Market design for offshore wind parks

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Introduction

• The offshore grid is different from a regular electricity market:
  • Flat supply function (~ 0 MC),
  • No demand.

• What should be the market design for an offshore wind energy grid?
  • Should the national markets be extended into the North Sea?
  • Should the North Sea Grid have its own pricing zone?
    • Or multiple zones?
    • LMP?
Objectives

• Economic efficiency:
  • The wind parks should maximize their output whenever there is a price > MC of wind.
  • The produced electricity should be transported to the markets with the highest prices first.
  • The network capacity should be used to its maximum.
  • Offshore energy storage or power-to-gas should be incentivized efficiently.

• Transmission network recovery: not an objective of congestion management.
  • Is best done through fixed (stable) tariffs
Assumptions

- We review two time slices (high and low wind) with no intertemporal dependencies.
- The variable operational costs of wind parks are assumed to be zero.
- The power flows through the offshore grid are controllable.
- There is no congestion within the connected national price zones.
- Congestion between price zones is handled through a form of auctioning.
- There is no exercise of market power.
Wind generation / line capacity (MW)

Power line capacity

Maximum wind generation capacity

Time
Example

- Optimal flows: maximize flows to Country B (which has the higher price).

These parks, as well as Wind Park 2, need to curtail part of their capacity.
Less wind

- The lines to Country B are always congested in our example due to its higher price.
- (We assume Country A can export more power than the 1500 MW import capacity of B.)
Due to congestion of the line from Wind Park 2 to Country B, this line is not used in a scenario with optimal economic dispatch. Maximizing cross-border dispatch is only possible with counter trading.

Current situation: national price zones

- Price in EEZ = onshore price (extension of the onshore bidding zone to the national EEZ)
- The northern cross-border line (Wind Park 1-2) is not used. This may conflict with EU cross-border regulations.
- Country A could be allowed to export 600 MW to B if the TSOs would counter trade the same volume.
**National price zones – different scenario**

- This energy hub exports from the high price zone to the low price zone.
- Alternative: to curtail hub generation by 1000 MW.
- To maximize the availability of cross-border capacity from A to B, the TSOs would need to counter trade 2000 MW along the South network, in addition to 600 MW on the North interconnector.
Problems with national price zones

- Efficient dispatch may require moving electricity from a high-priced zone to a low-priced zone.
- Economically efficient dispatch decisions may not correspond with EU regulations that require the cross-border capacity between the countries to be maximized.
  - This may lead to costly requirements for counter trading.
  - Or uneconomically large network investments.
Small price zones
High Wind

- Price in offshore zone = marginal value of power.
- Zones are defined by network congestion
- Efficient incentives for power-to-X
- But low wind park revenues in case of congestion
Small price zones, less wind

- Due to less wind, the parks now can produce 550 MW each.

- The parks receive the marginal price, i.e. the price they would receive for the next 1 MWh of additional output.

The lines into Country B are congested due to imports from A as long as the price in A < price in B. In this case, the hub is in the price zone of Country A.
Small price zones: analysis

• Parks receive their marginal market value
• In an efficient design with some overplanting, this may lead to low prices in high wind scenarios.
• Price zone definition corresponds to physical reality

• Advantages:
  • Efficient dispatch, also of storage and power-to-X
  • No flows from high to low price zones
  • If the price zones’ boundaries count as borders, no problems maximizing cross-border capacity.
Price hedge for wind parks: put options

- Due to overplanting, 200 MW wind needs to be curtailed.
- The marginal value of wind generation is 0, so the price is 0 €/MWh.

Solution: provide the park with a put option for the onshore price for a volume of 1000 MW.
  - It may sell up to 1000 MW at the price of Country B.
  - This is equivalent to a Financial Transmission Right for the wind park & Country B

- The park operator may choose how much generation capacity to build.
- There is no need to compensate the park for curtailment: generation in excess of 1000 MW has no value.
Each park operator has 250 MW of put options for the price in A and 250 MW for the price in B.

The remaining 50 MW needs to be curtailed. The hub price is 0 €/MWh: no need for compensation.

If there is less wind, the park operator prefers to use its put options for B (the highest price).
Wind Park 1
\[ P = 0 \, \text{€/MWh} \]

Country A
\[ P_A = 23 \, \text{€/MWh} \]

Onshore generation

Demand

Power line (flow/capacity)

Wind park (output/max. output)

Energy hub parks:
- Park 1: Put option for \( P_A \)
- Receives 1000 MW \( \times 23 \, \text{€/MWh} = 23,000 \, \text{€/h} \)
- Park 2: Put option for \( P_B \)
- Receives 1000 MW \( \times 30 \, \text{€/MWh} = 30,000 \, \text{€/h} \)
- 200 MW is curtailed.
- Energy hub parks:
  - 250 MW put option for \( P_B \) and 250 MW put option for \( P_A \)
  - Each park receives 250 MW \( \times 30 \, \text{€/MWh} + 250 \, \text{MW} \times 23 \, \text{€/MWh} \)
  - 50 MW is curtailed.
Small price zones + put options, less wind

- Park 1: Contract with A
  - Receives 500 MW x 23 €/MWh.

- Park 2: Contract with B
  - Receives 600 MW x 30 €/MWh.

- Energy hub parks receive 225 MW x 30 €/MWh from their put options.
  - (If they generated >250 MW, the additional power would receive $P_A$.)
Assessment – market designs

- Wind park revenues + congestion rent = constant
- Higher wind park revenues limit the need for financial support, reduces the need to ‘pump money around’
- National price zones:
  - Create counter-intuitive flows;
  - Don’t provide efficient incentives for storage and power-to-gas.
- Single offshore zone also has the latter objection, plus low revenues.
- Zonal pricing approach most efficient
  - Zero prices when wind needs to be curtailed: bad for wind parks, good for power-to-X.
Assessment – congestion price risk

• If overplanting is allowed, the small zones model may lead to very low prices during periods of over production.

• Solution 1: no overplanting. Consequence: higher average cost of wind energy due to under utilized network.

• Solution 2: limit the sum of the capacities of the connection cables of the parks to the meshed offshore grid capacity. Park operators need to self-curtail if they overplant. More efficient than solution 1, but not optimal.

• Solution 3: provide put options to the wind parks, include the payments in the market settlement.
  • Then the wind park price risk is the same as in the national price zone model
    • Except for ‘overplanted’ capacity, which may need to be curtailed during high wind.
    • Economically efficient incentives, both for over planting and operations

• Solution 4: provide financial transmission rights to the wind parks
  • Same economic effects as the put options, but the TSO collects congestion rent and pays it in return for the FTRs.
Proposal: zonal pricing + put options

• Provide wind parks with put options for the price in country x for contract volume y (MW). The TSO determines y as the guaranteed feasible transport capacity between the wind park and country x.

• The put options are allocated at the time of tendering for the park, so the project developers can price them into their bids.

• A wind park that is connected to multiple countries can have put options with all connected countries.
  • The simple structure of a meshed offshore grid and the ability to control flows make this solution much simpler than in the onshore AC grid.
Conclusions

• Zonal pricing provides optimal incentives for efficient dispatch
  • Also in the presence of (hydrogen) storage or other types of consumption offshore.
• Zonal pricing avoids the need for counter trading.
• Put options stabilize generator revenues.
  • They reduce congestion rents from the meshed offshore grid.
• In this market design:
  • The wind park operator can choose to what extent he overplants
  • There is an optimal incentive for curtailment, without a need to compensate the owners (because they could choose the degree of over capacity of their parks).
Single offshore price zone

- Price in offshore zone = marginal value of wind energy (because there is a surplus).
- In this case, the price = 0 because Park 2 and the energy hub are curtailed.
- No counterintuitive flows.
- But low revenues for offshore wind.
- Unintuitive result for parts of the grid that are not congested (not shown here).
- How to define the offshore zone?
- How to price parks that are not (yet) connected to the meshed grid?
Single offshore price zone: analysis

• Low wind park revenues.
  • Parks may receive less than their market value

• How to define the price zone boundaries?
  • If the line capacities had been different and the North parks would not need to be curtailed, shouldn’t they be in a different price zone?

• Advantages:
  • Efficient dispatch
  • No flows from high to low price zones
  • If the price zone’s boundaries count as borders, no problems maximizing cross-border capacity.
The connections between the parks and the hub are 500 MW each.

No congestion is possible → the hub price will always be equal to the lowest onshore price. No need to curtail.

But: if a park has maintenance outages, other parks cannot use the unused line capacity.

Similarly, if the parks are not all built at the same time, the first parks cannot produce at full power even though the hub to land connections have excess capacity.