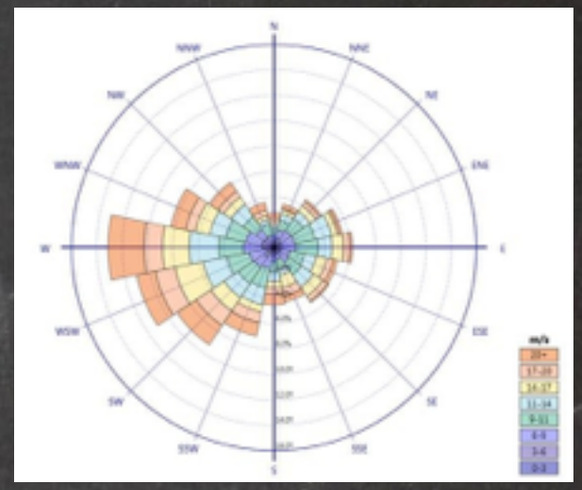
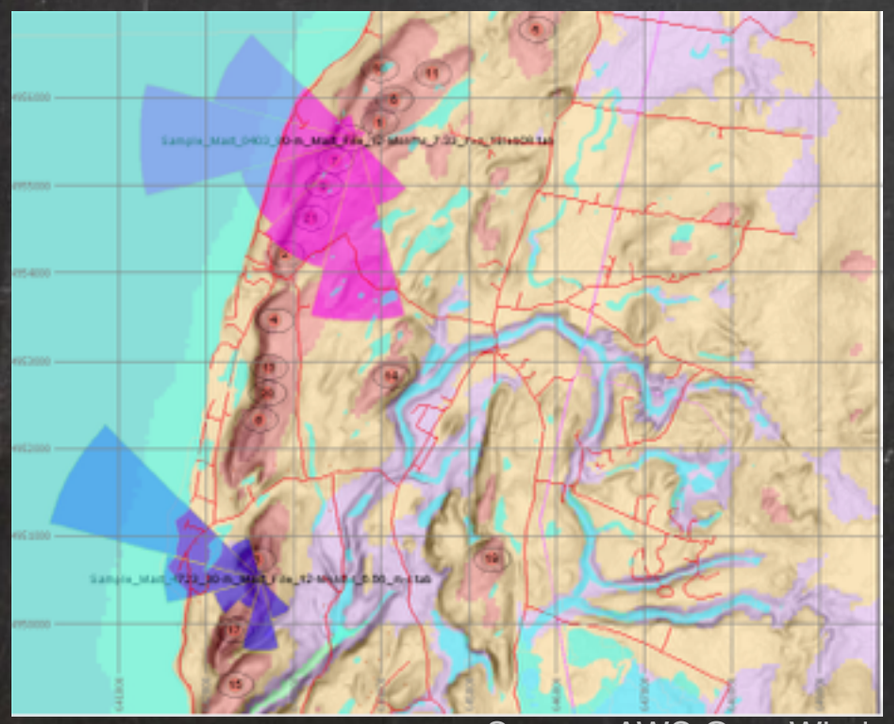
First Wind Farm Layout Optimization Competition

D. Wilson, S. Cussat-Blanc,

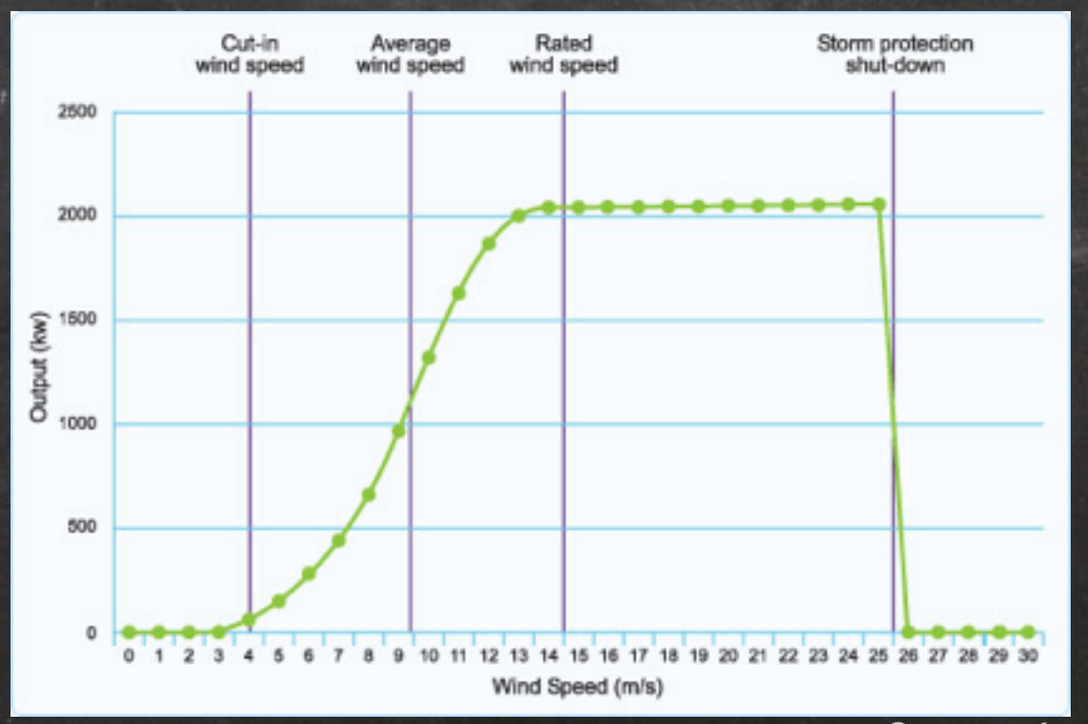
Wind farm layout optimization

- Objectives:
  - Optimize a layout of
  - Optimizer in the middle of a design loop that include
  - Multiple
    - Wind distribution and wake effects
    - Safety constraints
    - Turbine power curve
    - Economic constraints (construction and maintenance cost, cable and road optimization, etc.)
    - Topographic constraints (lakes, mountains, roads, buildings, etc.)





Source: AWS OpenWind

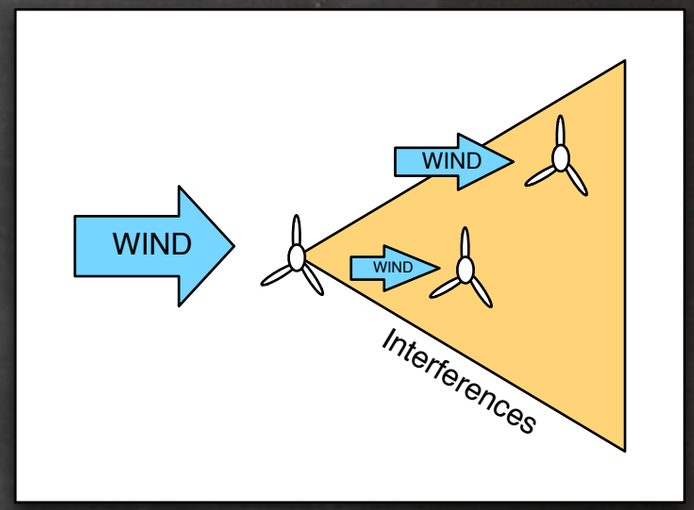


Source: pfr

Wind farm layout optimization

- Energy capture model from
  - Each turbine generates for other turbines behind it
  - Based on a Weibull distribution, reduced by the wake generated per the turbines:

$$E^i[\eta] = \int_\theta P(\theta) \int_v p_v^\theta(v, c_i, k_{,i}\, x_i, y_i, X, Y)\beta^i(v)$$



  - $P(\theta)$
  - p^θ_v
  - $\beta(v)$
- Provides the global energy capture of the layout and for each turbines
- Compute the wake free ratio: $R_{wf} = \frac{E_{tot}}{E_{wf} * n}$
  - E_{tot}
  - E_{wf}
  - n: number of turbines in the layout

Wind farm layout optimization

- Energy capture model from
  - Implemented in the open-source WindFLO API
    - Matlab
    - C++
    - Java
  - Available online: https://github.com/d9w/WindFLO
  - Provides a set of random and real test scenarios

Competition

- 2 tracks:
  - Track 1:
    - Position a given number of turbines
    - Optimize the energy output of the layout (wake free ratio)
    - 5 scenarios with different wind scenarios and layout sizes
    - 5000 layout evaluation credits for all 5 scenarios
  - Track 2:
    - Position as much as possible turbines
    - keep the wake free ratio over a threshold
    - 5 scenarios with different wind scenarios and layout sizes
    - 5000 layout evaluation credits for all 5 scenarios
- Evaluation:
  - Competitors ranked per wake free ratio (track 1) and number of turbines (track 2)
  - Points given for each scenarios according to the position of the competitors
    - 1st = 10 pts, 2nd = 6 pts, 3rd = 4 pts, 4th = 3 pts, 5th = 2 pts, 6th = 1 pt

Competitors

- For this first instance, 2 competitors:
  - Markus Wagner, University of Adelaide, Australia
    - Start with a gridded layout in a continuous space
    - Randomly select one turbine in the layout
    - Move this turbine away from the n-closest neighbors
    - Repeat multiple time
    - Stop criteria: 1000 evaluations per scenario
  - Ilya Loshchilov, Ecole Polytechnique Fédérale de Lausanne, Switzerland
    - Fill up the space with a gridded layout of turbines
    - Remove extra turbines until reaching the required conditions (number of turbines or wake free ratio threshold)
    - 3 removing strategy: random, random with moving the turbines on the same column and random with moving the turbines on the same line
    - Stop criteria: 1000 evaluations per scenario

State-of-the-art approaches

- To improve the comparison, 2 state-of-the-art algorithms are added:
  - Genetic algorithm:
    - Track 1: fixed-size vector of 2*n floating-point values, variation around a central position, fitness=wake free ratio
    - Track 2: matrix of boolean, on/off of turbines in a discretised environment, fitness=number of turbines
  - CMA-ES (track 1 only):
    - Track 1: use of a CMA-ES on a 2*n floating-point values, reparation mechanism in case of invalid layout, fitness=wake free ratio

Results

- Track 1: Fixed number of turbines

Wake free ratio	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Score
Wagner	0.9157 6pts	0.9112 6pts	0.8535 4pts	0.8777 6pts	0.8373 4pts	26
Loshchilov	0.9402 10pts	0.9305 10pts	0.8798 10pts	0.9076 10pts	0.8649 10pts	50
CMA-ES	0.8996 3pts	0.9100 4pts	0.8453 3pts	0.8768 3pts	0.8269 3pts	16
GA	0.9021 4pts	0.9051 3pts	0.8570 6pts	0.8775 4pts	0.8482 6pts	23

Results

- Track 2: Variable number of turbines

# turbines	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Score
Wagner	373 6pts	238 4pts	793 4pts	427 6pts	969 4pts	24
Loshchilov	489 10pts	310 10pts	974 10pts	459 10pts	1133 10pts	50
GA	358 4pts	243 6pts	820 6pts	397 4pts	1081 6pts	26

Conclusion

- We want you!

- There is a lot to do to solve this complex problem
- A lot of constraints can be added to increase the complexity of the optimization