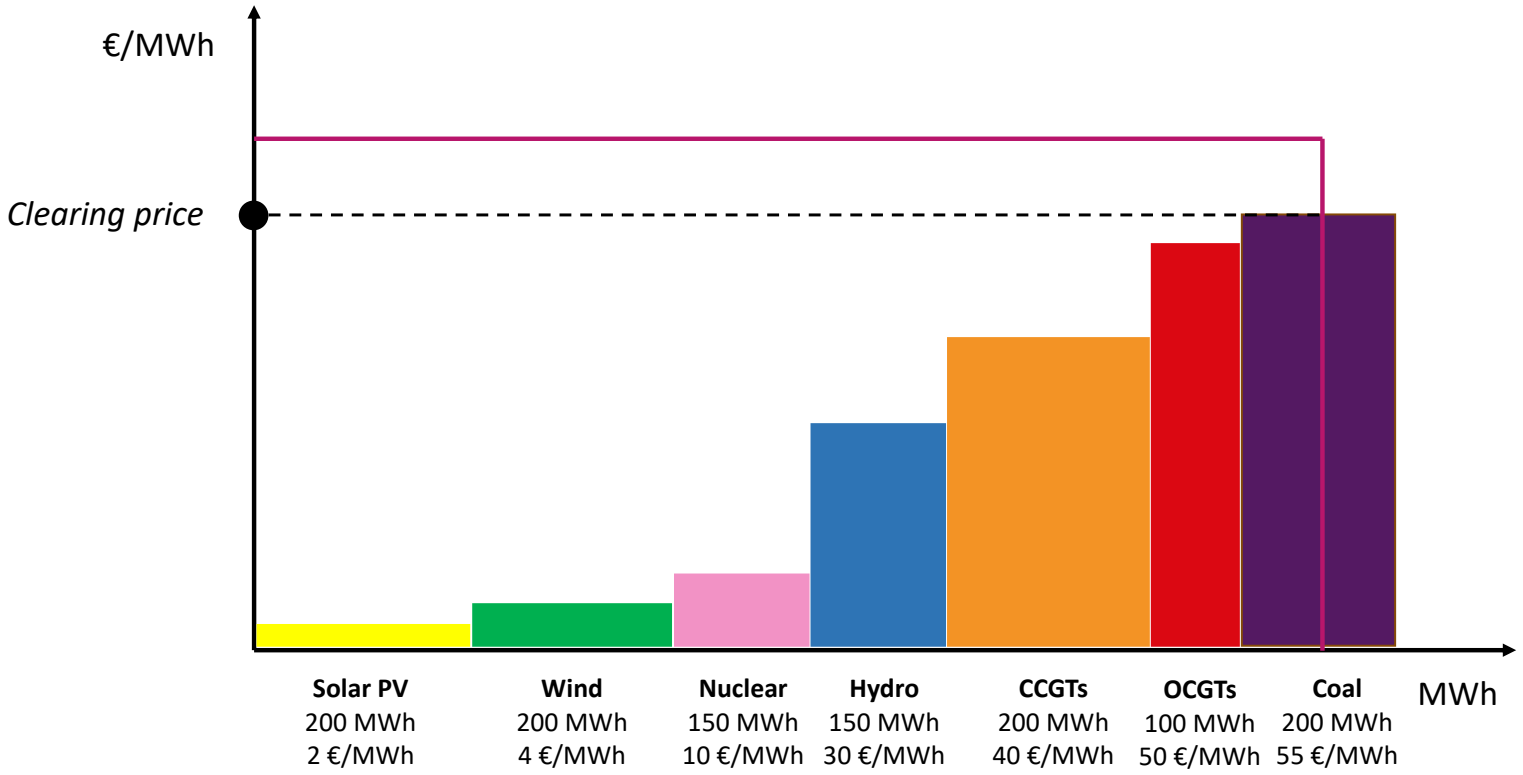
Missing money problem

As the revenues of units with very high variable costs rarely exceed their variable costs (typical level of bids), units devoted to flexibility may not fully recover their costs via an Energy-Only Market.

Several solutions can be engineered: higher price caps, capacity markets, ORDCs, etc.

Quiz question 3

What happens to the clearing price if solar PV and wind power double their outputs compared to the situation below?



a) 40 €/MWh

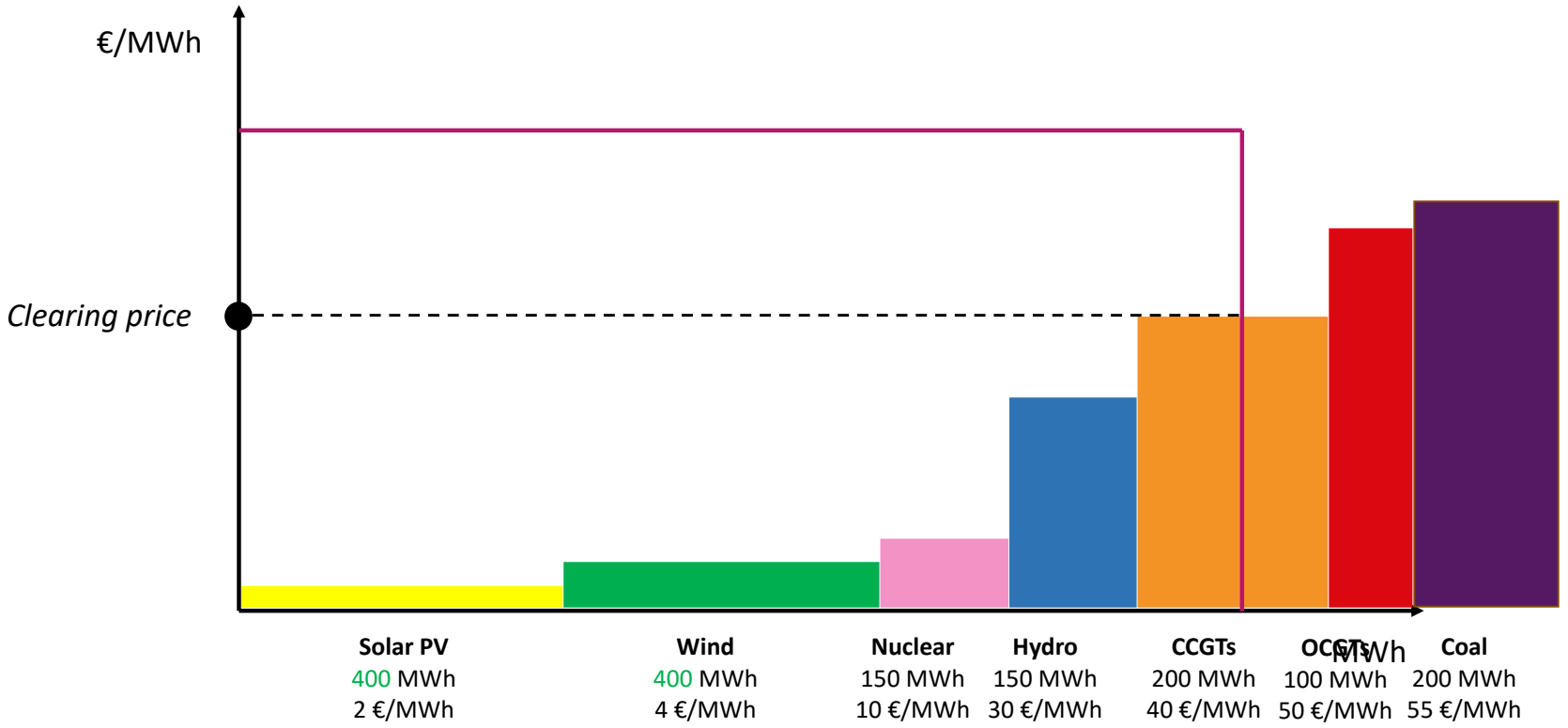
b) 0 €/MWh

c) 60 €/MWh

d) 30 €/MWh

Quiz question 3 - Answer

What is the producer surplus (aka inframarginal rent) of the selected coal units in the situation depicted below?



a) 40 €/MWh

b) 0 €/MWh

c) 60 €/MWh

d) 30 €/MWh

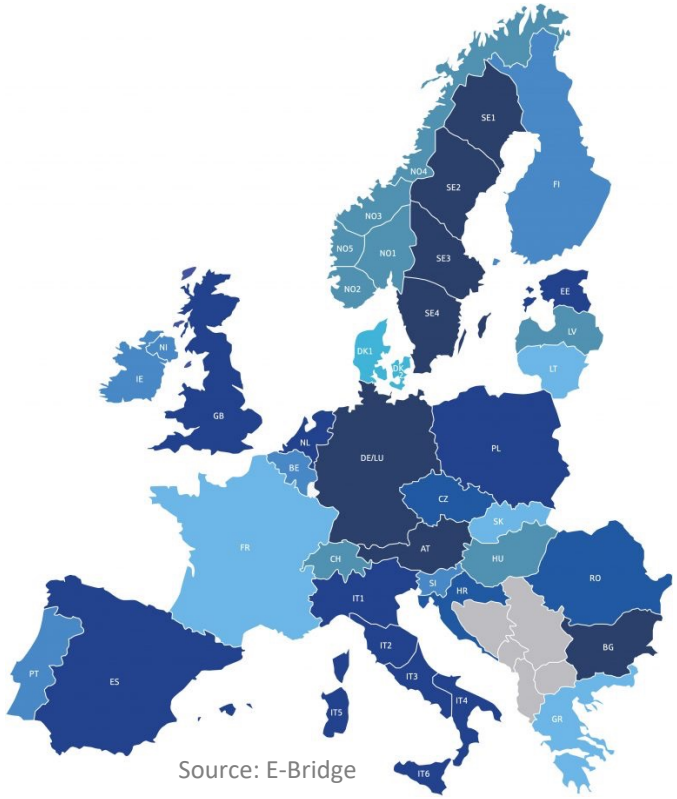
Market coupling

The situations described in the examples so far apply to a system with a single market zone. How does it extend to the case of multiple bidding zones?

Market Coupling

When markets are coupled, a single algorithm is used to jointly clear the market in several bidding zones, taking into account the cross-zonal transmission capacities.

In the day-ahead timeframe, all interconnected EU+NO bidding zones are jointly cleared.



Source: E-Bridge

How does market coupling impact prices?

Country A
Demand = 10 MWh
Generation capacity 40 MWh @ 40 €/MWh

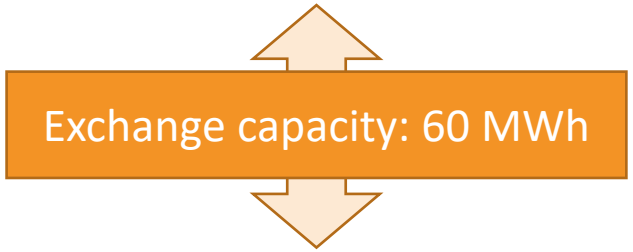
Country B
Demand = 45 MWh
Generation capacity 20 MWh @ 150 €/MWh

How does market coupling impact prices?

Country A

Demand = 10 MWh

Generation capacity
40 MWh @ 40 €/MWh

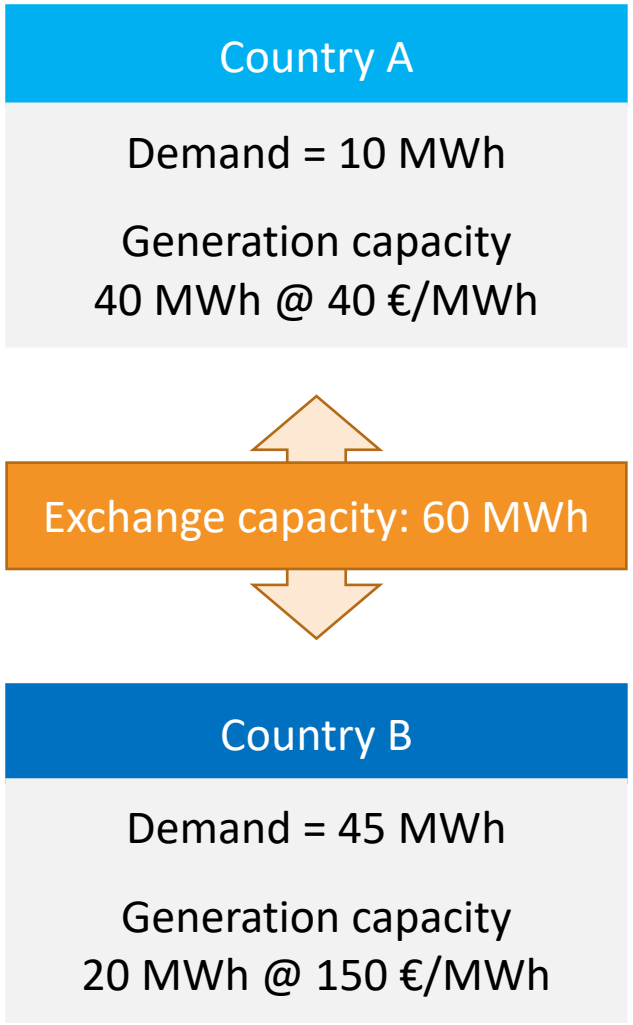


Country B

Demand = 45 MWh

Generation capacity
20 MWh @ 150 €/MWh

How does market coupling impact prices?



Market outcome

Production of 40 MWh in Country A

Transfer of 30 MWh from Country A to County B

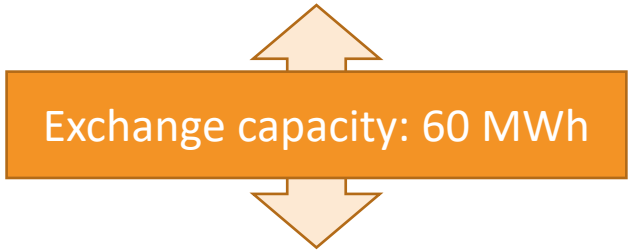
Production of 15 MWh in Country B

How does market coupling impact prices?

Country A

Demand = 10 MWh

Generation capacity
40 MWh @ 40 €/MWh



Country B

Demand = 45 MWh

Generation capacity
20 MWh @ 150 €/MWh

Market outcome

Production of 40 MWh in Country A

Transfer of 30 MWh from Country A to County B

Production of 15 MWh in Country B

What are the resulting market prices?

We need to consider the following question for each country:

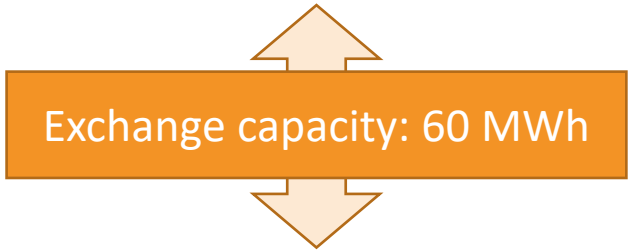
"What would be the additional cost (in €) to meet a demand that is 1 MWh higher in the considered country?"

How does market coupling impact prices?

Country A

Demand = 10 MWh

Generation capacity
40 MWh @ 40 €/MWh



Country B

Demand = 45 MWh

Generation capacity
20 MWh @ 150 €/MWh

Market outcome

Production of 40 MWh
in Country A

Transfer of 30 MWh
from Country A
to County B

Production of 15 MWh
in Country B

What is the price in Country B?

Demand in B increases to **46** MWh

The solution is to produce 1 additional MWh
in Country B.

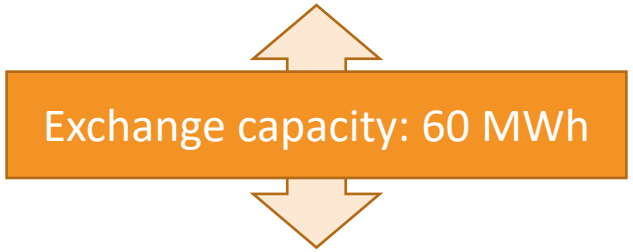
Price in B = 150 €/MWh

How does market coupling impact prices?

Country A

Demand = 10 MWh

Generation capacity
40 MWh @ 40 €/MWh



Country B

Demand = 45 MWh

Generation capacity
20 MWh @ 150 €/MWh

Market outcome

Production of 40 MWh in Country A

Transfer of 30 MWh from Country A to County B

Production of 15 MWh in Country B

What is the price in Country A?

Demand in A increases to **11** MWh

The solution is to reduce exports by 1 MWh, requiring an additional MWh to be produced in Country B.

Price in A = 150 €/MWh

What is the price in Country B?

Demand in B increases to **46** MWh

The solution is to produce 1 additional MWh in Country B.

Price in B = 150 €/MWh

Effects of the propagation of market prices

Impact of market coupling

As market prices have been shown to propagate in the absence of congestions, it is not because one country uses cheap resources that its electricity prices are mecanically low.

However, this means that the inframarginal rent in these countries are high, allowing investments to recover their fixed costs.

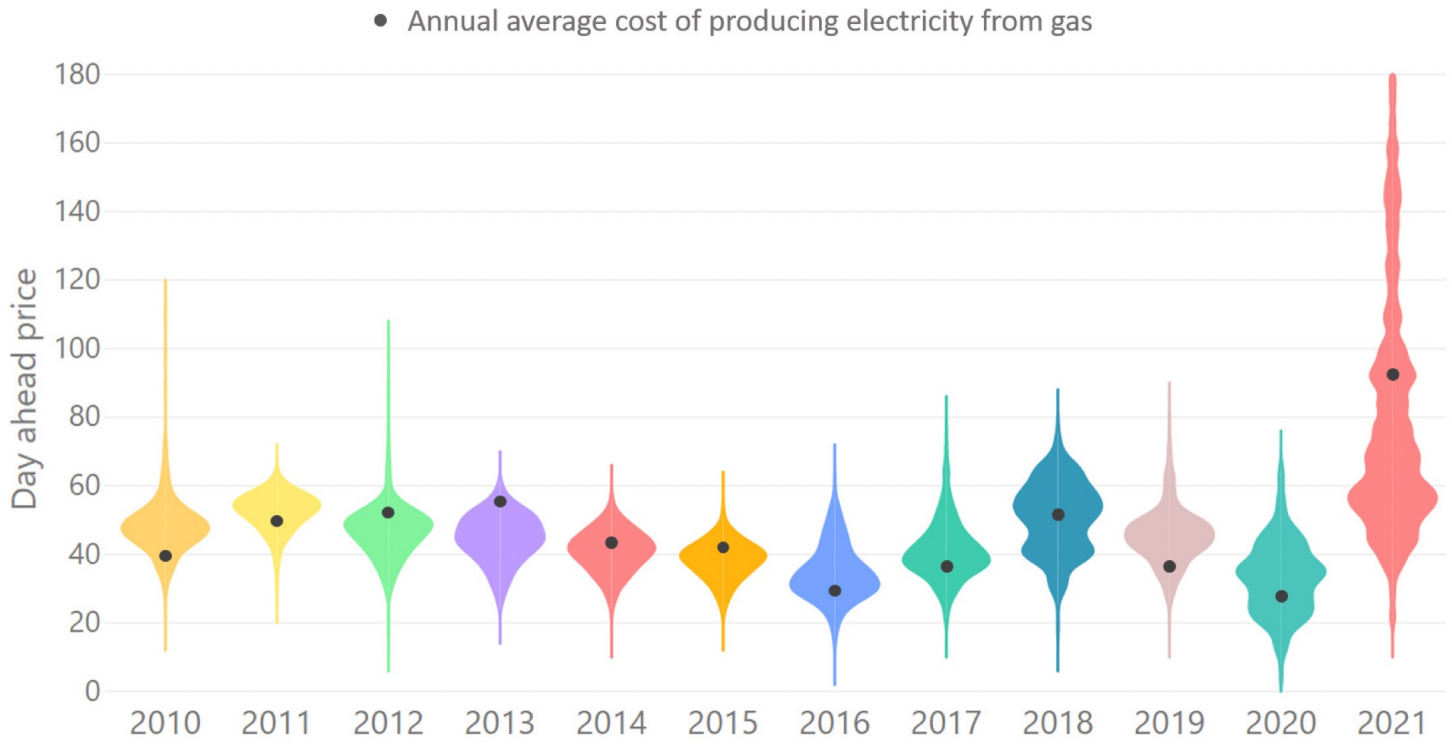
What is the link between gas and electricity prices?

During the energy crisis, some have mentioned that the link between gas and electricity prices is “structural”. What does it mean?

1. Higher gas prices translate into more expensive bids by gas-fired units
2. Even in systems with a relatively high RES deployment, gas-fired units are providing crucial flexibility services, leading to these units frequently being the marginal ones (in a system with 50% RES, the marginality of gas-fired units can occur more than 50% of the time)
3. On top of this, electricity prices propagate, leading to prices set by gas units in numerous countries

What is the link between gas and electricity prices?

Figure 1: Electricity day-ahead prices distribution compared to the cost of producing electricity with gas in Europe (2010–2021) (EUR/MWh)



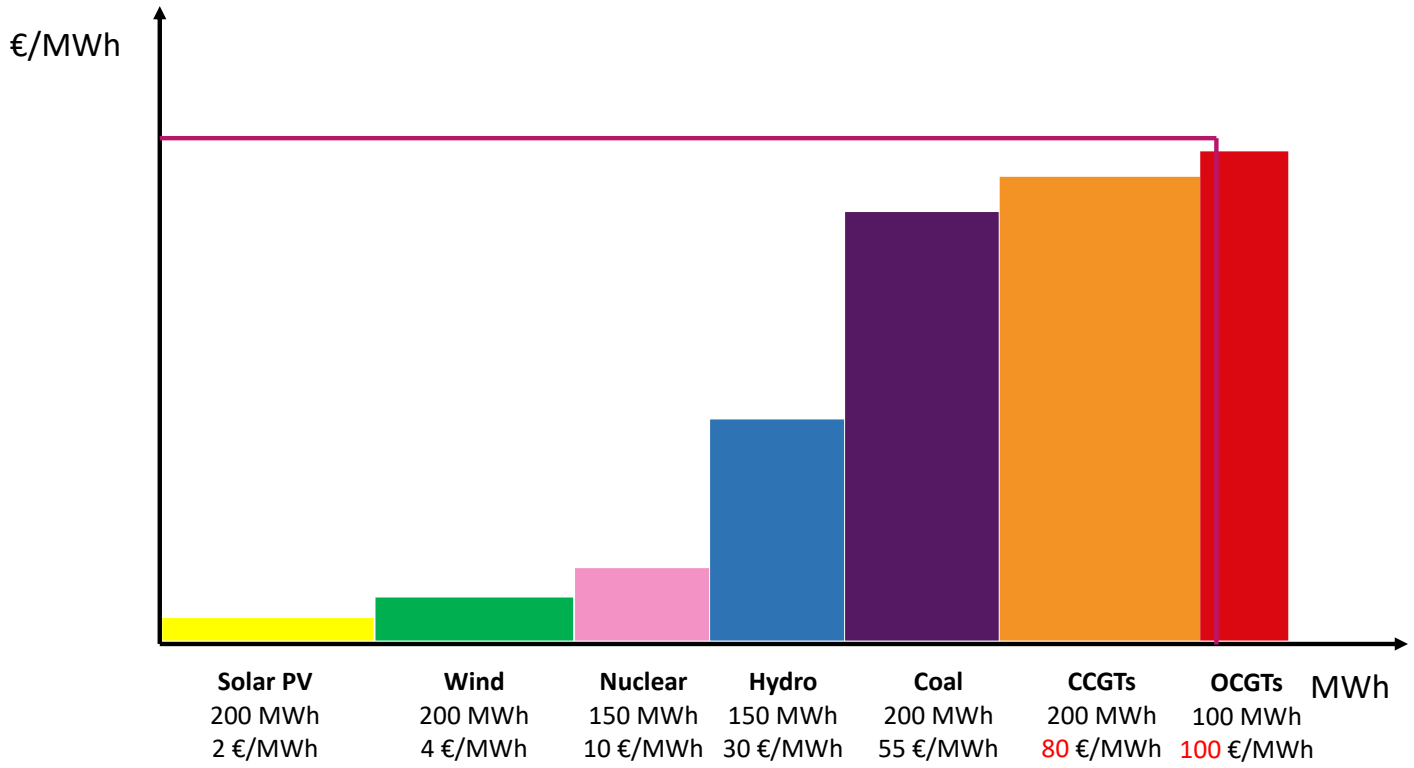
Source: ACER calculations based on ENTSO-E and Platts data

The level of gas price is an important driver of electricity prices

The frequent marginality of gas-fired units is due to the provision of flexibilty services by these assets. As a consequence gas price movements heavily impact electricity prices (in both directions).

The anchorage of electricity prices to gas prices may change with a further deployment of RES, and the competition from other sources of flexibility (from electric vehicles to interconnectors).

The gas infrastructure is a crucial enabler of G2P

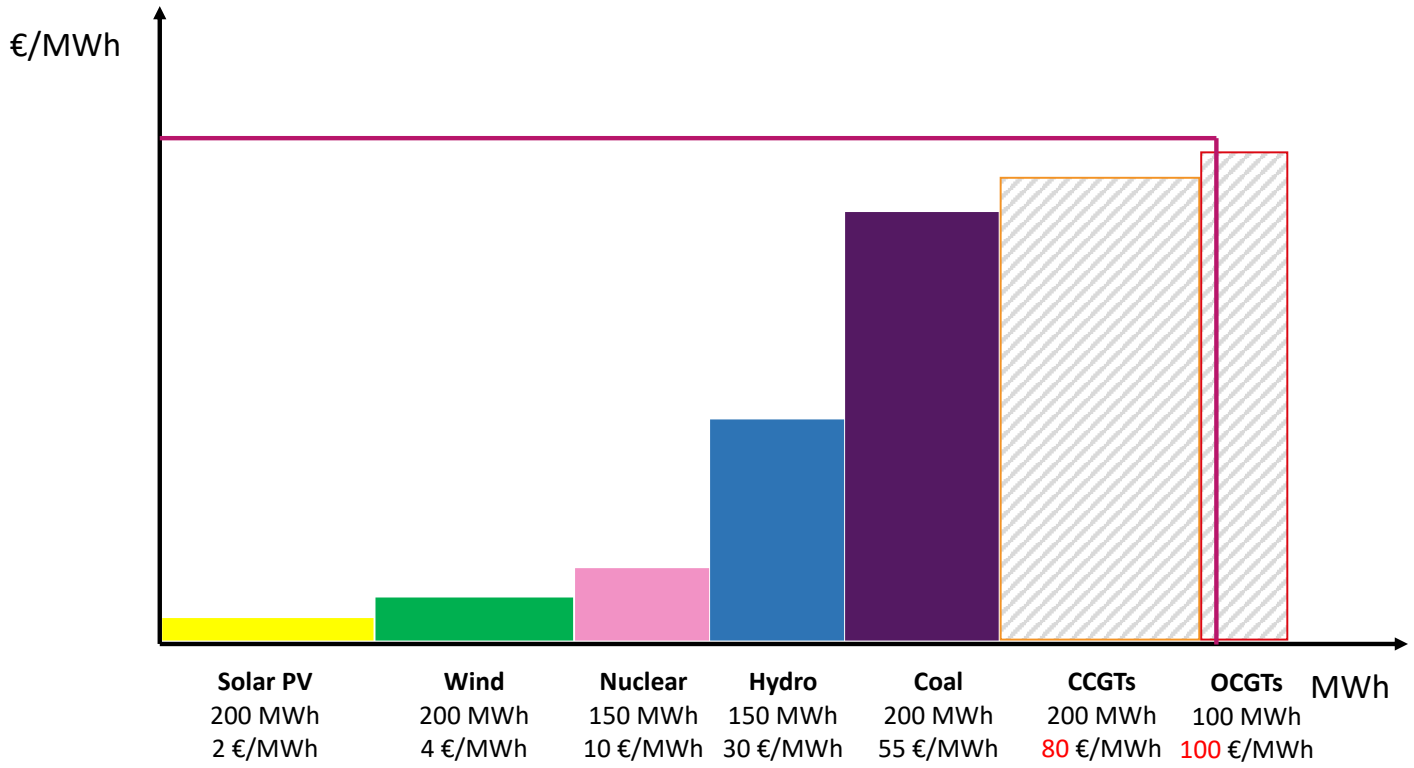


The current energy crisis results in high levels of revenues for gas-fired assets, with different levels of ”profits” depending on their hedging approach.

However, gas-fired assets can only generate electricity if the gas infrastructure is available (capacity) and that gas is available (energy). Without sufficient amounts of stored gas, security of supply issues can materialise.

The remuneration of the infrastructure that enables the provision of flexibility services by gas assets is therefore an essential question!

The gas infrastructure is a crucial enabler of G2P



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Artelys study on cross-sectoral value of gas storage

Value of the gas storage infrastructure for the electricity system

In this study, Artelys proposes a methodology to evaluate the benefits brought by gas storage assets from a cross-sectoral point of view, recognising the crucial enabling role of gas storage assets.

More about it during the panel discussion ☺

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