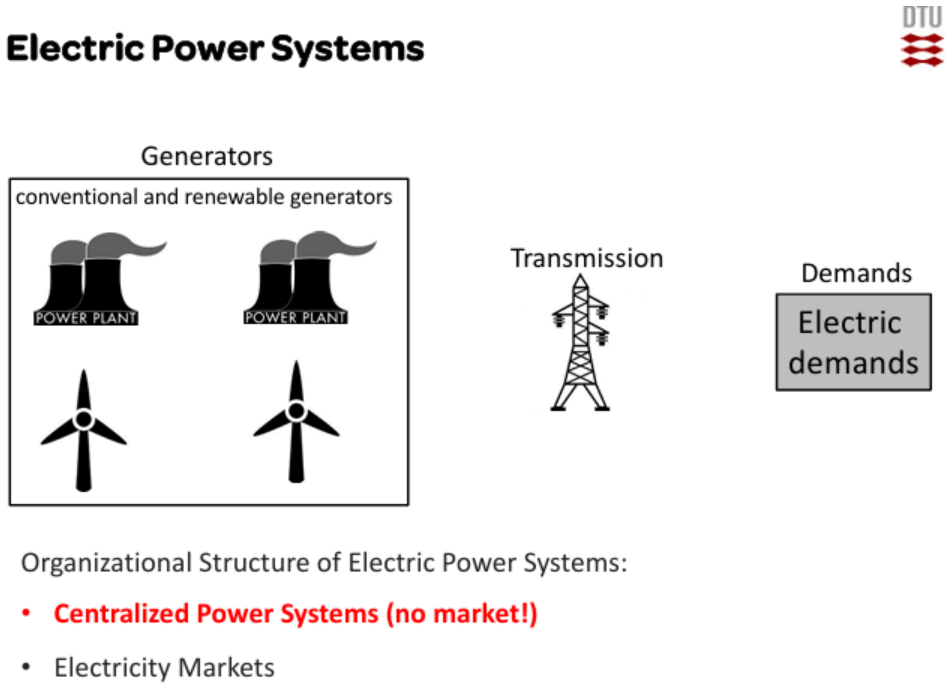
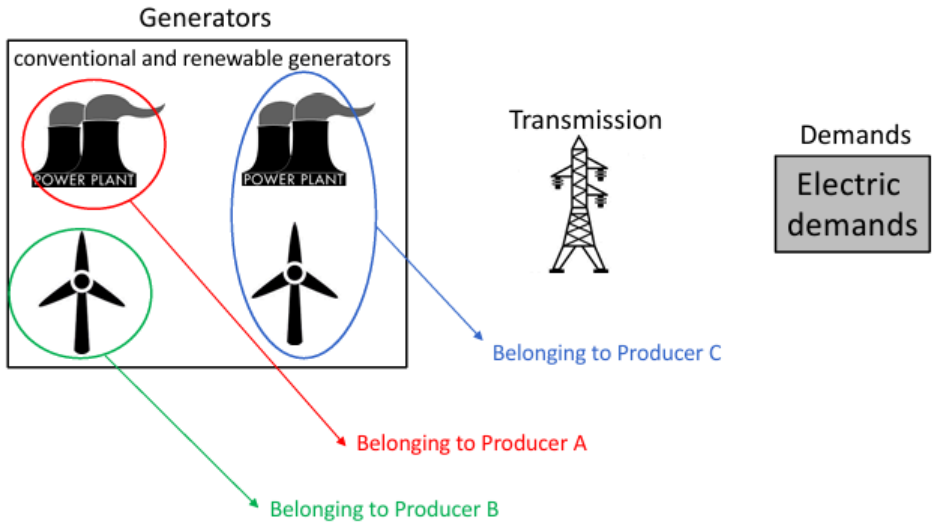
Lecture 1 _ Introduction to electricity markets



Electric power systems include: generators (producers) + tranmission system + Demands

- Centralised power system (no market): A single entity, such as the system operator, is responsible for making all **operational** and **planning** decisions (e.g: tranmission line planning example) for the entire power system.
  - Goal of system operator when making operational + planning decisions: To meet the entire demand by dispatching power generators across the network in a **feasible** and **cost-effective** manner.
  - Example in Denmark: independent state-owned company that owns and operates Danish energy infrastructure.
  - Example about security: n-1 problem. If 1 generator outs -> can we sastify the demand or not
- Electricity market



- Now every power plant is belongs to different producer
  - Producers in Denmark: Vattenfall (major wind farm operator), European Energy A/S (better Energy A/s), Eurowind Energy, Orsted A/S, Eurowind Energy
  - Each producer: aims to maximise their own profit by making optimal operatiuonal and planning decisions
  - Unlike centrelised systems -> there multiple decision-makers involved

🎯 What is game theory in electricity markets?

Game theory is used when **multiple market participants make strategic decisions**, and the outcome depends on how they interact.
In electricity markets, this means:

- Generators choose **offer prices** and **quantities**
- Consumers choose **bid prices**
- Aggregators choose **flexibility strategies**
- Wind producers choose **risk-based offering strategies**
- Balancing providers choose **reserve bids**
  Each player wants to **maximize profit**, but their decisions affect the market price and each other.
  This is a **game**.

Electricity Markets

How can an electricity market be operated where each market participant (e.g., generators) makes their own profit-maximizing decisions?

For clarity, let us consider an apple market!

Market

Assume there is an apple market with multiple sellers and buyers:

Sellers:

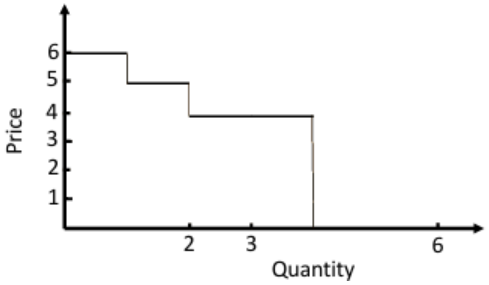
- Seller A sells 2 apples at a price of $1 each.
- Seller B sells 1 apple at a price of $2.
- Seller C sells 3 apples at a price of $3 each.

Supply curve:
a non-decreasing curve where sellers are ranked based on the least-cost "merit order principle"!

Assume there is an apple market with multiple sellers and buyers:

Buyers:

- Buyer A buys 1 apple at a price of $6.
- Buyer B buys 1 apple at a price of $5.
- Buyer C buys 2 apples at a price of $4 each.

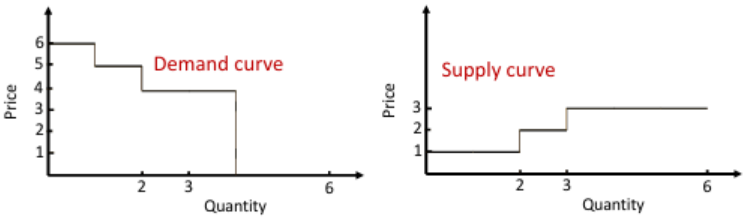


3 sellers and 3 buyers

Utility: **Utility = how much satisfaction or benefit someone gets from buying something.** Super short, with the apple example.

🍎 Example

- Buyer A pays **$6** for 1 apple → their **utility is high** (they really want it).
- Buyer C pays **$4** for each apple → their **utility is lower** (they want apples, but not as much).

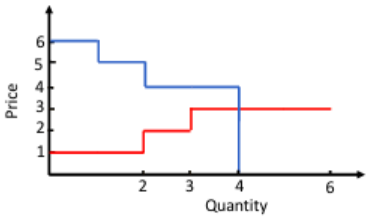


Now that we have both supply and demand curves, let's determine their intersection!

DTU Wind, Technical University of Denmark Jalal Kazempour

Market

Supply-demand curve



This is known as the "**market-clearing**" procedure, which is carried out by a non-profit entity, the market operator!

Market-clearing price: It is the price at which the quantity supplied = quantity demanded in the market

- **Nord Pool** → Scandinavian operator (Norway, Sweden, Finland, Denmark)

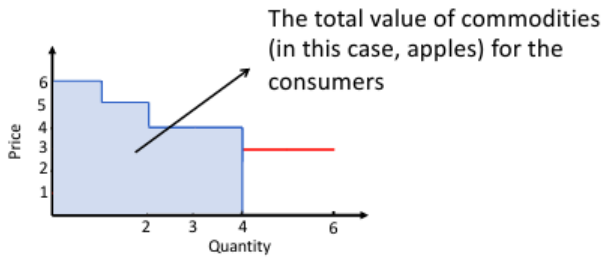
- **EPEX SPOT** → French operator that also runs markets in Denmark

> Note: Why does a French company operate in Denmark?
> Because Europe uses **market coupling**, meaning countries share:

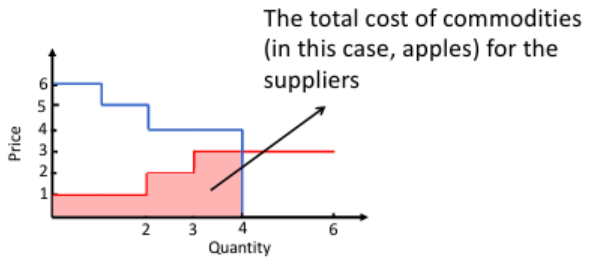
- common auction algorithms (EUPHEMIA)
- common price zones
- cross-border trading

  So multiple exchanges can operate in the same country.

Market



Market



Why does the market operator want to maximise social welfare?

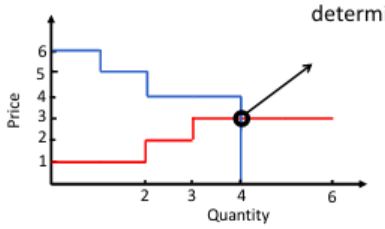
because the market operator is non-profit entity whose job is to clear the market in the way that:

- Maximises total value for consumers (their willingness to pay)
- Minimise total cost for suppliers (their offer prices)
  -> this creates the large possible gap betwen:
- What buyers are willing to pay
- What sellers are willing to accept
  -> the gap is called social welfare (or surplus)

The market operator clears the market by ***maximizing*** "social welfare", which is the area between the supply and demand curves!

- By maximizing social welfare, the total value of commodities for consumers is maximized, while the total cost for suppliers is minimized—resulting in satisfaction for both the demand and supply sides!

Equilibrium point: The point where the market-clearing **price** and **quantity** are determined.



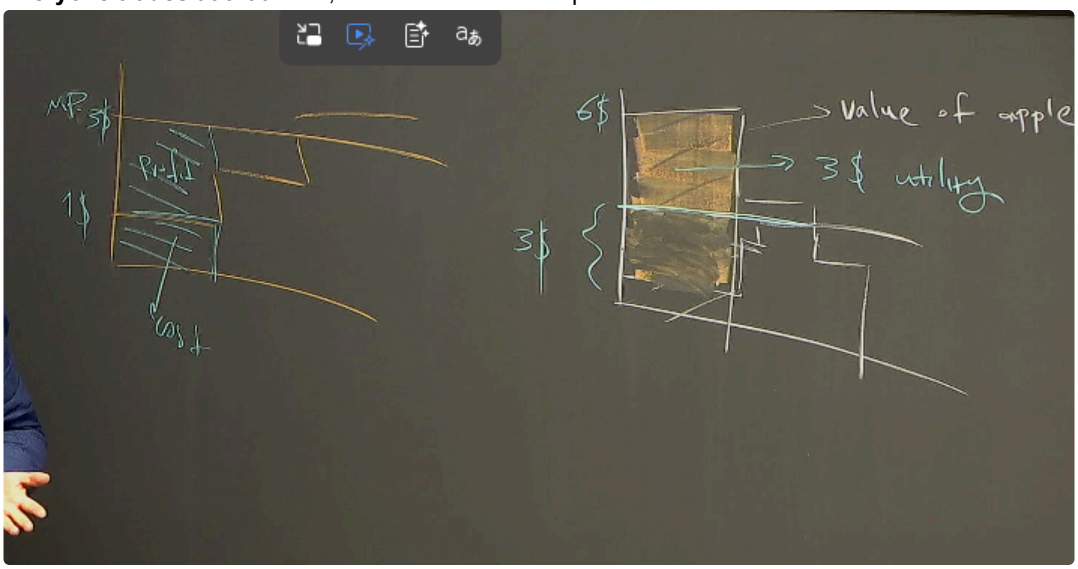
- At the equilibrium point, the social welfare is maximized.
- Based on the equilibrium point, four apples are traded at a price of $3 each (uniform pricing)!

Beautiful Mind - John Nash
Nash equilibrium point: The point is everyone okay with that

Question: Based on uniform pricing, does any buyer (or seller) necessarily pay (or receive) the price they submitted to the market?

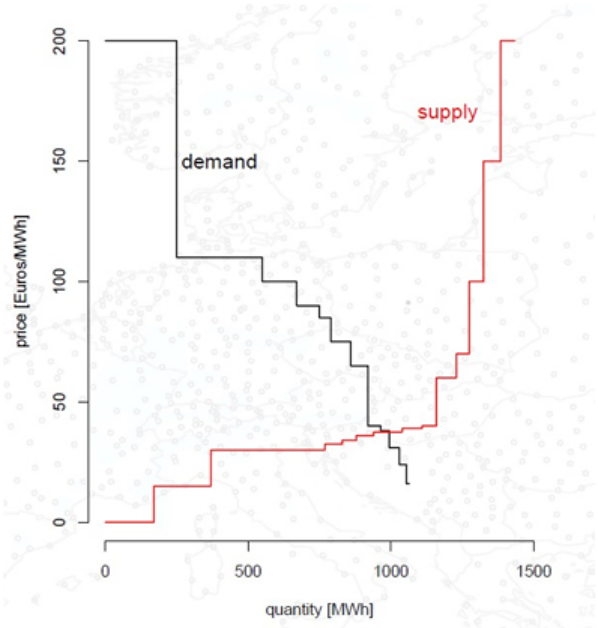
The answer is **No**: In **uniform pricing**, buyers and sellers **do NOT pay or receive the price they submitted**. They all settle at **one single price**: the **market-clearing price (MCP)**.
Uniform pricing means:

- Buyers submit **bid prices** (their willingness to pay)
- Sellers submit **offer prices** (their minimum acceptable price)
- The market operator finds the **intersection** → the MCP
- **Everyone trades at that MCP**, not at their submitted price

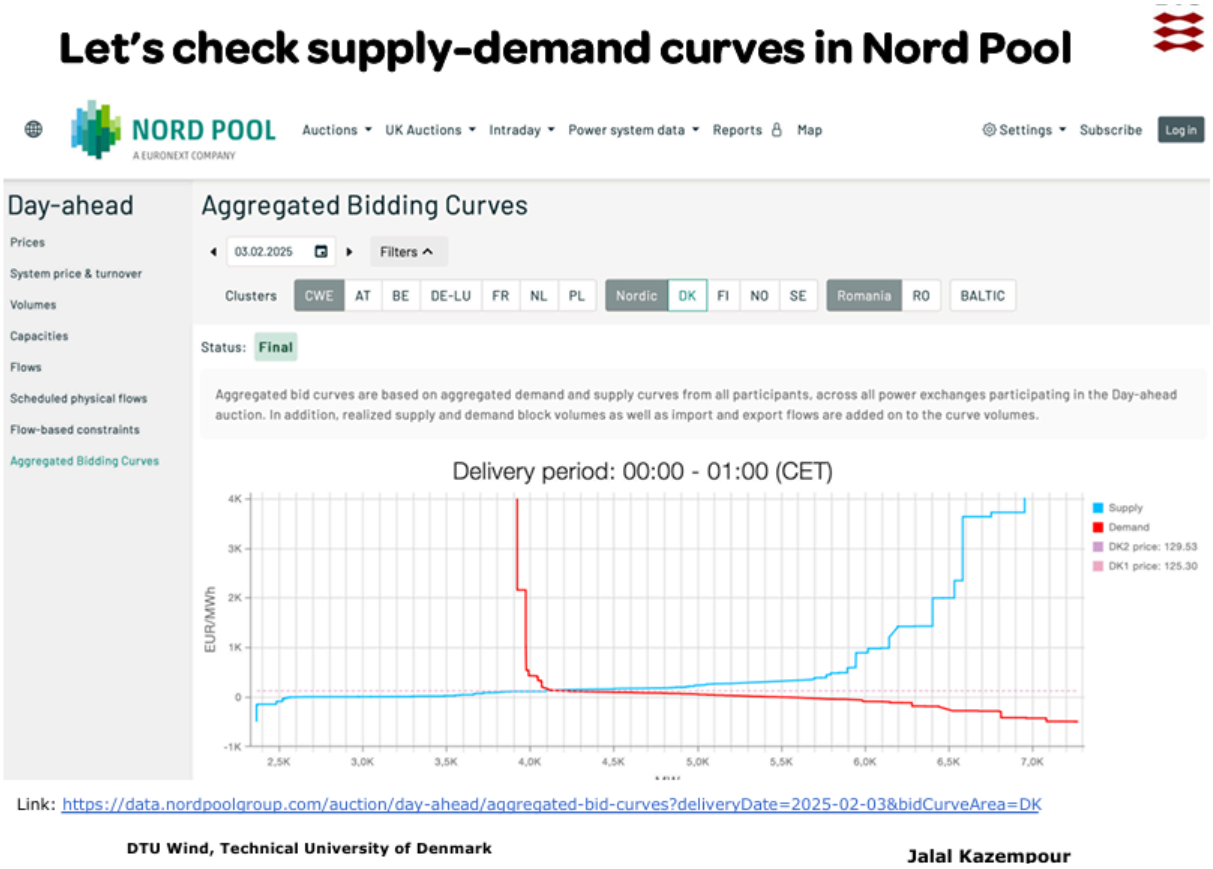


Electricity market

- Quantity: MWh
- Price: Euro/MWh or DKK/MWh



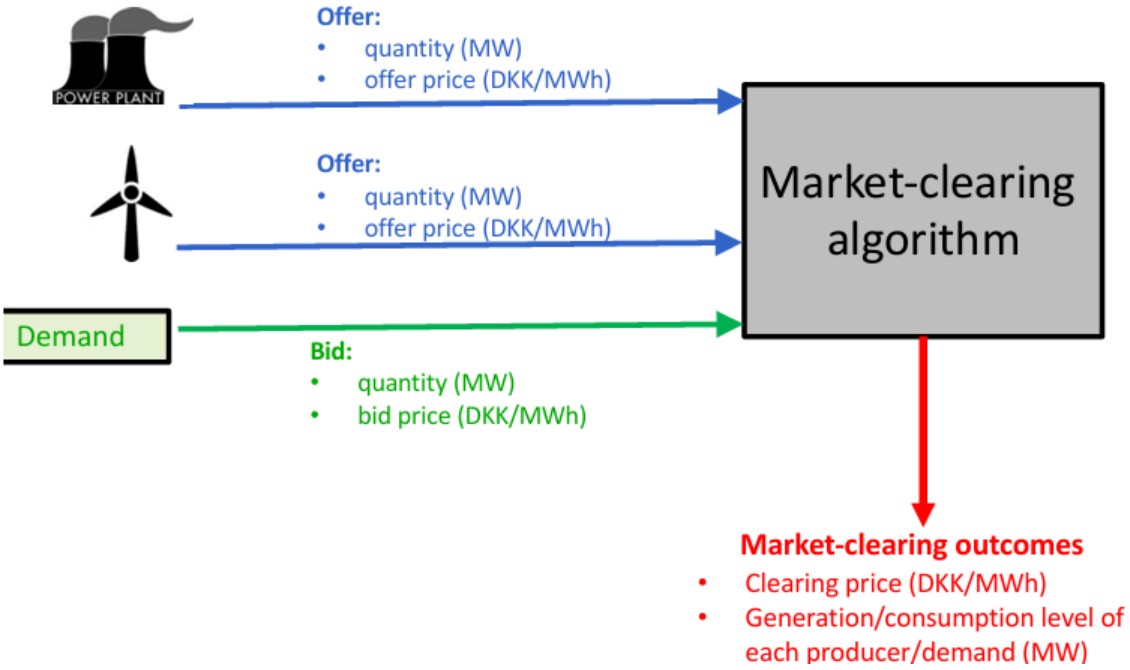
- There are some generator bidding at 0 Euros/MWh -> who are they? -> could be Renewable generator, or even negative (like -5 Euros/MWh - Tariff,)
- Bid at very high price -> who are they? Could be gas power plant -> cause the gas price is high



Discussion:
What aspect of an electricity market differentiate it ffrom markets for other commodities, such as the apple market?

- Apple can be stored, but electricity can not be stored (at very very large scale)

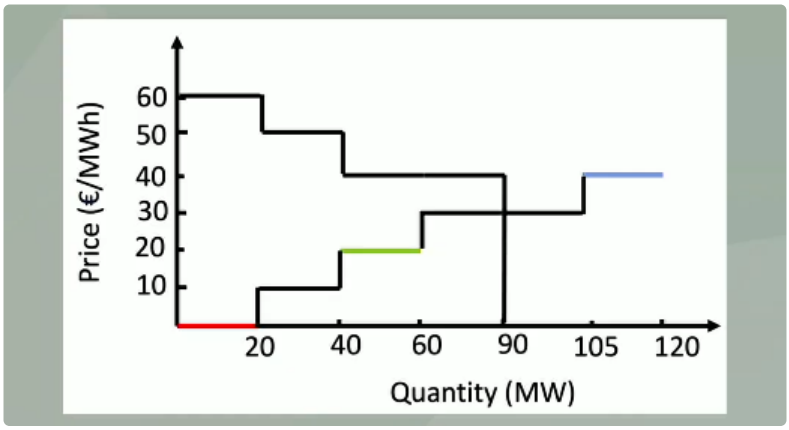
- Electricity demand is typically highly inelastic to price, though this is changing
- the electricity market-clearing algorith miuust take into accoutn the physical laws of electricity netwroks (Kirffschoff Law)



Further constraints: line constraints, mathematical programs

Kahoot:

1. What is "social welfare"?: the area between the supply and demand curves
2. At the equilibrium point, the social welare is maximised
3. Which suppliers have an accepted bid in the market?

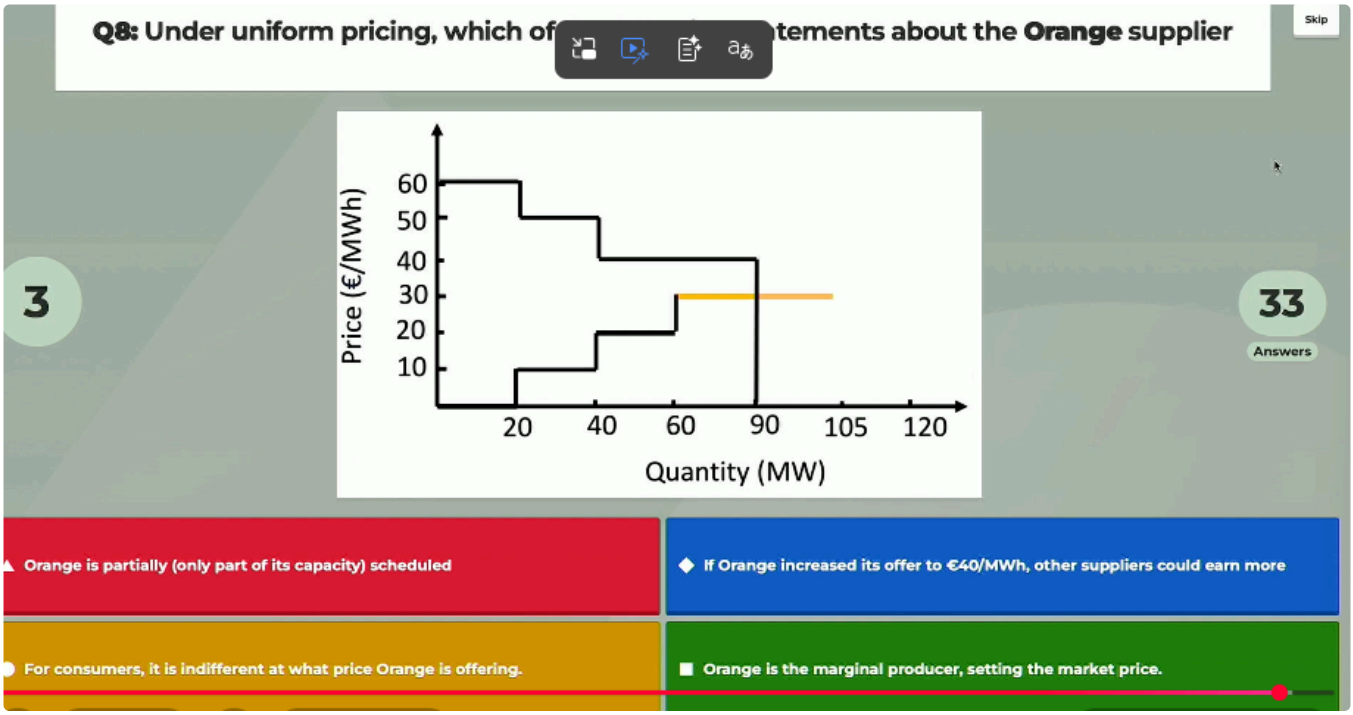


- Red + Green, Blue is outside
  3.Under uniform pricing, at what prices are the REd and Green suppliers paid, respectively? 30 and 30 -> we pay people at the same price. In **uniform pricing**, buyers and sellers **do NOT pay or receive the price they submitted**. They all settle at **one single price**: the **market-clearing price (MCP)**

1. Under uniform pricing, what is the "payment" to the green supplier? and what is tis profit (revenue minus cost)
    1. 30 Euro x 20 = 600 revenue
    2. Cost = (60 - 40) x 20 = 400
    3. Profit = 600 - 20
2. What is the social welfare?
    1. 2700 Euros = Total area under demand - generation cost
3. At what price is the green supplier paid under the uniform and pay-as-bid pricing schemes, respectively?

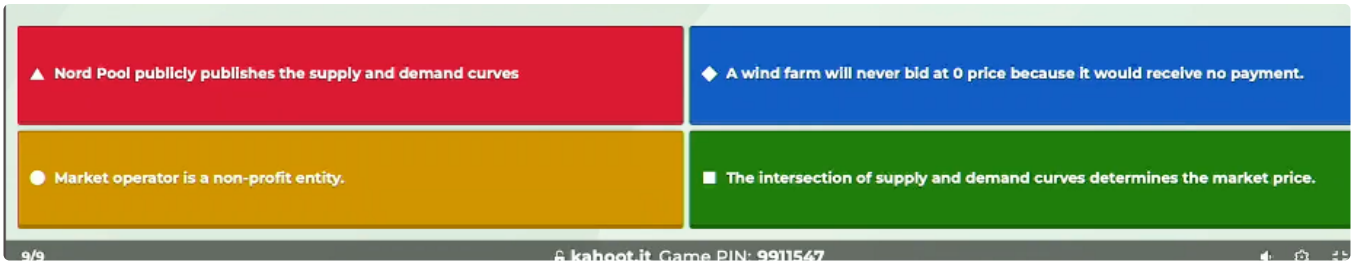
1. 30 Euros/ Mwh and 20 Euros/Mwh

4. Under uniform pricing, which of the following statements about the Orange supplier is incorrect?



Incorrect: For consummers, it is indifferent at what price Orange is offering. => they are different

5. Multiple choice: Which statements are correct? (There maybe more than once correct answer). if relevant, it is uniform pircing.



Except blue one, other answer is correct