Optimization models in the offshore wind industry

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Reducing Levelized Cost of Energy (LCoE) of offshore wind farms

- ▶ Increasing the energy production
  - ▶ optimize turbine positions while considering wake effects

(Courtesy: Vattenfall)

Reducing Levelized Cost of Energy (LCoE) of offshore wind farms

- Reducing the costs
  - Turbine costs
  - Operation and maintenance costs
  - Logistics costs (both installation phase and operational phase)
  - Fatigue costs
  - Cable costs
  - etc.

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Problem

- ▶ Given:
    - ▶ a set T of turbine locations
    - ▶ a set S of substation locations
    - ▶ a set $A \subset L \times L$ of possible connections ($L = T \cup S$)
- ▶ Goal:
    - ▶ Connect each turbine to a substation
    - ▶ such that total cable length/cost is minimized
- ▶ Constraints:
    - ▶ Upper bound q (cable capacity) on turbines per cable
    - ▶ Upper bound b (branching capacity) on branches at turbines
    - ▶ Cables cannot cross

Integer programming model - variables

▶ Decision variables:

▶ $x_{ij}^t = \begin{cases} 1, & \text{if } (i,j) \text{ connects } t \text{ turbines} \\ 0, & \text{otherwise} \end{cases}$

$x^1=1$

$x^1=1$

$x^2=1$

$x^4=1$
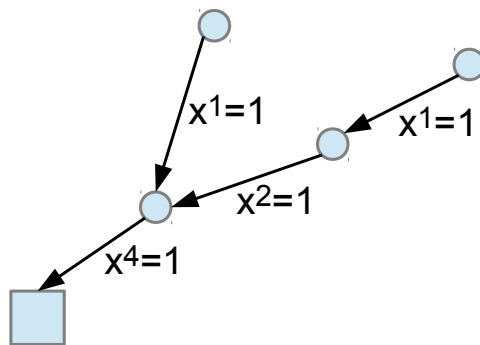
Integer programming model - objective and constraints

- Minimizing costs:
  - $\min \sum_{(i,j) \in A} \sum_{t=1}^{q} c_{ij} x_{ij}^{t}$
- Constraints:
  - Bound on the branches at j: $\sum_{i:(i,j) \in A} \sum_{t=1}^{q} x_{ij}^{t} \leq b$
  - etc.
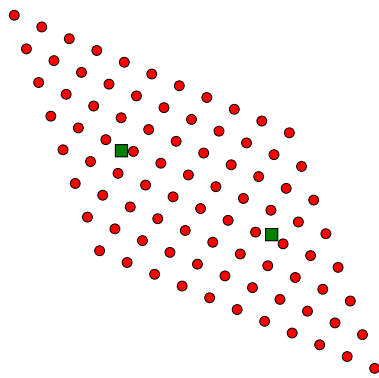- Extension: Two (or more) cable types
  - Costs: $c_{ij} < C_{ij}$
  - Capacities: $q < Q$

$\Rightarrow$ Integer programming model (INF170, INF270, INF271)

Wind farm data

- ▶ Turbine and substation position data of offshore wind farms
  - ▶ Sheringham Shoal
  - ▶ Walney 1
  - ▶ Walney 2
- ▶ Euclidean distances as edge cost c_{ij}
- ▶ All possible cable connections allowed $A = L \times L$
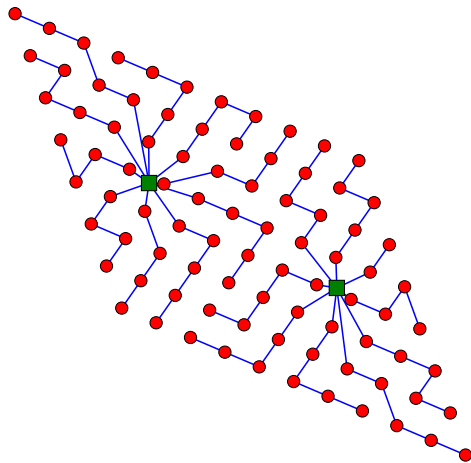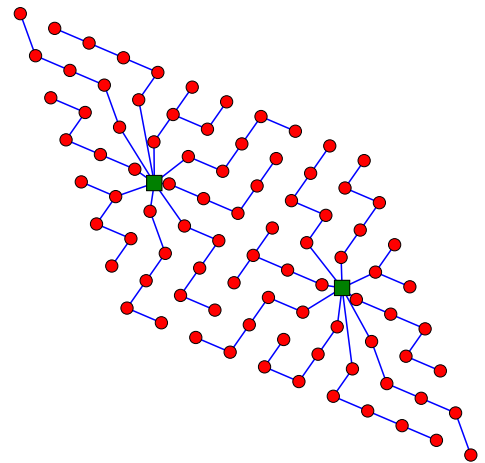- ▶ Branching capacity $b = 3$

Sheringham Shoal
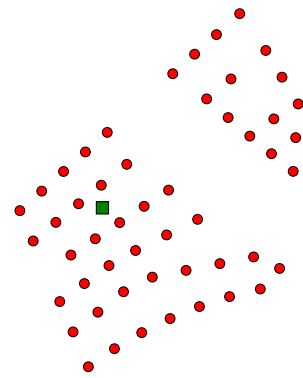
Walney 2

Illustration of experimental results - one cable type

Example: Sheringham Shoal with $q = 5$
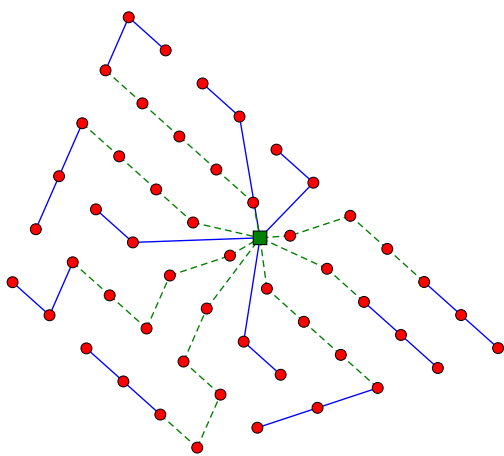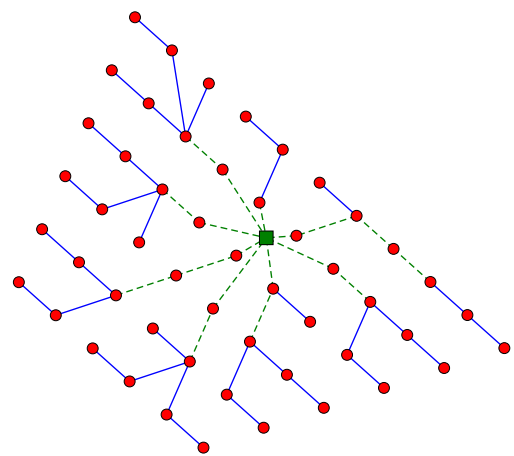
No branching ($b = 1$)

Branching ($b = 3$)

Illustration of experimental results - two cable types

Example: Walney 1, $q = 2$, $Q = 7$
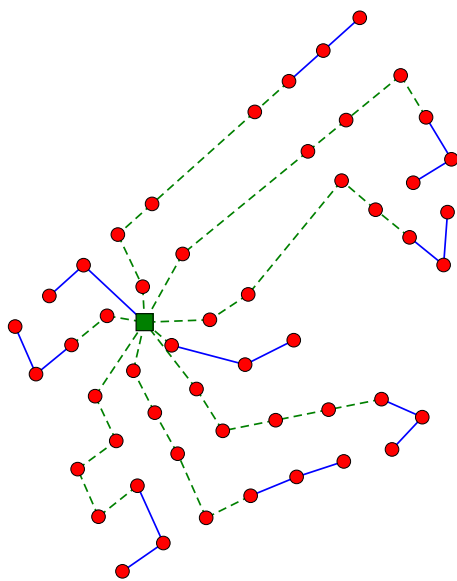

No branching ($b = 1$)　　　　　Branching ($b = 3$)
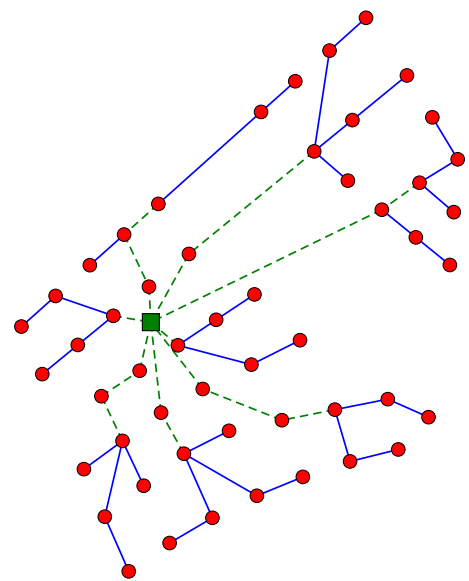
Illustration of experimental results - two cable types

Example: Walney 2, $q = 2$, $Q = 7$

No branching ($b = 1$)   Branching ($b = 3$)

Observations - Further work

Branching vs. no branching:

- One cable type: Small differences ($< 1\%$) between $b = 1$ and $b = 3$
- Two cable types: Large differences ($\approx 14\%$ at Walney 2 when $q = 2$, $Q = 7$)

In progress (Klein et al. 2016):

- Parallel cables
- Cables around obstacles
  - Optional nodes in addition to turbines and substations
- More realistic cable costs