Evolutionary lessons for wind energy efficiency

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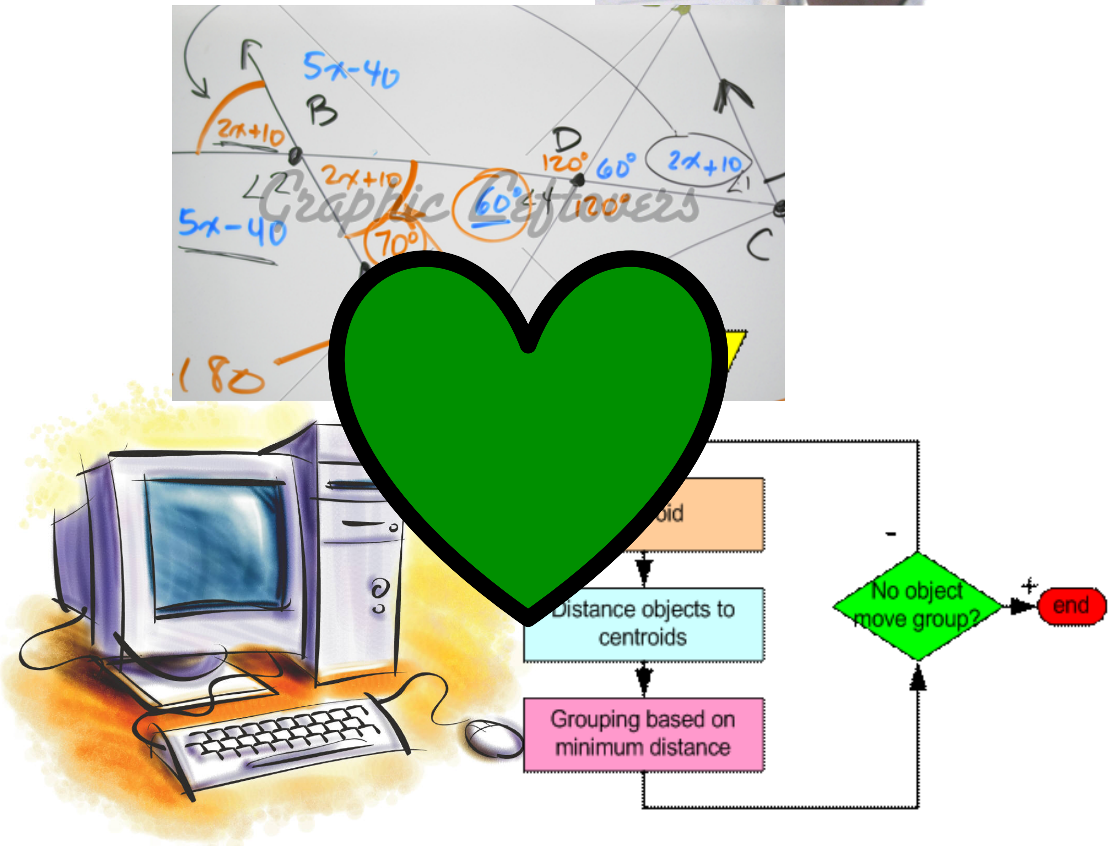


Motivation

Renewable Energy:

- Has gained increasing interest
- Is clean
- Substantial to decrease CO_2 emission
- Is a huge market
- Large developing effort
- Has many challenging questions.

Wind Energy:

- Major player in renewable energy
- Since 2005 the cumulative installed capacity of wind energy within the EU has almost doubled (from 40 GW to 74 GW).
- In 2009, 39% of all new energy capacity installed in the EU was based on wind.
- Roughly 8800 wind turbines in Europe which helped to save 180 Mio tons of CO_2 since the beginning of 2009.

Largest Wind Farms:

- Roscoe Wind Farm (Texas, 627 turbines, 781 MW)
- Vlorë Wind Farm (Albania, 250 turbines, 500 MW)

Recent News:

- Thanet Wind Farm (Offshore (UK), 100 turbines, 300 MW)
- Ontario's 21,000 Megawatts Offshore Potential
- Google invests 38.8 Mio. USD in Wind Energy

Recent News (9 May 2011):

"Special Report on Renewable Energy Sources and Climate Change Mitigation"

→ Renewable energy could make up 77% in 2050

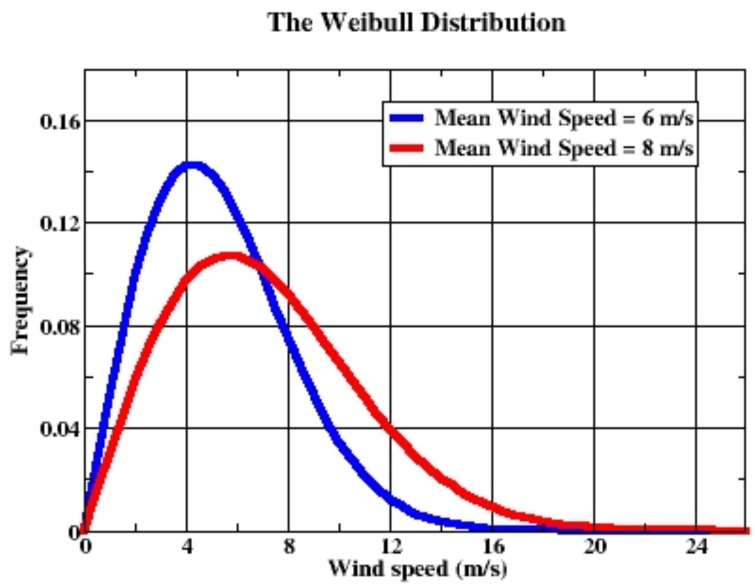
→ Wind energy could be responsible for 20%

Source: Wind Power Ninja

Wind Speed and Energy

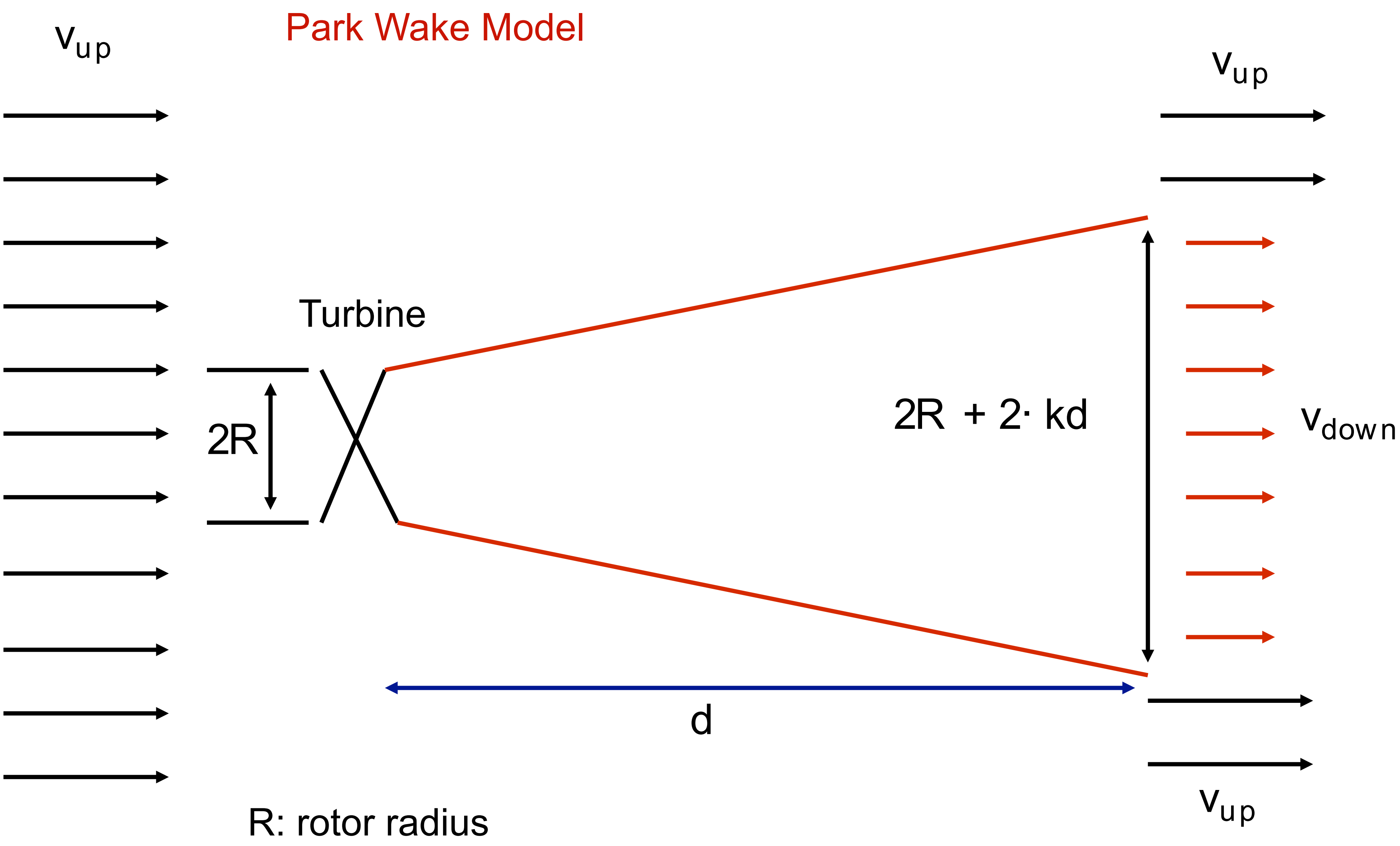
Wind Speed:

- Most crucial for energy production
- Varies over time
- Depends on seasonal effects
- Weibull distribution gives a good representation of the variation in hourly mean wind speed over a year at many typical sites



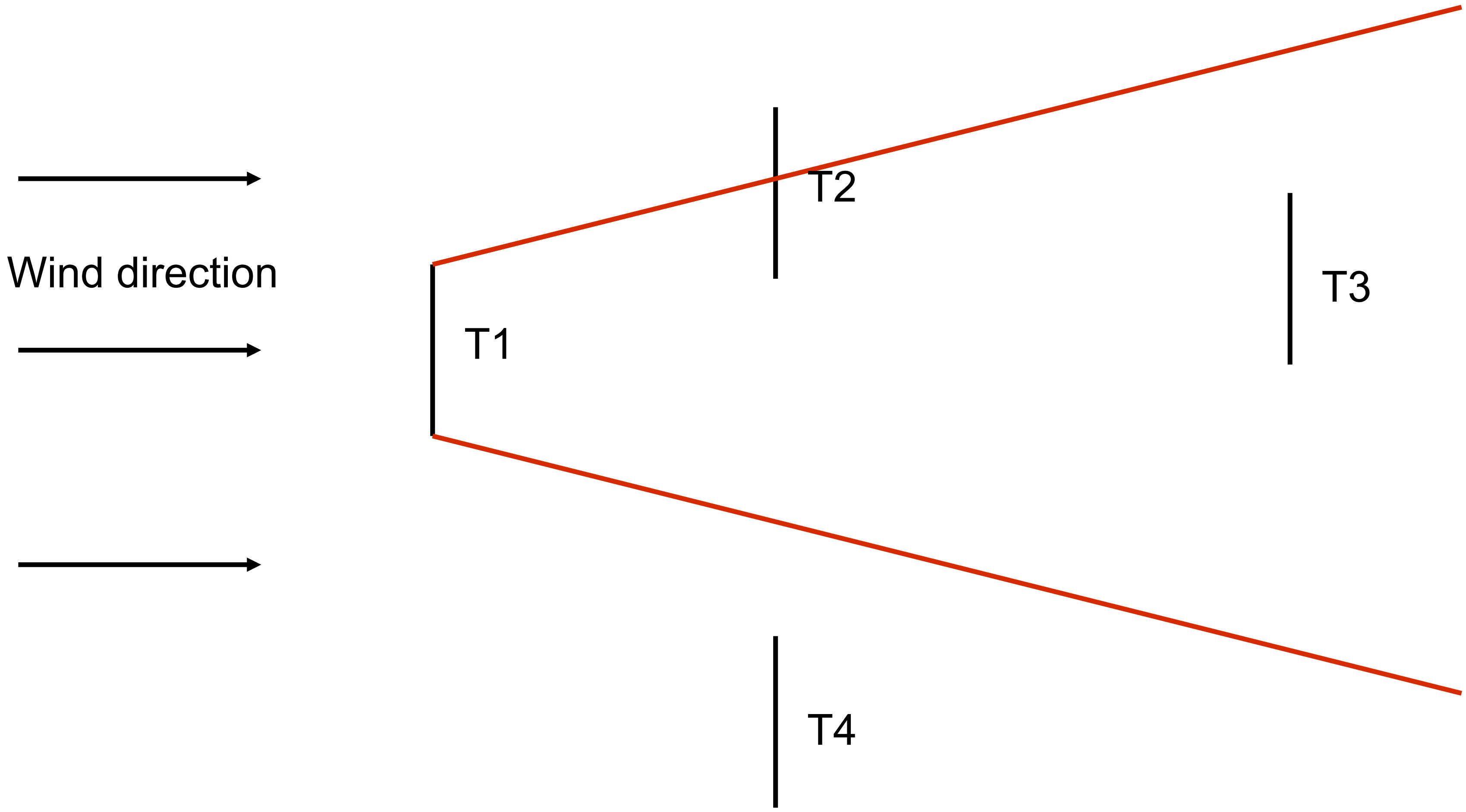
Wake

Source: Cooperative Institute for Research in Environmental Science



v_{up}
Park Wake Model
v_{up}
Turbine
2R
$2R + 2\cdot kd$
v_{down}
d
R: rotor radius
v_{up}

Wake effect



Computation of the wake effect (Kusiak and Song 2010)

Let $X = \{x_1, \ldots, x_n\}$ and $Y = \{y_1, \ldots, y_n\}$ be x and y coordinates of the n turbines

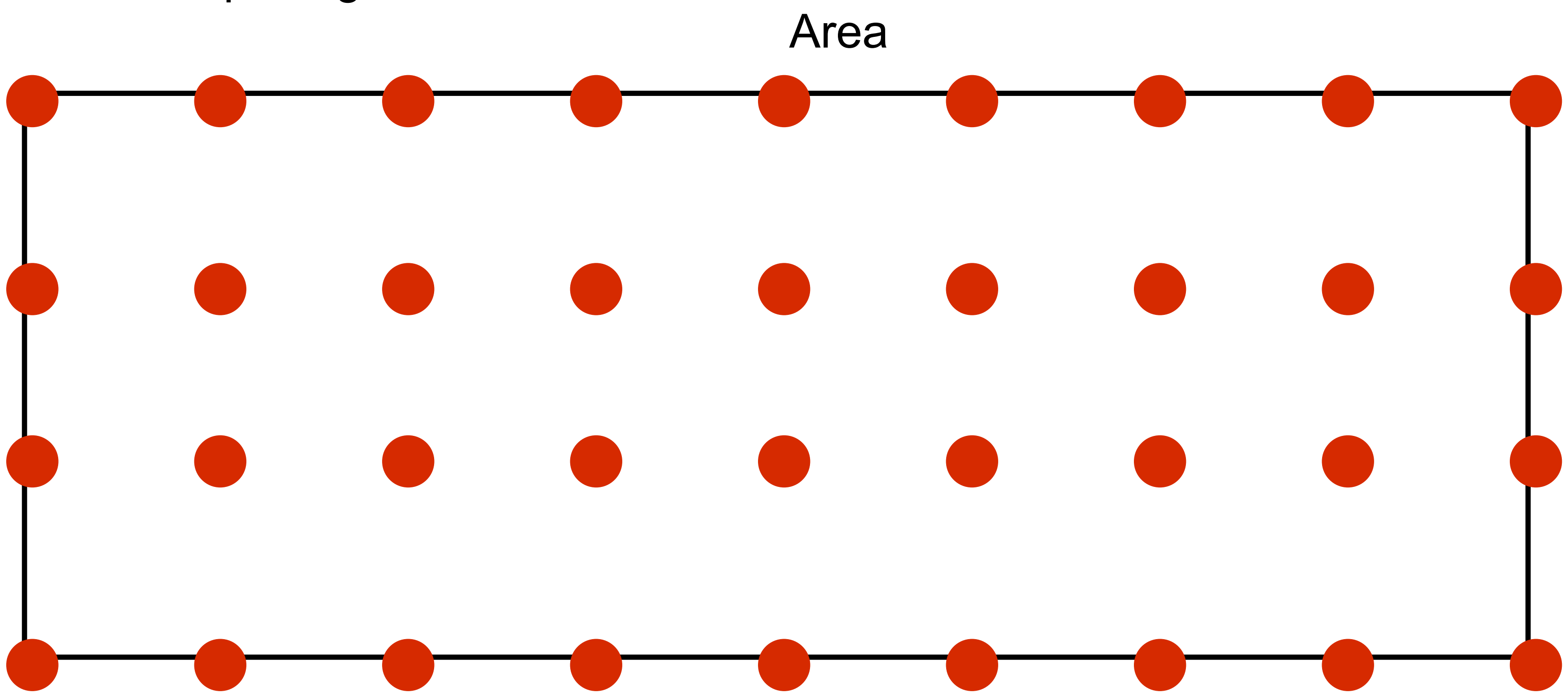
for $i = 1$ to number of turbines **do**
  for $\theta = 0^0$ to 360^0 **do**
    for $j = 1$ to n-1 and $j \neq i$ **do**
      $\delta_{i,j} = cos^{-1}\{\frac{o+R/\kappa}{\sqrt{(x_i - x_j + (R/\kappa)cos\theta)^2 + (y_i - y_j + (R/\kappa)sin\theta)^2}}\}$
      $Vdef_{(i,j)} = u(\delta_{i,j} - \alpha)\frac{a}{(1+bd_{i,j})^2}$
    end for
    $Vdef_i^\theta = \sqrt{\sum_j (Vdef_{(i,j)})^2}$
    $\boxed{c_i(\theta)} = c_i(\theta) \times (1 - Vdef_i)$
  end for
end for

Wake effect only changes scaling parameter of Weibull distribution

Experimental Study

Turbine Placement on wind farm

Maximal spacing initialization



Wind Scenario (Kusiak and Song, Renewable Energy 2010)

$l-1$	θ^{l-1}	θ^l	k	c	$P(\theta)$	$l-1$	θ^{l-1}	θ^l	k	c	$P(\theta)$
0	0	15	2	7	0.0002	12	180	195	2	10	0.1839
1	15	30	2	5	0.008	13	195	210	2	8.5	0.1115
2	30	45	2	5	0.0227	14	210	225	2	8.5	0.0765
3	45	60	2	5	0.0242	15	225	240	2	6.5	0.008
4	60	75	2	5	0.0225	16	240	255	2	4.6	0.0051
5	75	90	2	4	0.0339	17	255	270	2	2.6	0.0019
6	90	105	2	5	0.0423	18	270	285	2	8	0.0012
7	105	120	2	6	0.029	19	285	300	2	5	0.001
8	120	135	2	7	0.0617	20	300	315	2	6.4	0.0017
9	135	150	2	7	0.0813	21	315	330	2	5.2	0.0031
10	150	165	2	8	0.0994	22	330	345	2 4.	5	0.0097
11	165	180	2	9.5	0.1394	23	345	360	2	3.9	0.0317

Kusiak and Song use evolution strategy

Only results for up to 6 turbines.

Evolutionary Algorithm

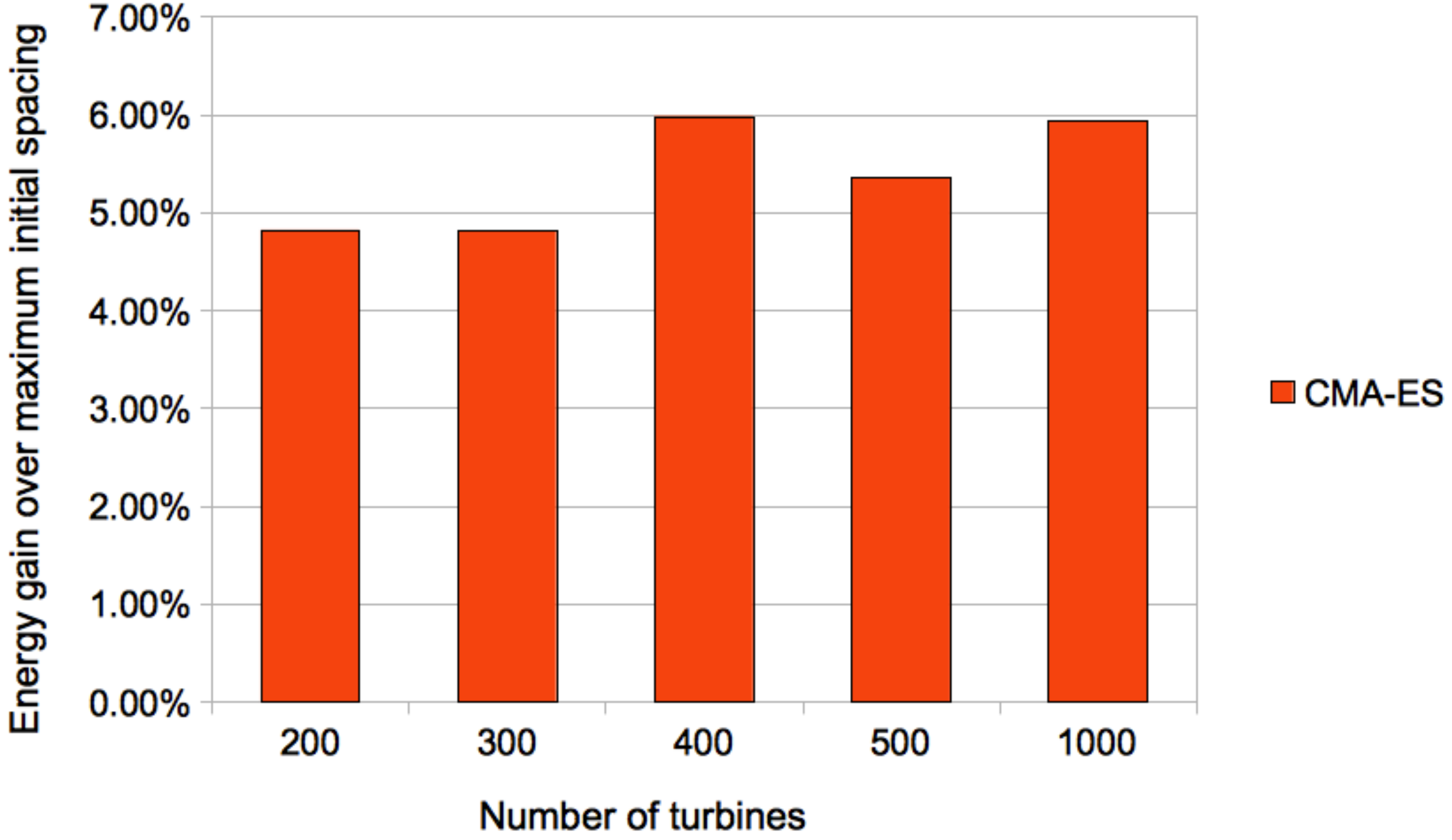
- Optimization recipe
- Mimic nature (mating: crossover & mutation)
- Very robust

Experimental Studies:

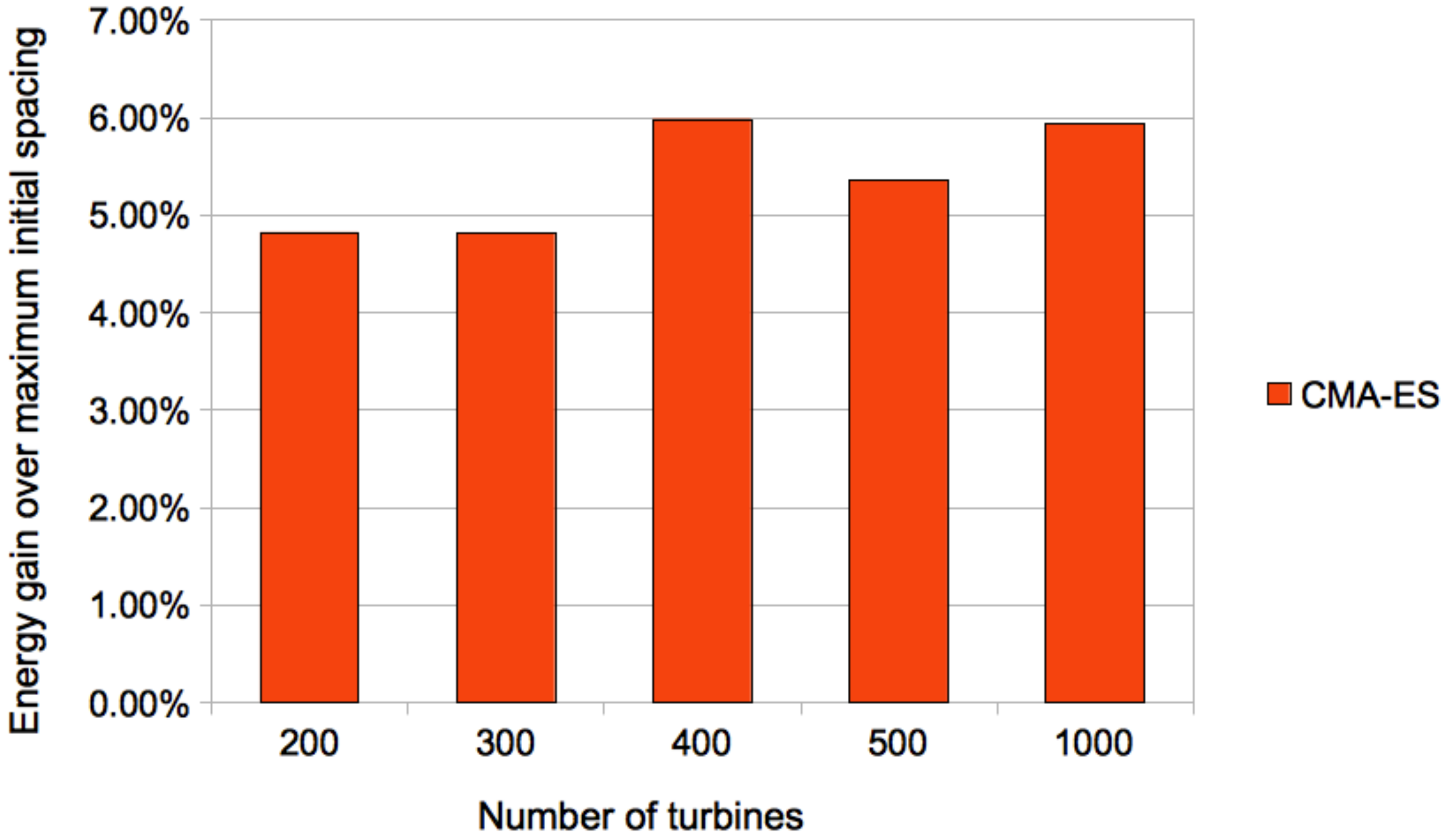
- Use maximal spacing
- Improve by (10,20)-CMA-ES
- Include mechanism to deal with boundary constraints
- Improves results of Kusiak and Song
- What results do we get for large wind farms?

Problem:

- Evaluation is very costly for large number of turbines (single optimization: two weeks for 1000 turbines)

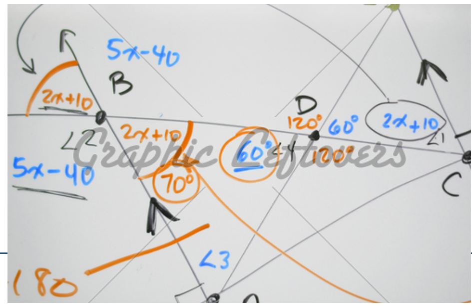

7.00%
6.00%
5.00%
4.00%
3.00%
2.00%
1.00%
0.00%
Energy gain over maximum initial spacing
200
300
400
500
1000
Number of turbines
CMA-ES

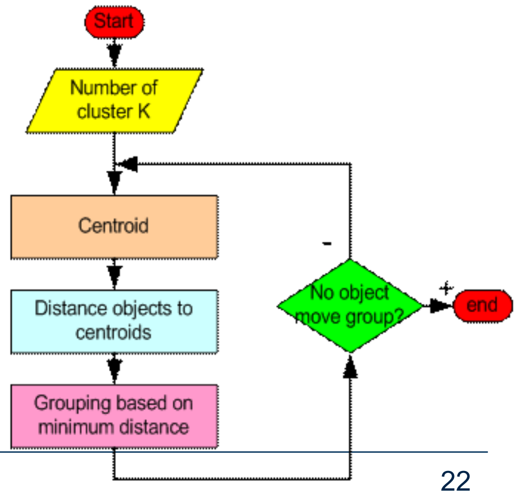
Assuming 7.2 Cent/kWh:
Can translate into 223.3 Mio / USD 1.4 Bio RMB per year



Summary:

- Renewable energy is an interesting field with challenging optimization problems
- Problems are very complex
- Evolutionary algorithms *(our key technology)* are well suited for tackling these problems
- There is a lot of money in this field (grants, government support, industry funding)
- Computer Science should play a key role





Future Work:

- Improve simulator: nonlinear power curves, mixed wind farms, more complex wake models
- Combination with other design parameters (cable length)
- Multi-objective problems
- Project at Future SOC Lab of the Hasso-Plattner-Institut

Thank you!