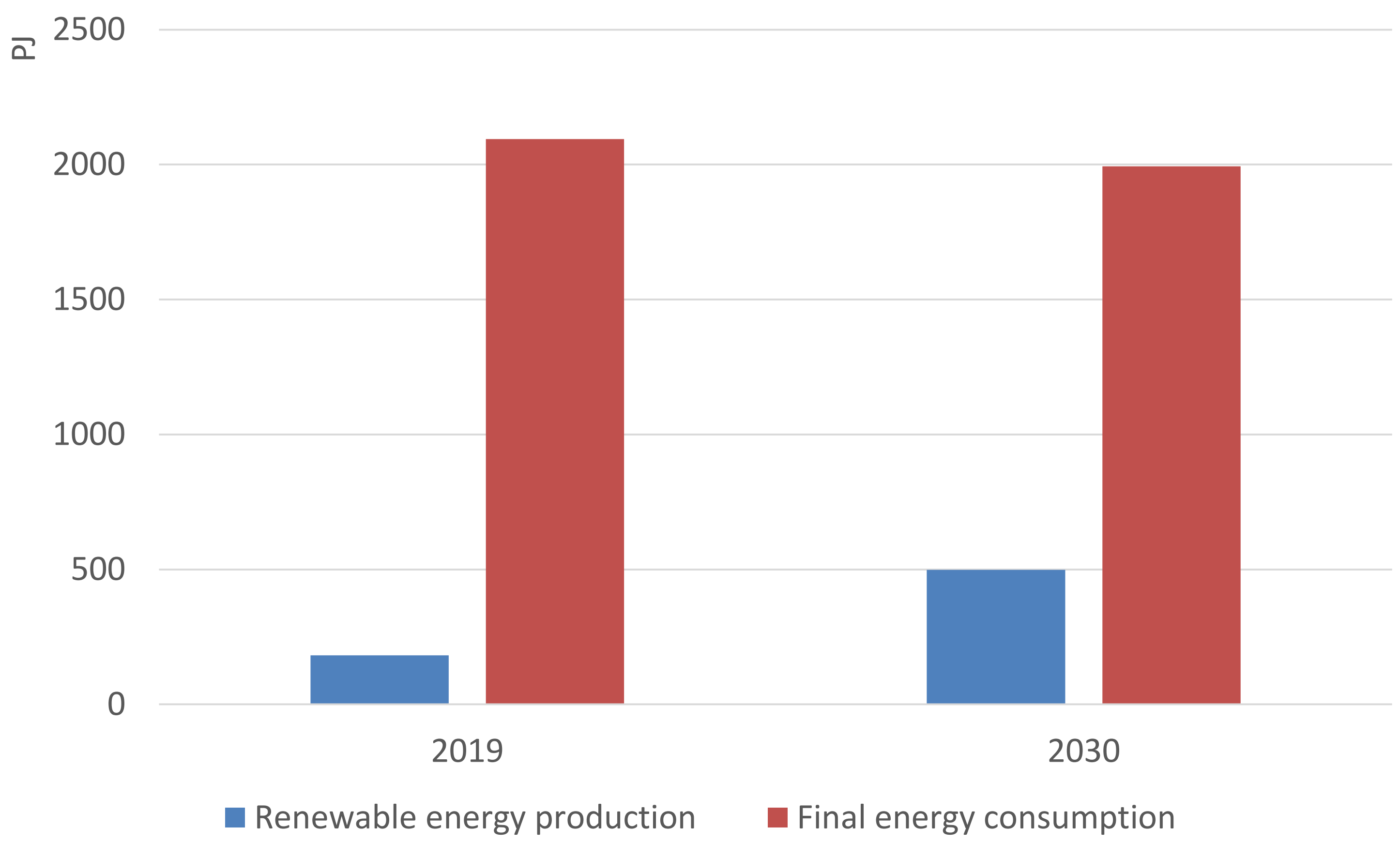
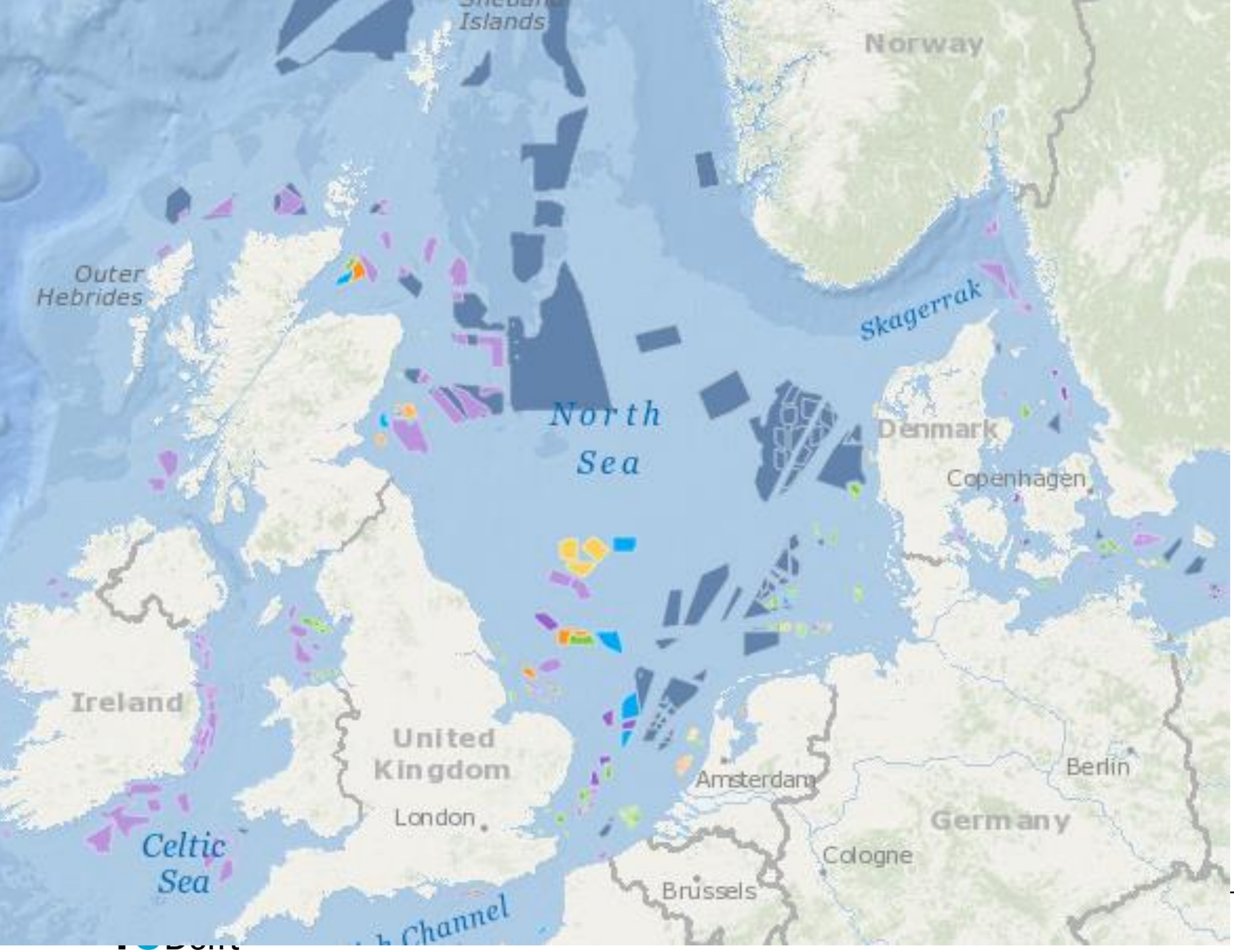
The North Sea energy grid:
Designing regulation for optimal techno-economic performance”

Laurens de Vries, Technology, Policy and Management

The challenge…



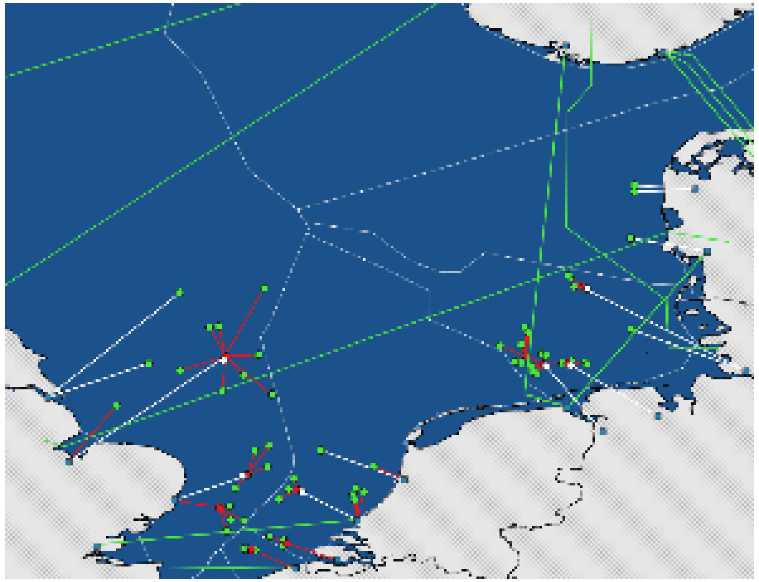
Data source: PBL

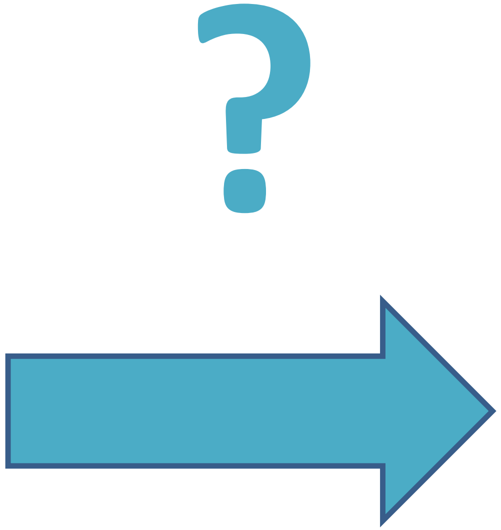


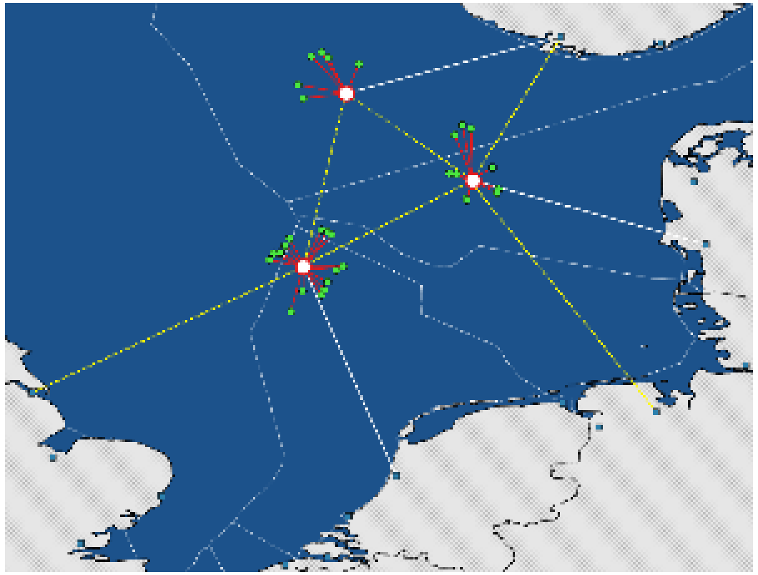
Wind Farms

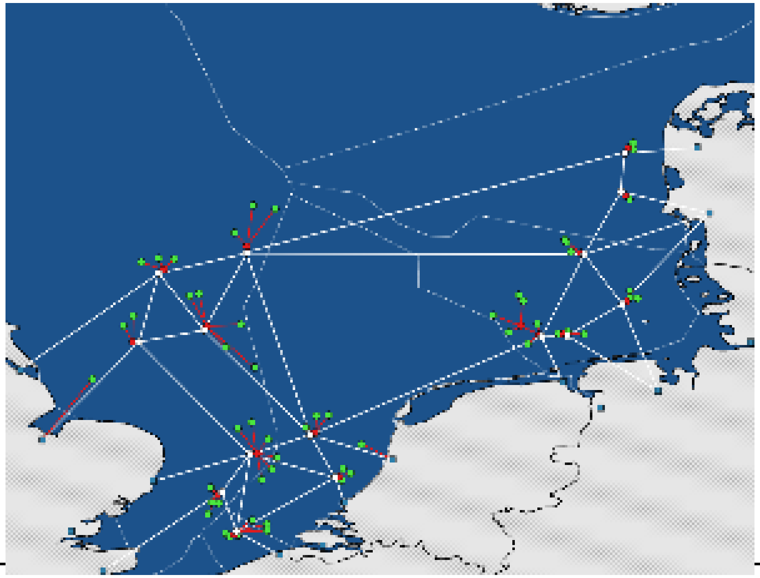
- Concept/Early Planning
- Consent Application Submitted
- Consent Authorised
- Pre-Construction
- Under Construction
- Partial Generation/Under Construction
- Fully Commissioned
- Decommissioned
- Development Zone

https://map.4coffshore.com/offshorewind/









The offshore energy system

- A multi-hub, multi-terminal energy system
- Based on conventional wind turbines, expanded with floating wind parks, wave energy, floating solar parks?
- Offshore hydrogen production?

- The PROMOTioN project provided a roadmap for a meshed offshore grid.
  - https://www.promotion-offshore.net.

Market design for an offshore energy system

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

- Should the national markets be extended into the North Sea?

- What if we get it wrong?
  - Unnecessary curtailment
  - Poor investment incentives
  - High grid operation costs.

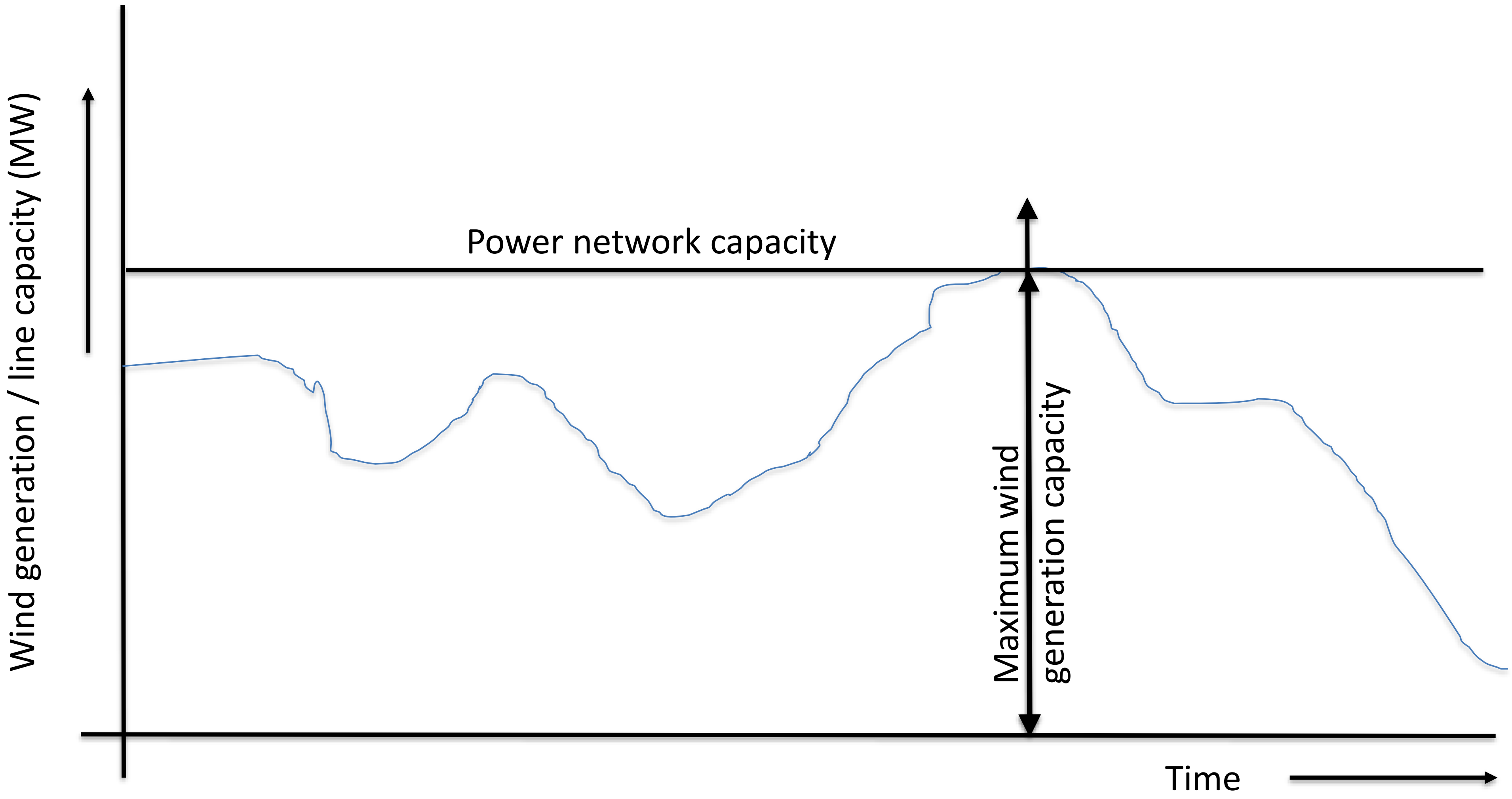
Objectives

- 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

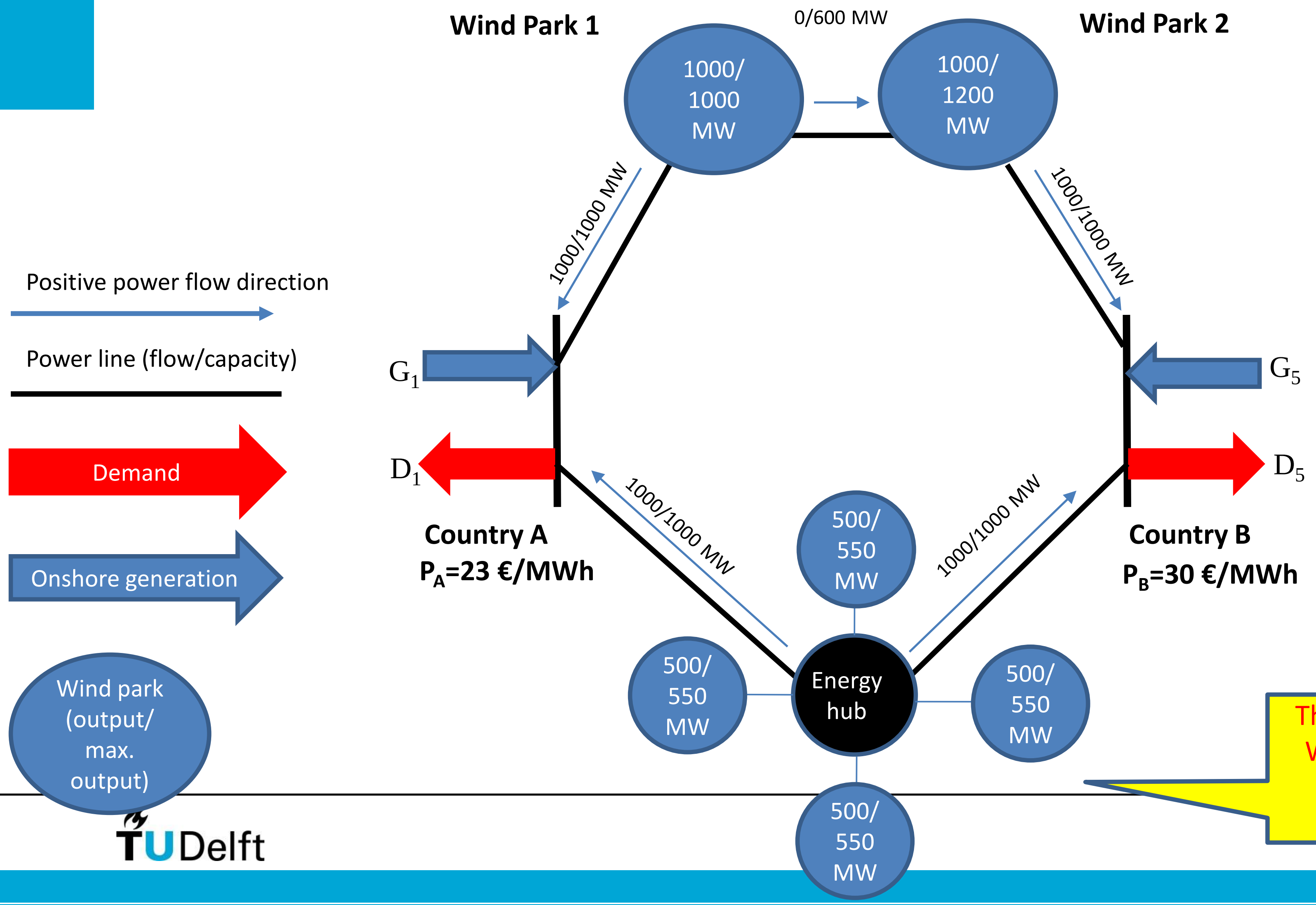
Approach and assumptions

- 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.

Overplanting: normal aspect of optimization



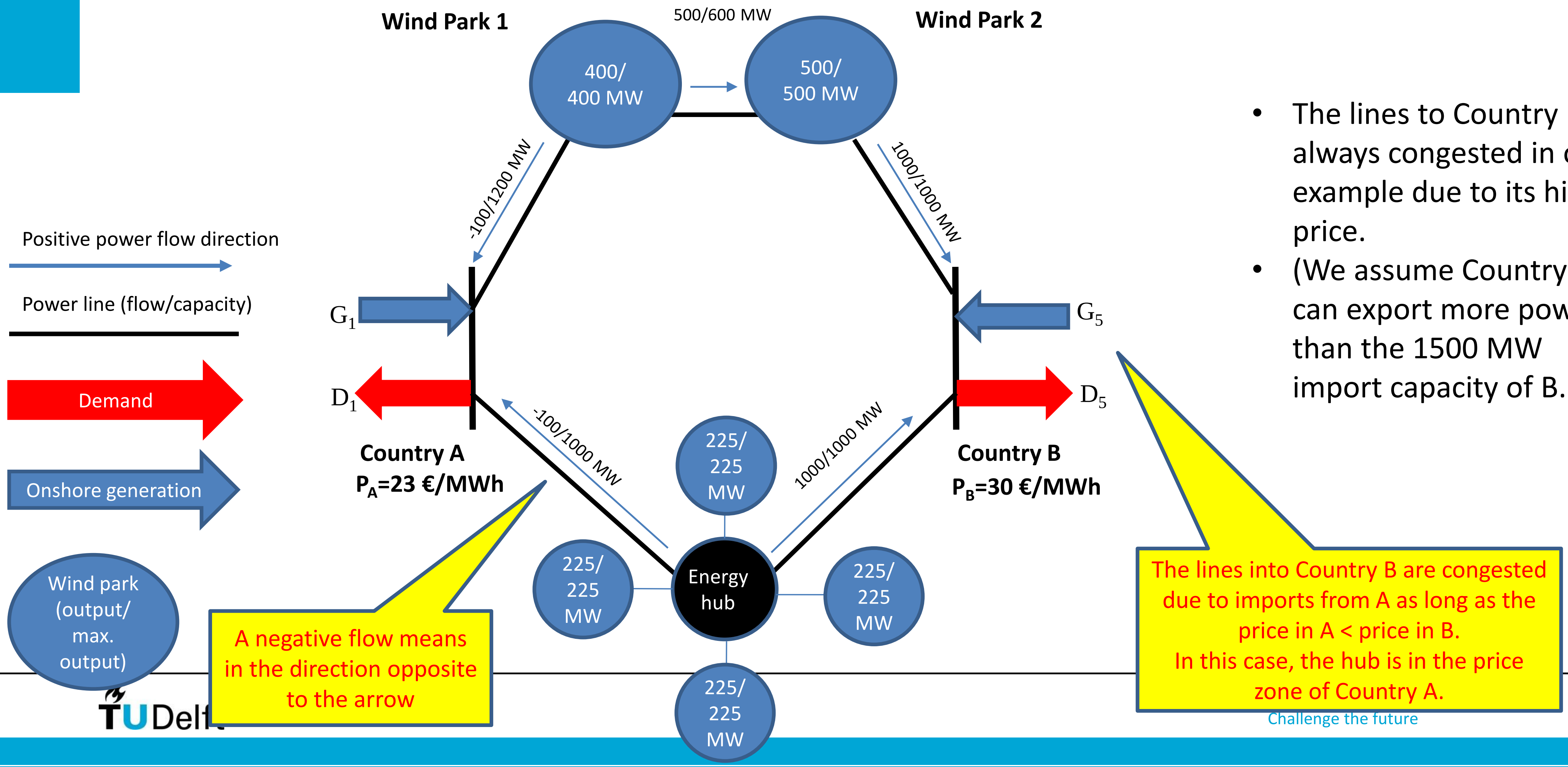
Example set-up



- 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.

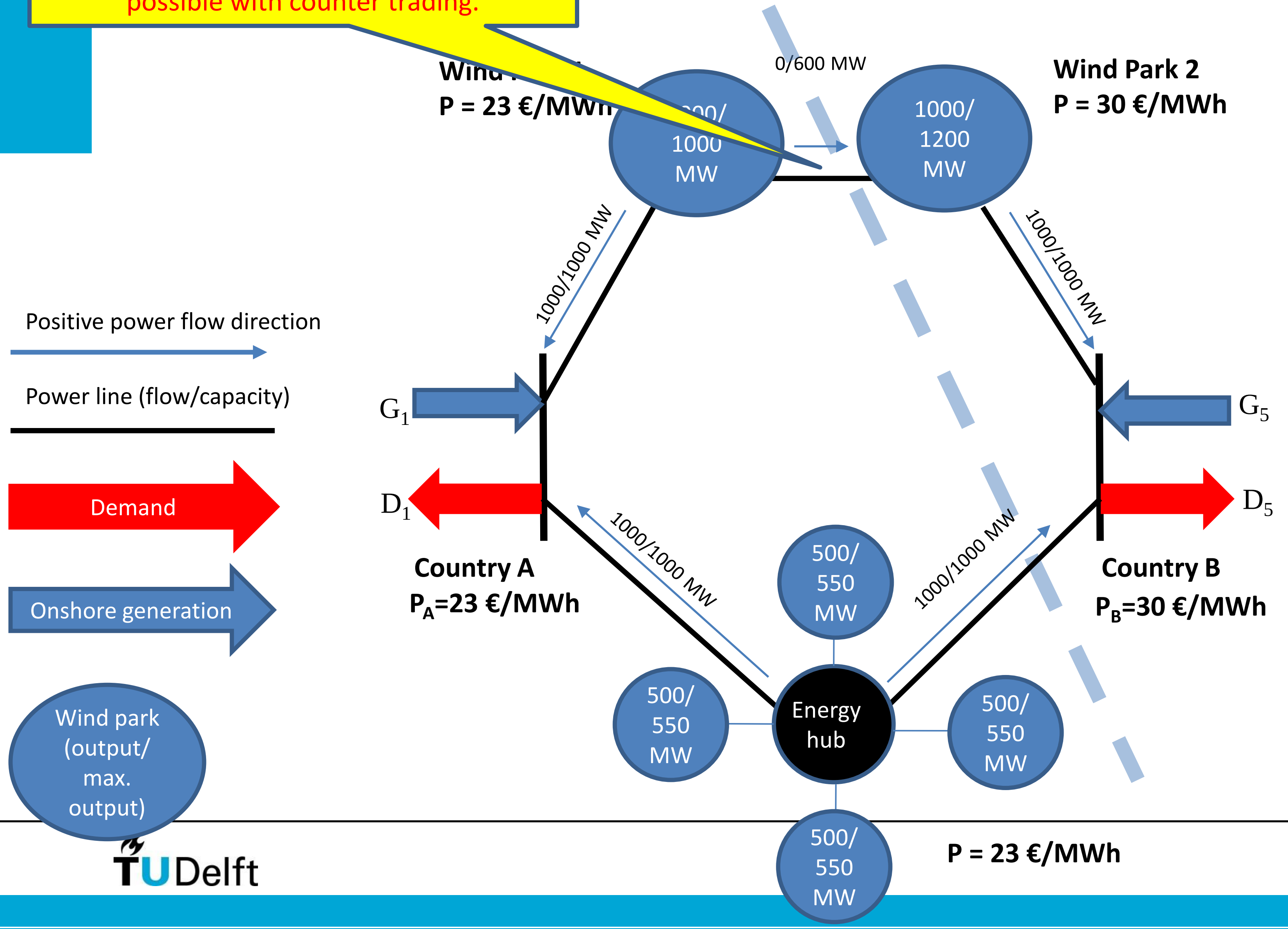
Less wind



- 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.)

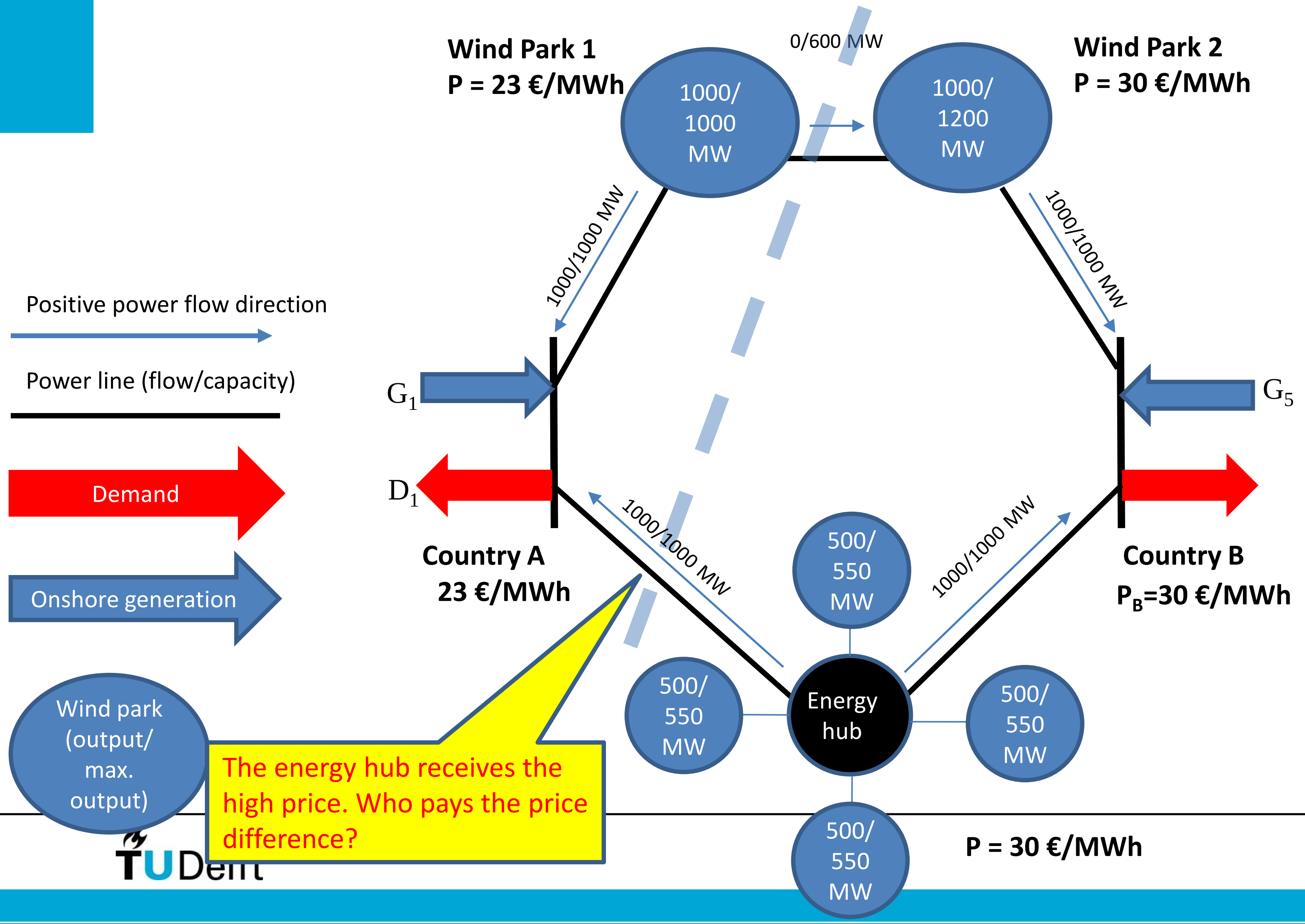
Due to congestion of the line from Wind Park 2 to Country B, this line is not used in a scenario with optimal economic dispatch. Maximizing cross-border dispatch is only possible with counter trading.

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

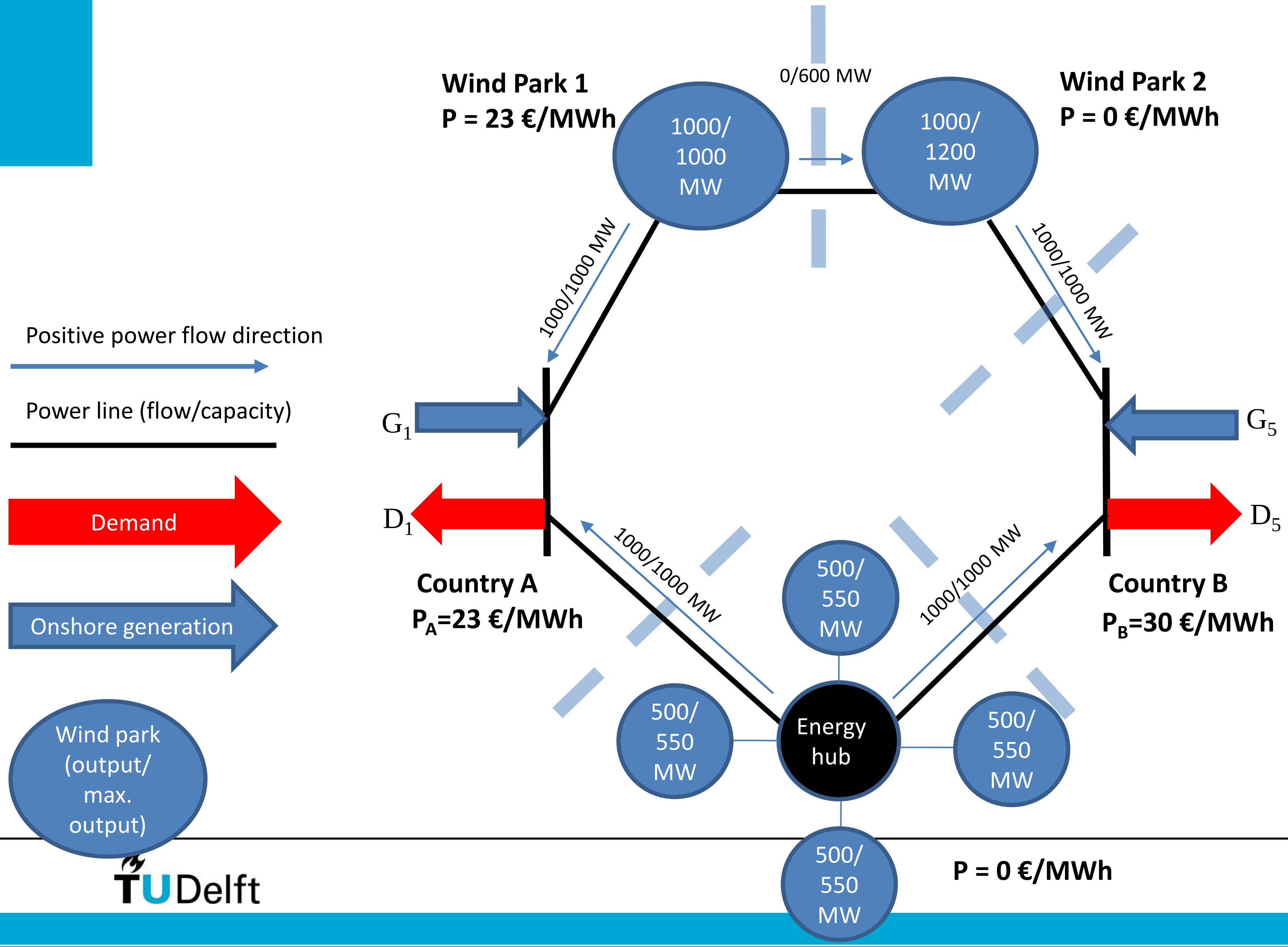


- This energy hub exports from the high price zone to the low price zone.
- Alternative: to curtail hub generation by 1000 MW.
- To maximize the availability of cross-border capacity from A to B, the TSOs would need to counter trade 2000 MW along the South network, in addition to 600 MW on the North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

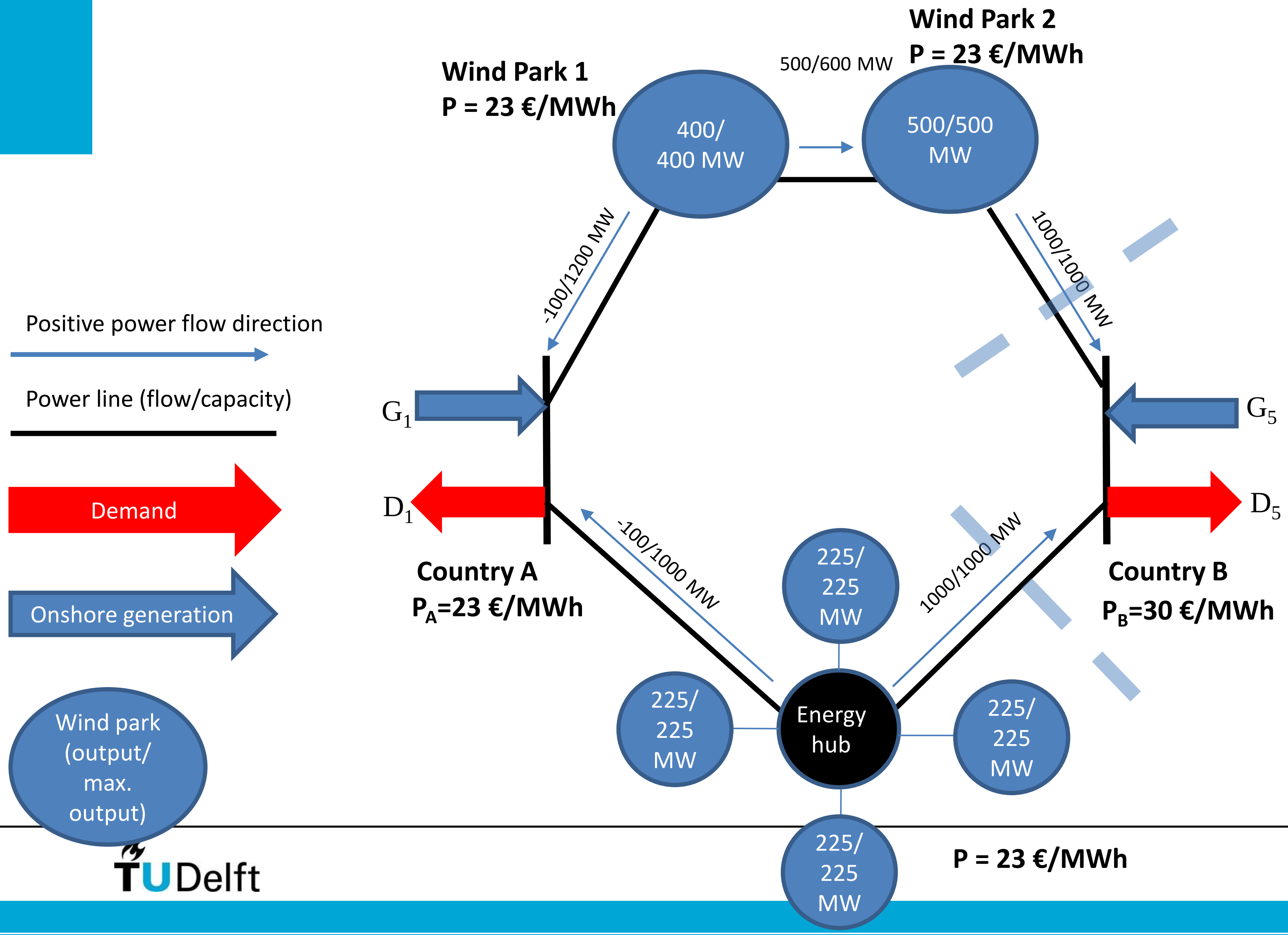
Small price zones High Wind



- 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.

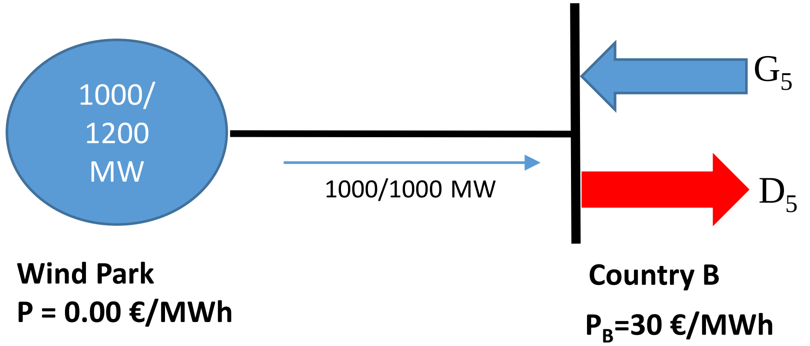
Small price zones: analysis

- Parks receive their marginal market value
- 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.

- Disadvantage:
  - In an efficient design with some overplanting, this may lead to low prices in high wind scenarios.

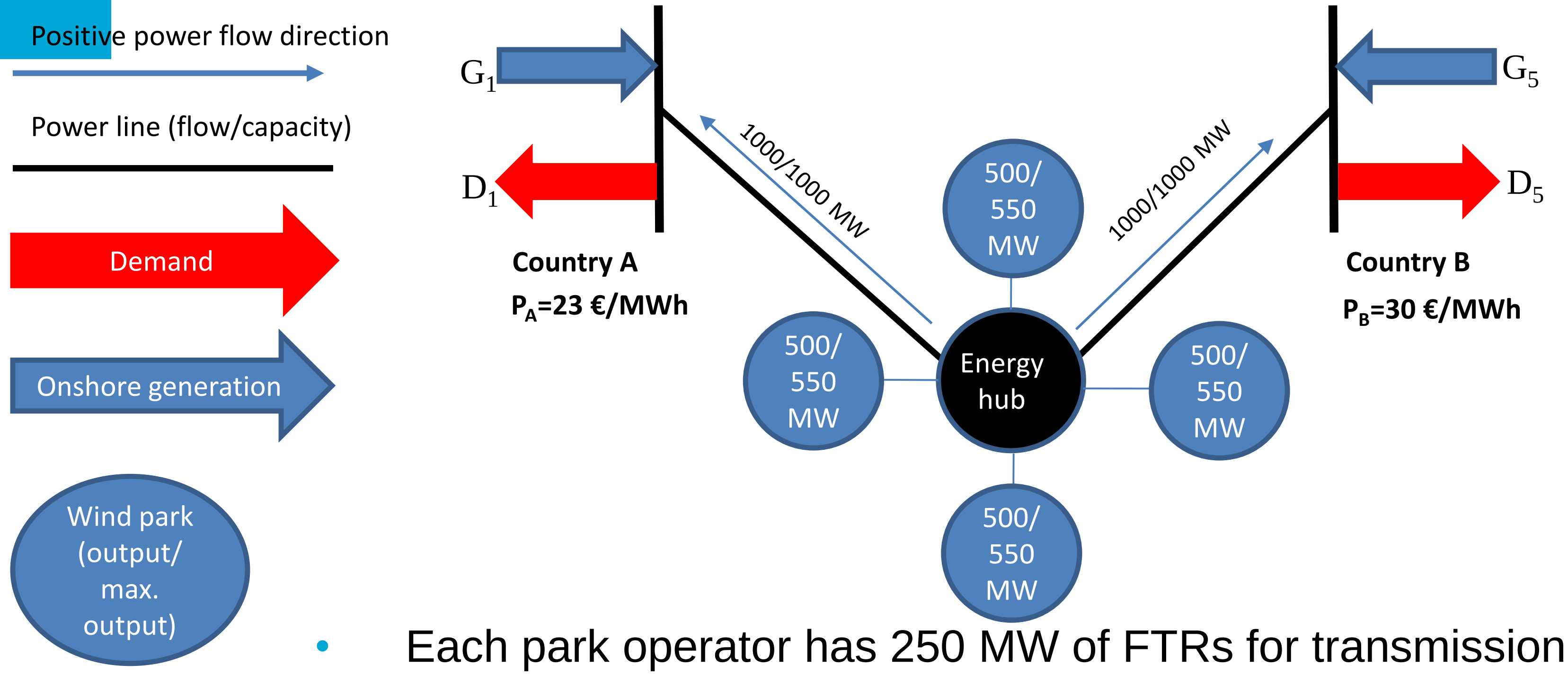
Price hedge: financial transmission rights (FTRs)



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

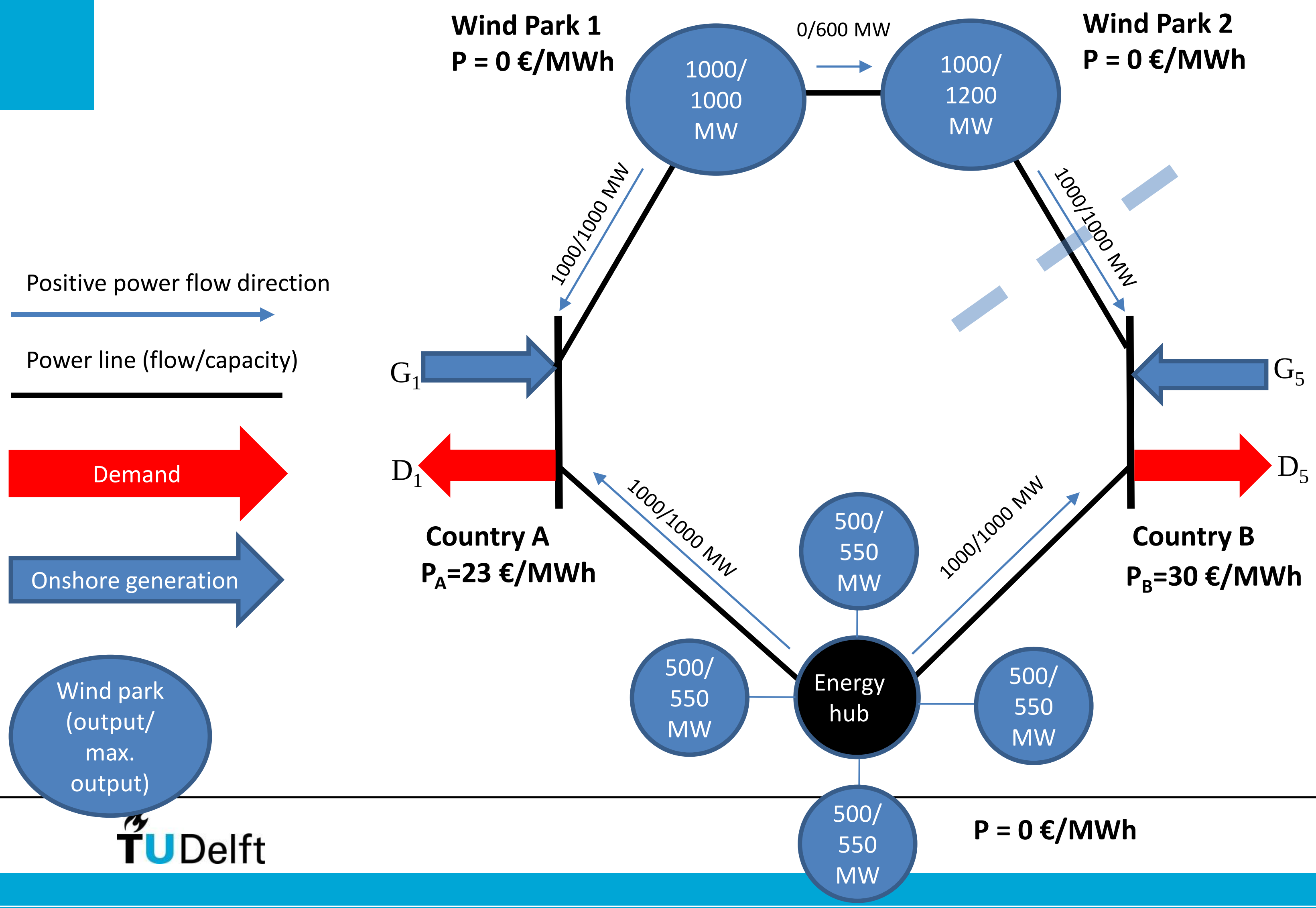
- Solution: provide the park with an FTR for the onshore price for a volume of 1000 MW.
  - It may sell up to 1000 MW at the price of Country B.
- The park operator may choose how much generation capacity to build.
- There is no need to compensate the park for curtailment: generation in excess of 1000 MW has no value.

Financial transmission rights for wind parks



- Each park operator has 250 MW of FTRs for transmission to A and 250 MW for 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).

Small price zones + FTRs

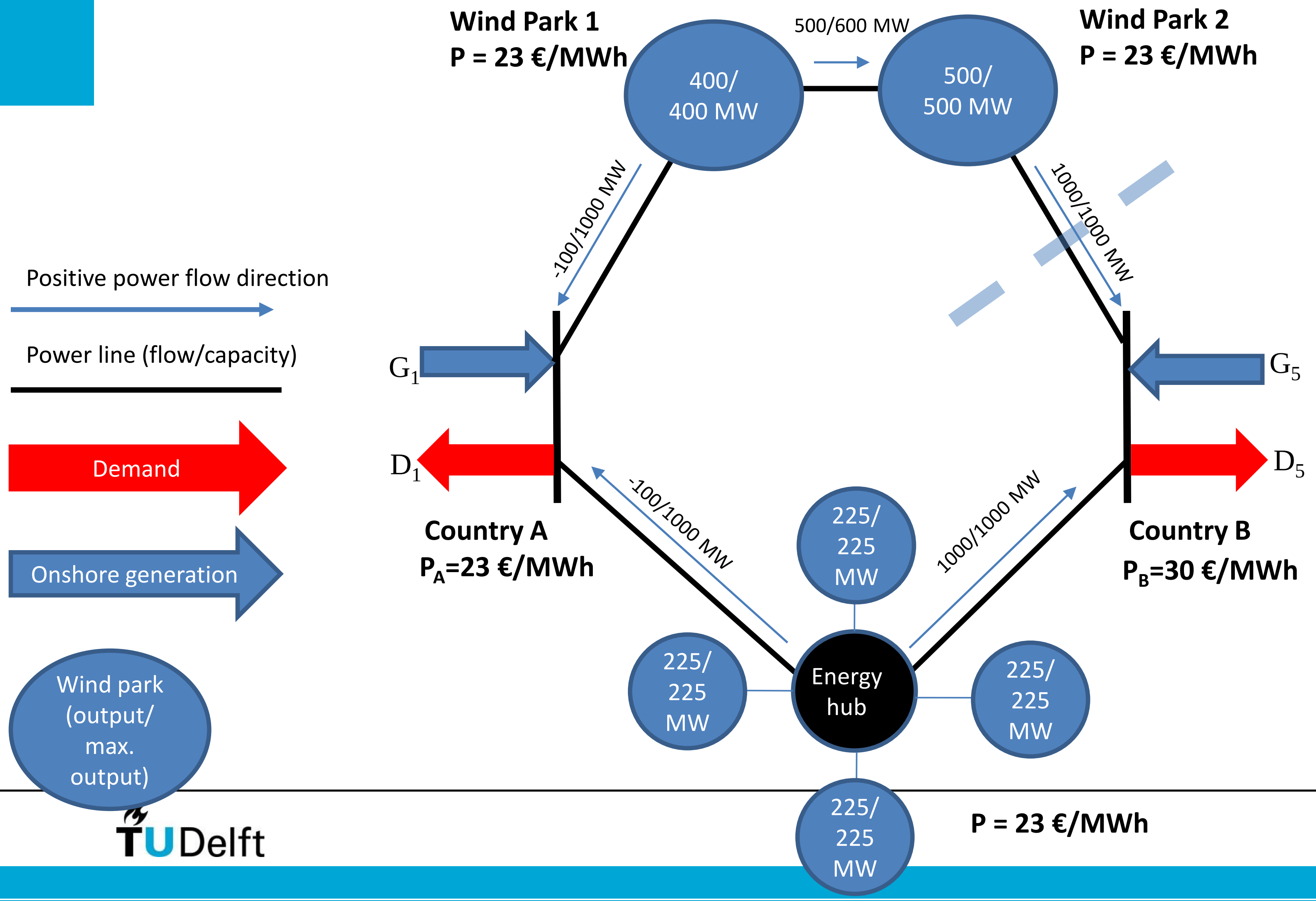


- Park 1: FTR of 1000 MW to A.
- Receives 1000 MW x 23 €/MWh = 23 000 €/h.

- Park 2: FTR of 1000 MW to B.
- Receives 1000 MW x 30 €/MWh = 30 000 €/h
- 200 MW is curtailed.

- Each park connected to energy hub:
- 250 MW FTR for A and 250 MW FTR for B.
- Each park receives 250 MW x 30 €/MWh + 250 MW x 23 €/MWh
- 50 MW is curtailed.

Small price zones + FTRs, less wind



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

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

- Energy hub parks receive 225 MW x 30 €/MWh from their FTRs.
- (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 curtailment.
- Solution 1: no overplanting. Consequence: higher average cost of 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 FTRs 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

Proposal: zonal pricing + FTRs

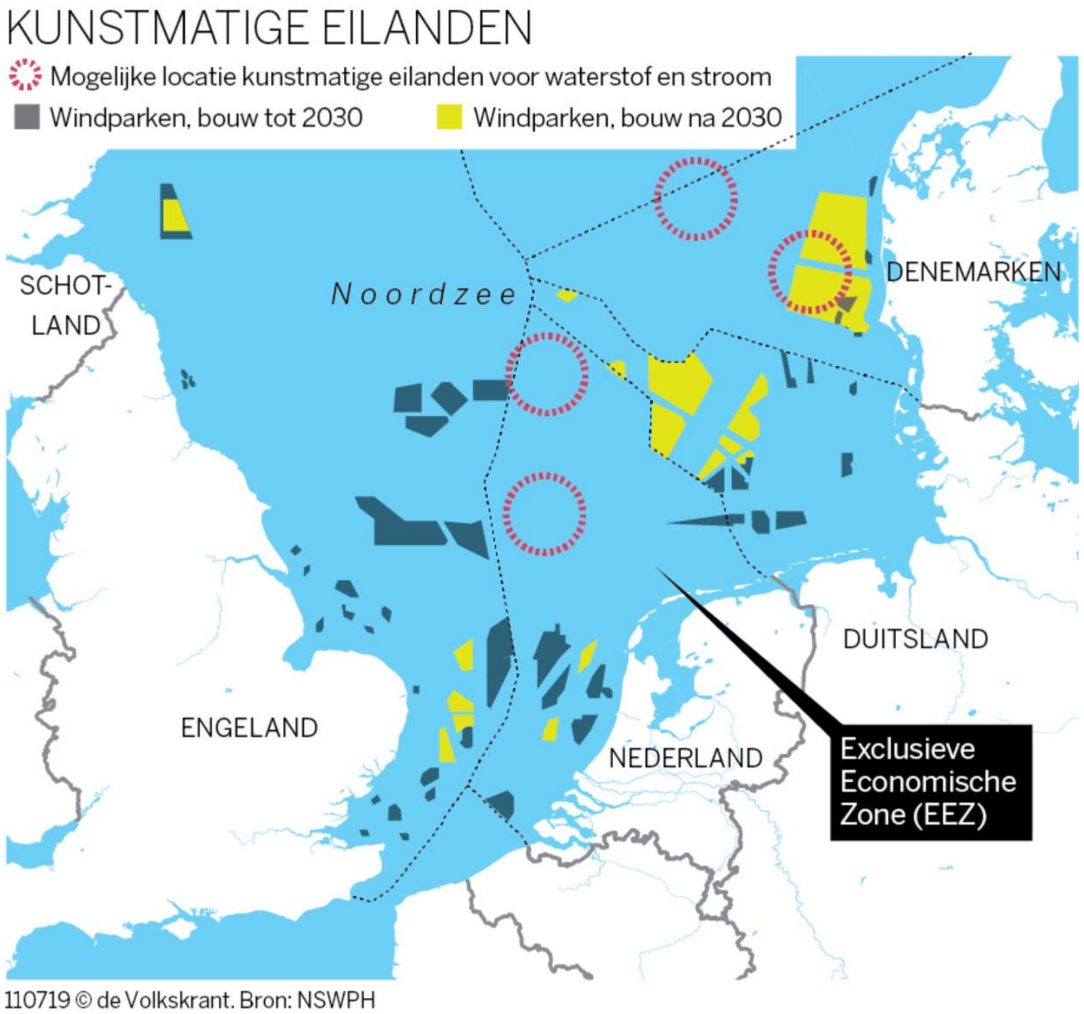
- Provide wind parks with FTRs for the transmission to country *x* for contract volume *y* (MW). The TSO determines *y* as the guaranteed feasible transport capacity between the wind park and country *x.*
- The FTRs are allocated at the time of tendering for the park, so the project developers can price 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.

- Problem: EU regulation does not allow TSOs to return congestion rents to generators…

Conclusions on market design

- 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).

Zooming out again…



Design questions for the offshore energy system

- Topology: how many hubs, where, how much generation capacity?
- Islands or platforms?
- Infrastructure:
  - balance between electricity and hydrogen,
  - network topology,
  - (deep) connection with onshore grid.
- For both electricity and hydrogen: voltage/pressure, capacity, topology.

Governance challenges

- Long-term offshore wind farm and grid planning
- Financing
- Allocation of network costs
- Renewable energy support instruments
  - Design, cost allocation
- Regulatory governance (formalise the cooperation between NRAs)
  - Grid fees, congestion management, connection rules
- Technical rules (e.g. network codes)
- Market design

Action needed!

- The current renewable energy plans are not adequate
- The North Sea provides the capacity for scaling up renewable energy production
- But the development time is long
- And many issues are still to be solved

- TU Delft has all the knowledge in house!