Technical University of Denmark

Wind farm design in complex terrain: the FarmOpt methodology

Feng, Ju; Shen, Wen Zhong; Hansen, Kurt Schaldemose; Vignaroli, Andrea; Bechmann, Andreas; Zhu, Wei Jun; Larsen, Gunner Chr.; Ott, Søren; Nielsen, Morten; Jogararu, Madalina Marilena; Thøgersen, Mikkel; Hu, Y.; Xu, C.; Liu, W.

Publication date:
2017

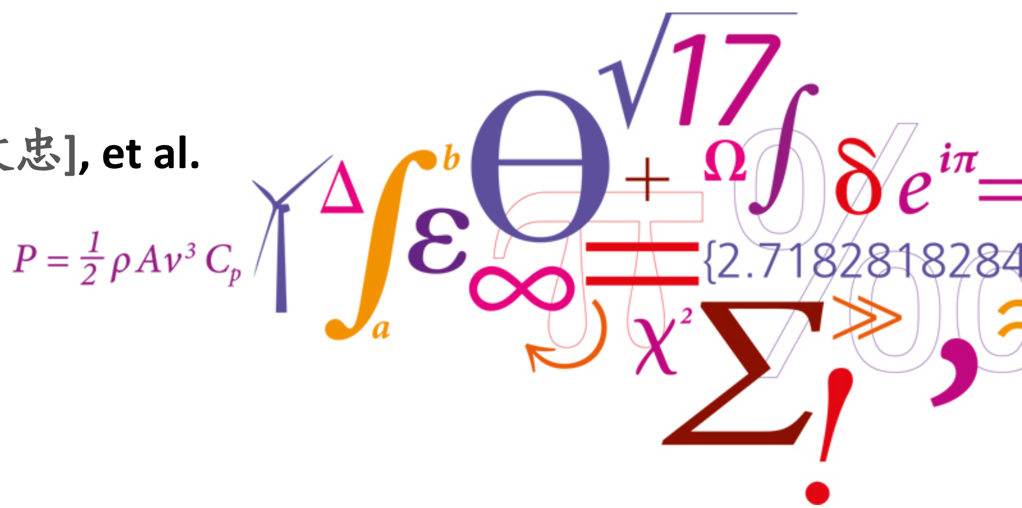
Document Version
Peer reviewed version

Wind Farm Design in Complex Terrain:

The FarmOpt Methodology

Ju Feng [冯驹], Wen Zhong Shen [沈文忠], et al.

Email: jufen@dtu.dk



DTU Wind Energy
Department of Wind Energy

CWP 2017, Beijing
Date: 2017-Oct-18

Acknowledgements

This tool was developed in the project "**Wind Farm Layout Optimization in Complex Terrain (FarmOpt)**", with funding from The Energy Technology Development and Demonstration Program (**EUDP**) under Danish Energy Agency.

Contributing organizations in this project include: **DTU Wind Energy**, **EMD International A/S**, **Ho-Hai University**, **North West Survey Institute**.

Outlines

0. About DTU Wind Energy
1. Introudction
2. Wind Farm Modelling
3. Layout Optimization
4. Test Case
5. Conclusions & Future Developments

Simens SWT-8.0-154
@ Test Centre Østerild
of DTU Wind Energy

0. DTU Wind Energy (Technical Univeristy of Denmark)

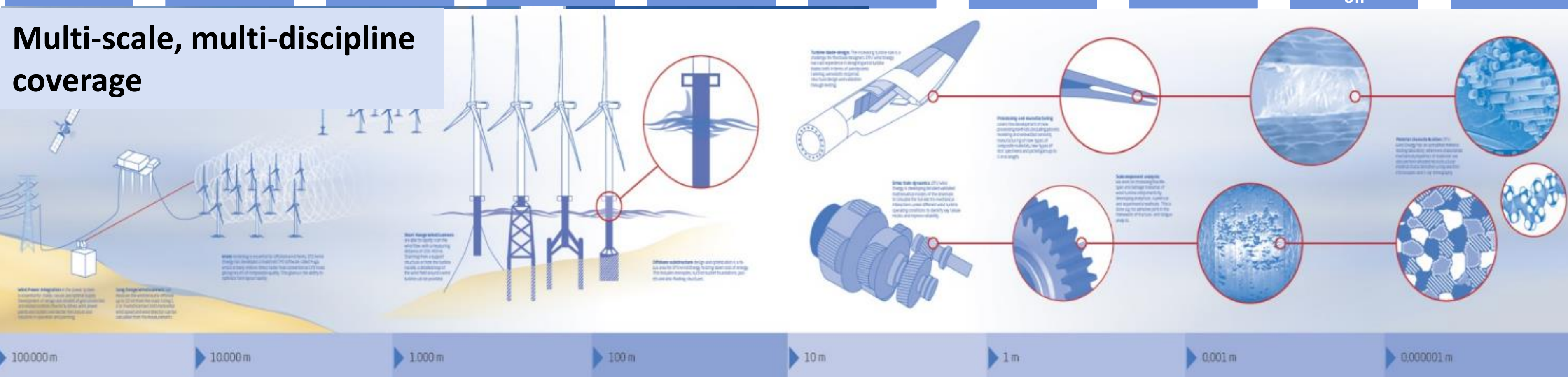
DTU Wind Energy is one of the world's largest centres of wind energy research and knowledge, with a staff of more than 250 people working in research, innovation, research-based consulting and education.

0. DTU Wind Energy (Technical Univeristy of Denmark)

DTU Wind Energy

RAM	MES	INP	LAC	FLU	AER	SAC	TEM	MAC	COM
Resource Assessment Modelling	Meteorology and Remote Sensing	Integration and Planning	Loads and Control	Fluid Mechanics	Aerodynamic Design	Structures and Component Design	Test and Measurements	Material Science & Characterization	Composites & Materials Mechanics

Multi-scale, multi-discipline coverage



Siting and integration

Offshore wind energy

Wind turbine technology

Education and teaching

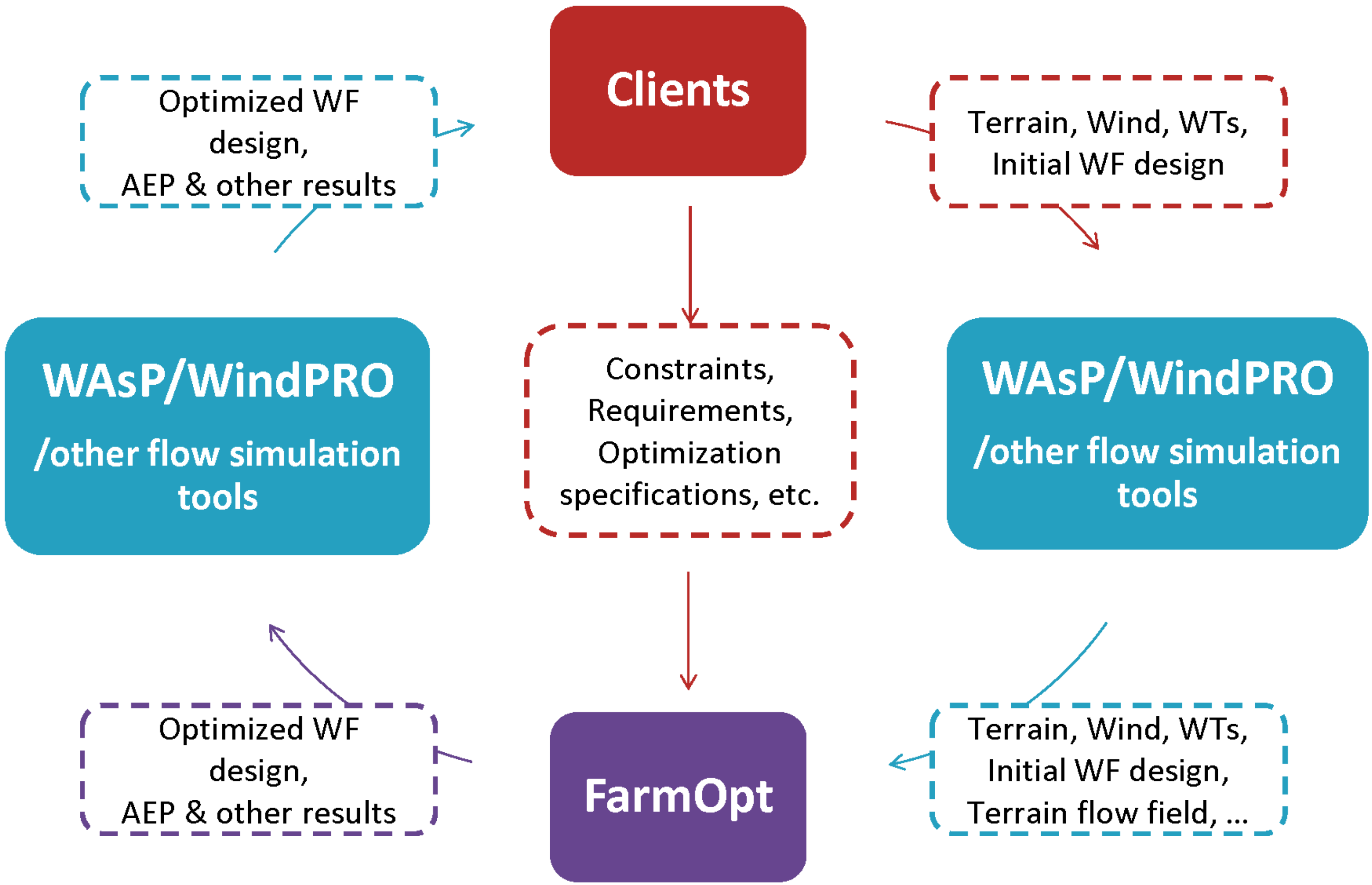
Research based consultancy and tests

1. Introduction

- More wind farms in complex terrain (esp. China)
- Great potential & many challenges
  - Richer wind resources
  - More complex flow, more expensive O&M
- Wind resource based micro-siting insufficient

- The FarmOpt methdology:
  - State-of-the-art flow simulation tool (WAsP CFD) +
  - Adapted wake model +
  - Advanced layout optimization algorithm +
  - Realisitic constraints or requirements.

- The FarmOpt tool:
  - Standard-alone tool
  - Modular design written in Python
  - Will be integrated with WindPRO and WAsP.



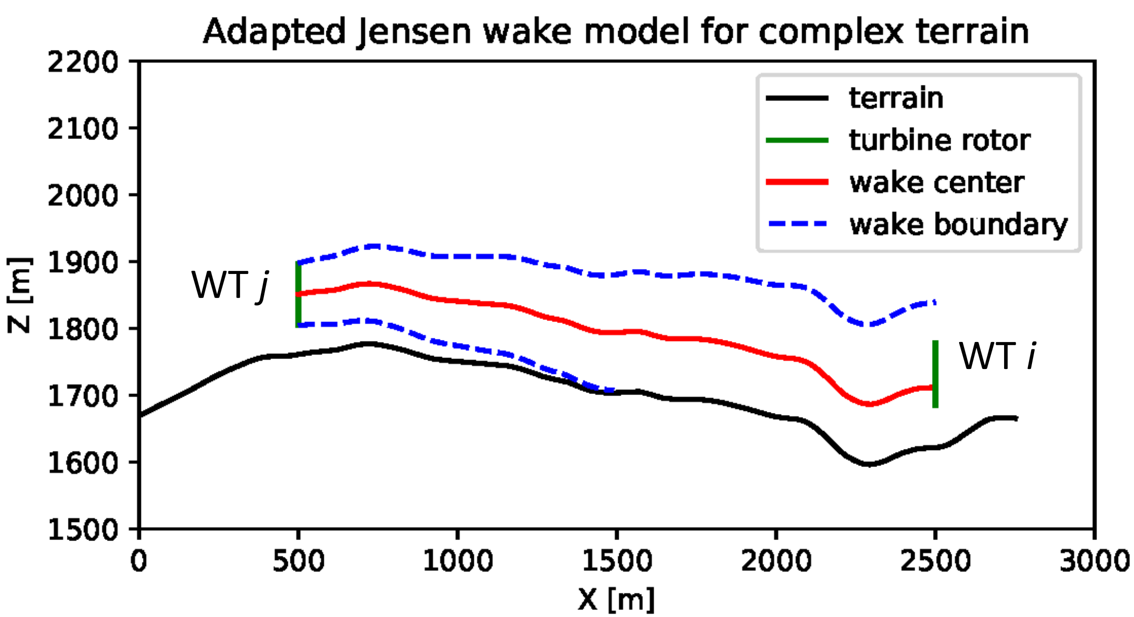
Flowchart of using FarmOpt

2. Wind Farm Modelling

- ❑ Wind resource
  - Sector-wise Weibull parameters, speed-up factors, turning-angles, mean wind speeds, etc.
  - Obtained from standard wind ressource assessment tools (WAsP, WindPRO)
- ❑ Constraint modelling
  - Inclusive boundaries, exclusive zones, …
  - Minimal mean wind speed, TI, …
  - Maximal terrain ruggedness degree, slope, …
  - Minimal distance between any two turbines, …

❑ Wake modelling (adapted Jensen wake model)

- Wake center follows terrain ground along wind direction
- Velocity deficit and wake zone radius dvelop linearly according to the travelling distance
- Multiple wakes and/or partial wakes merged at rotor satifying the kinetic energy deficit balance assumption



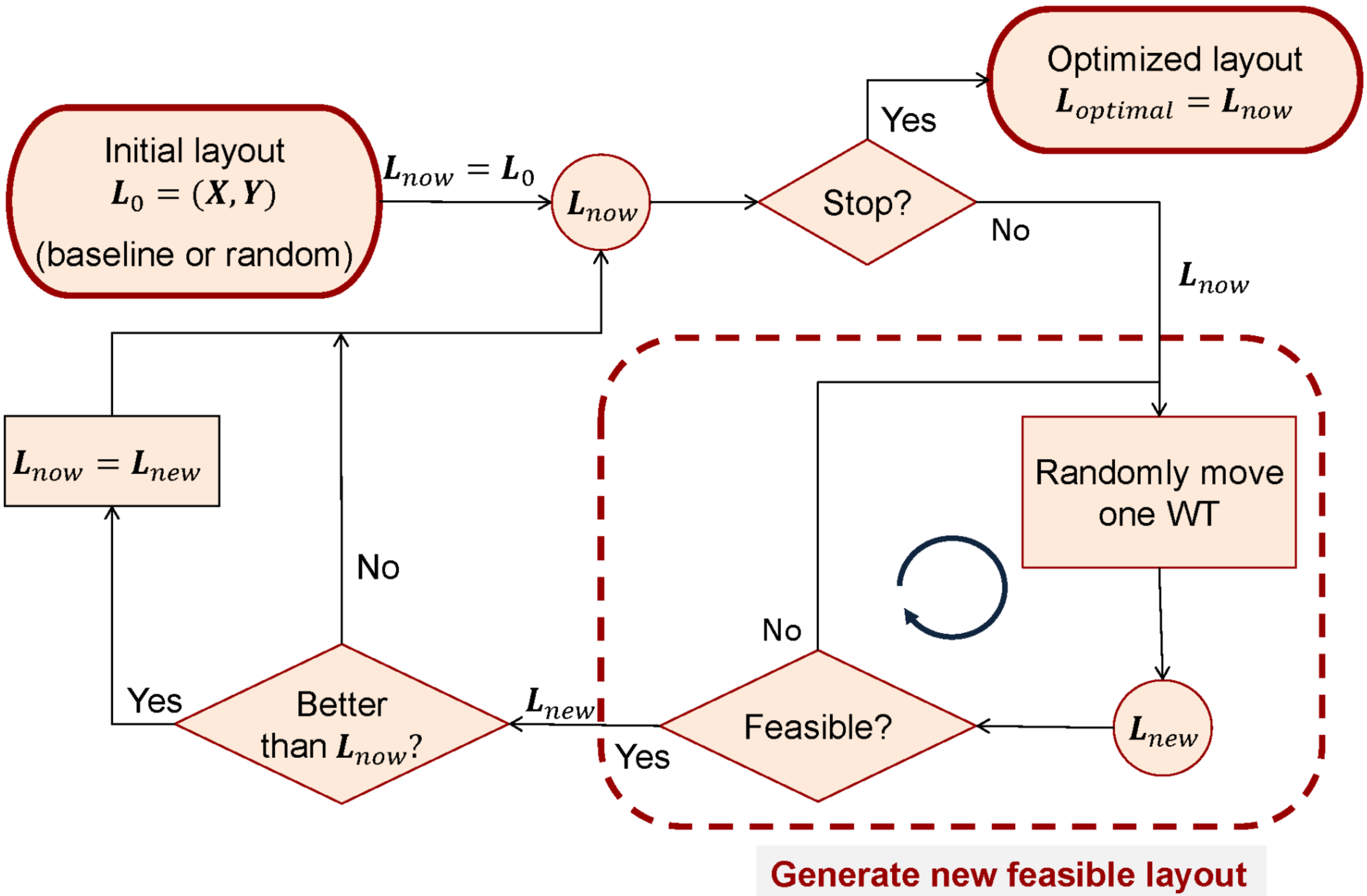
Wake influence wind speed and wake zone radius of WT*j*'s wake zone at WT*i*'s location:

$$V_{ij} = S(x_j)V_0\left[1 - \frac{1-\sqrt{1-C_T(S(x_j)V_0)}}{(1+\alpha(s_{ij}/R_r))^2}\right]$$

$$R_{ij} = \alpha s_{ij} + R_r$$

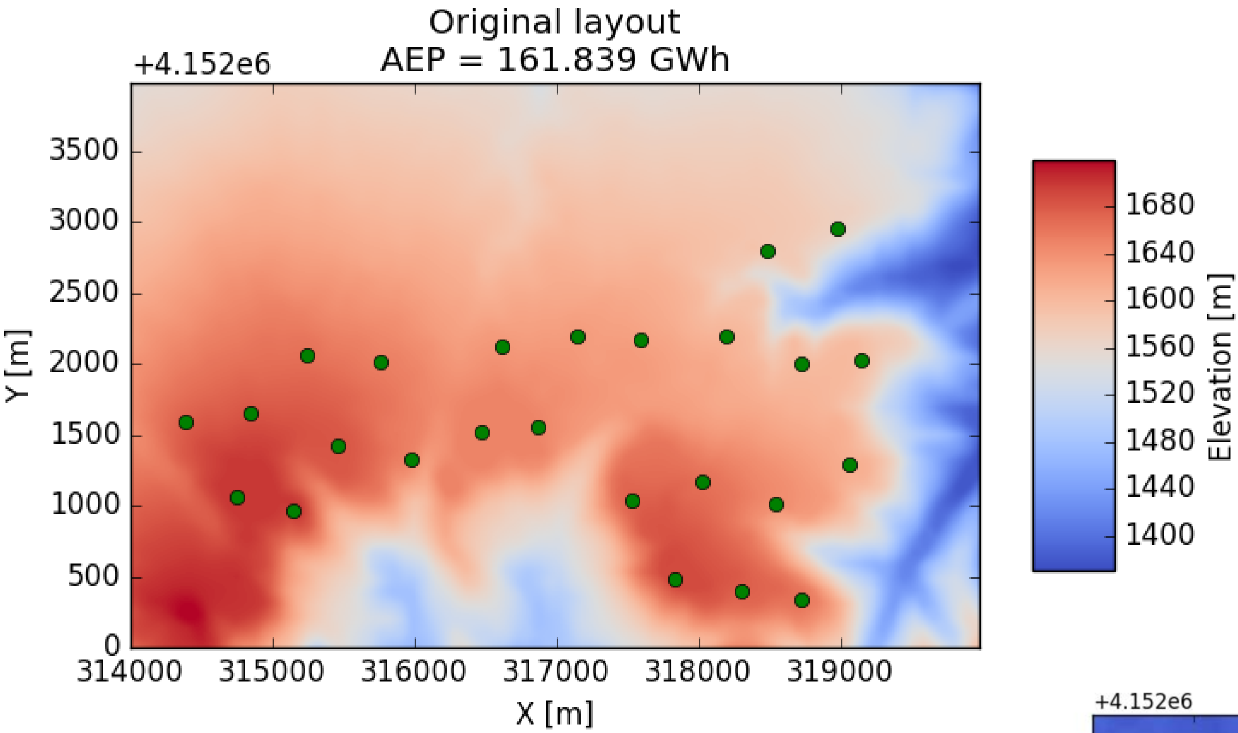
[Ref] Feng, J., & Shen, W. Z. (2014). Wind farm layout optimization in complex terrain: A preliminary study on a Gaussian hill. In Journal of Physics: Conference Series (Vol. 524, No. 1, p. 012146).

3. Layout Optimization (Random Search)

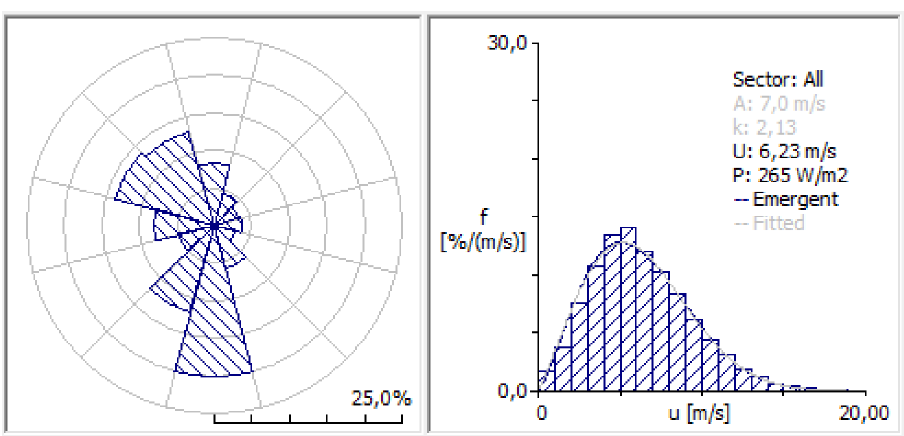


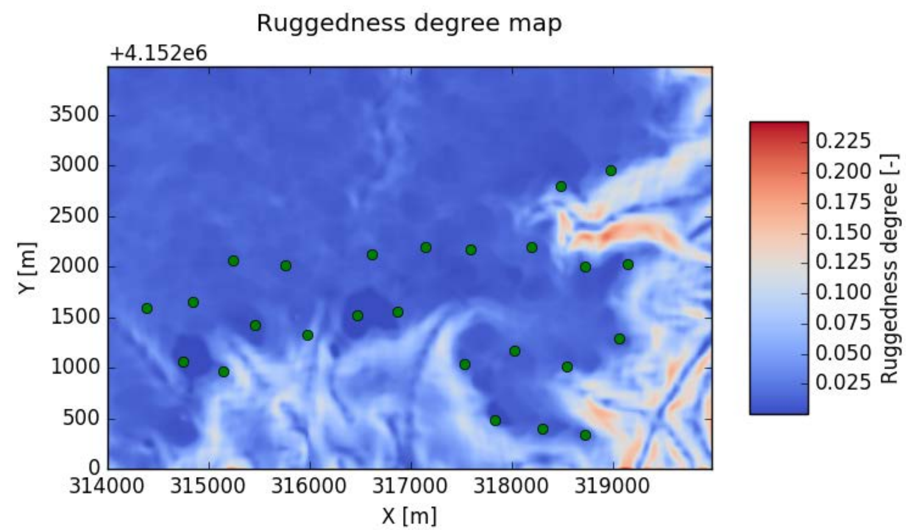
[Ref] Feng, J., & Shen, W. Z. (2015). Solving the wind farm layout optimization problem using random search algorithm. Renewable Energy, 78, 182-192.

4. Case study (a 25 turbine wind farm in China)

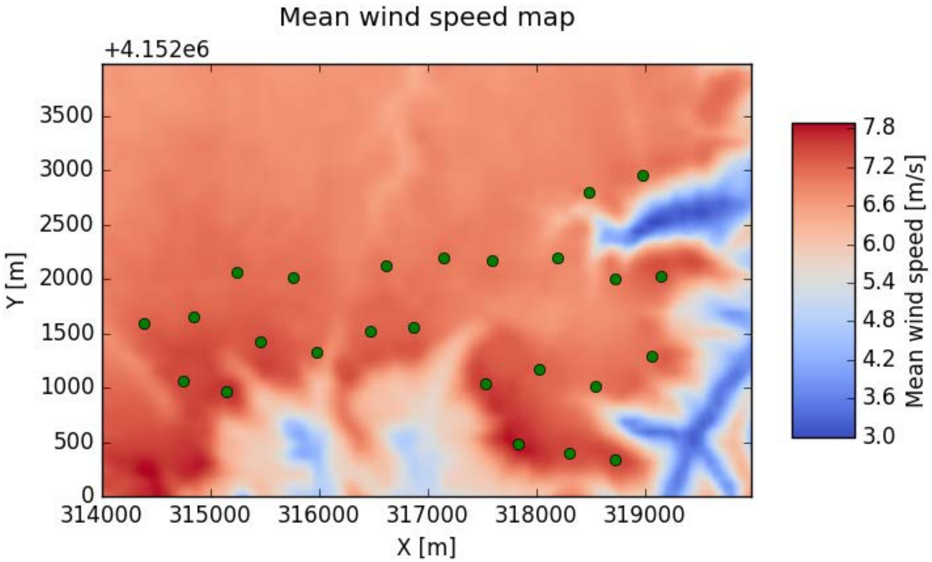


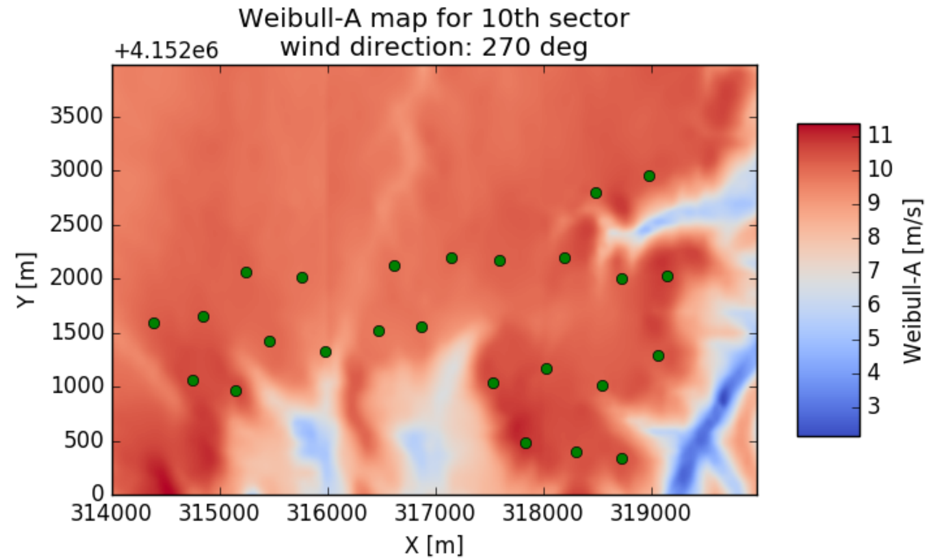
- 2 MW turbine by a Chinese OEM
- D: 93 m, H: 67 m
- Located in Northwest China
- Mean wind speed: 6.23 m/s

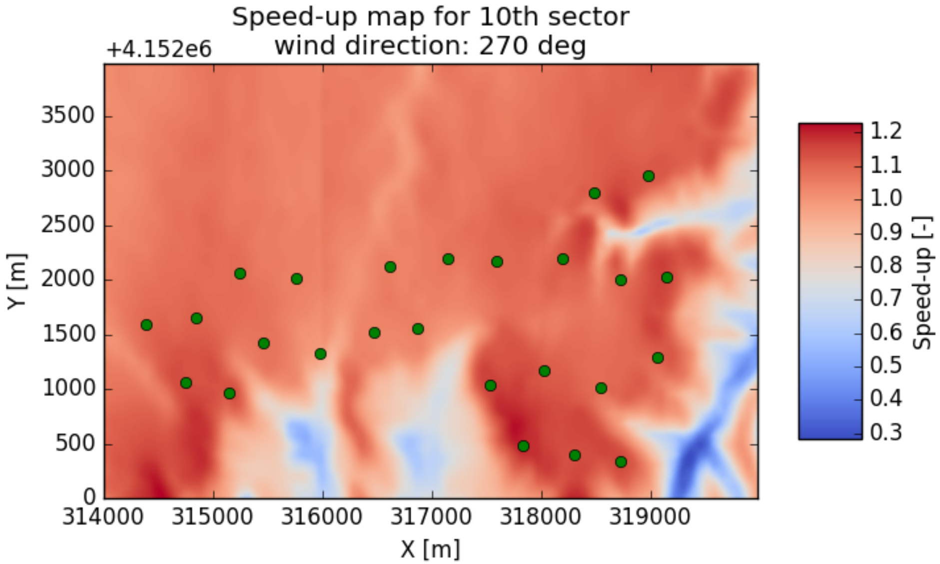


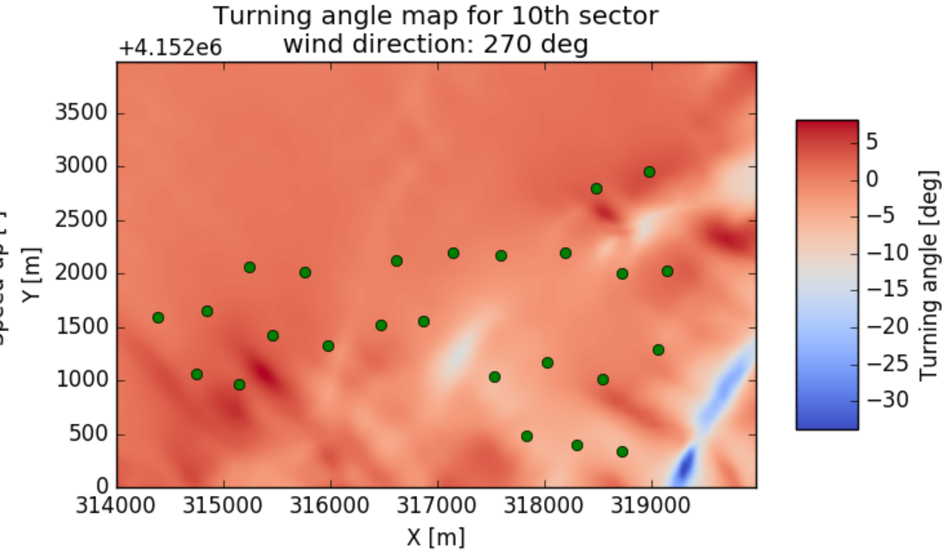


Wind resource and terrain effects from WAsP

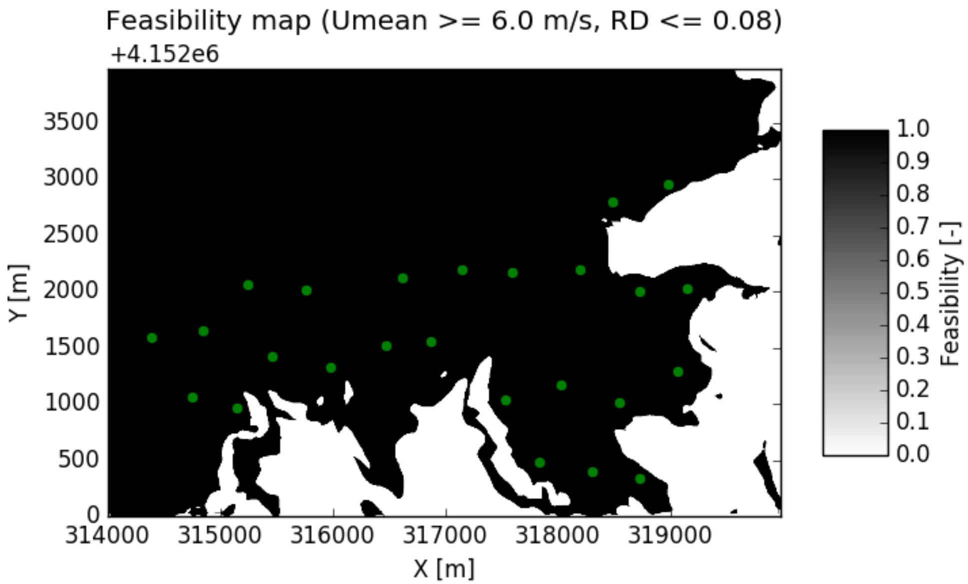




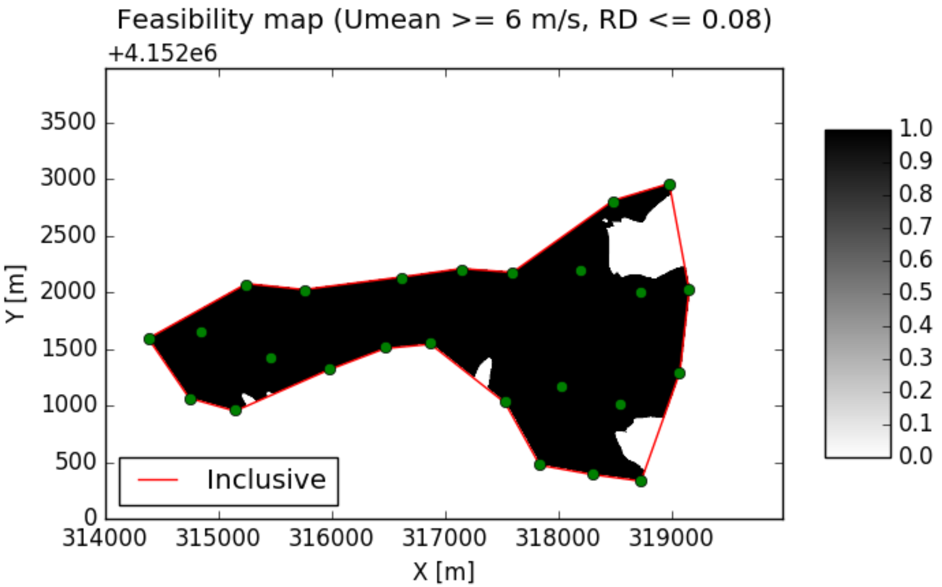


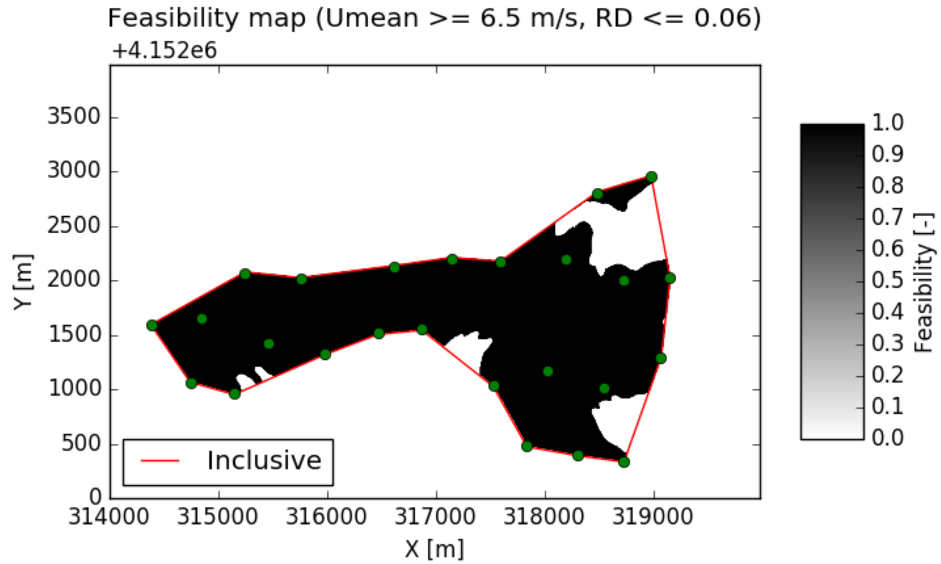


Constraints

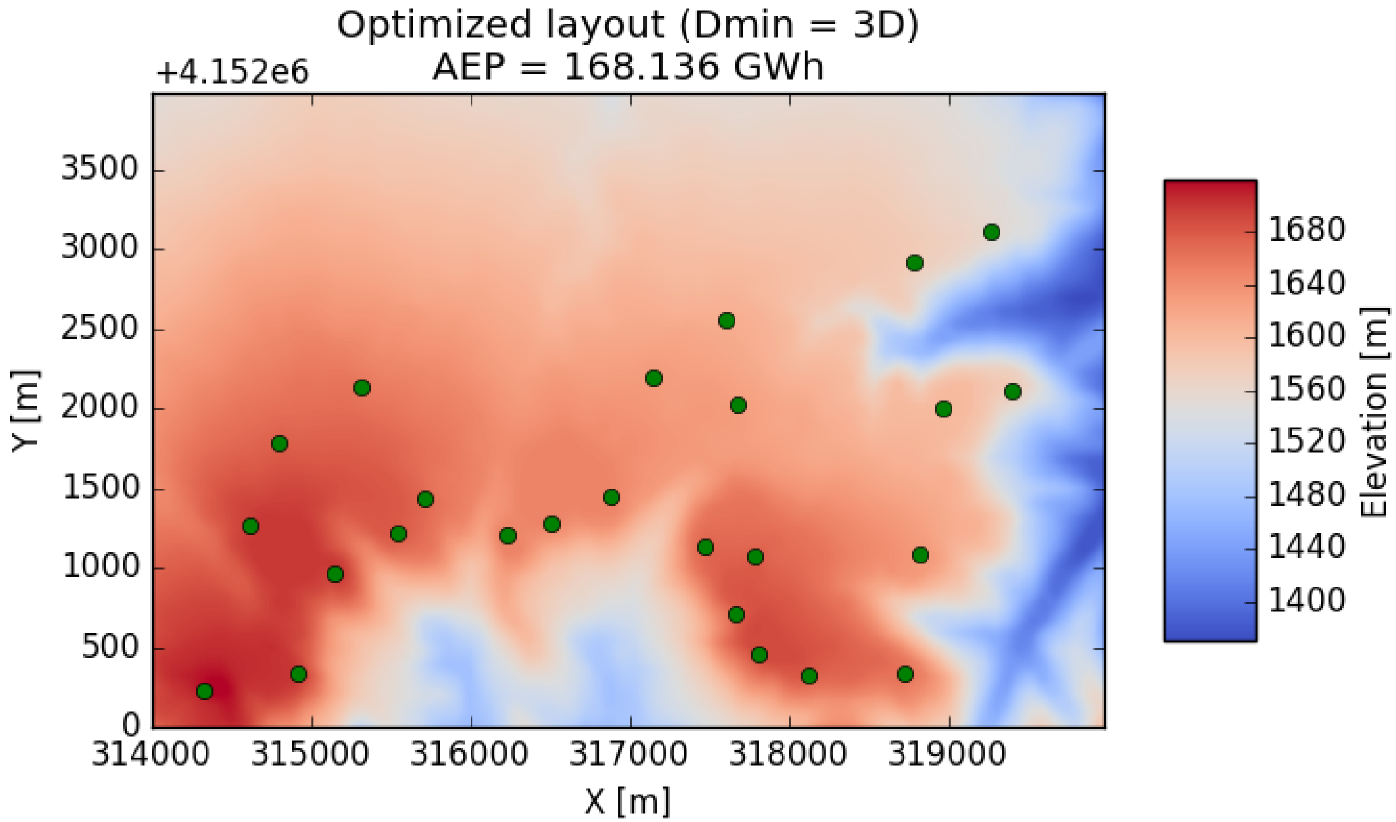


- Minimal Umean
- Maximal ruggedness degree (RD)
- Minimal distance (Dmin = n*D)
- Inclusive boundary
- Exlusive boudnaries
- Others on such as turbulence intensity, total capacity, noise …





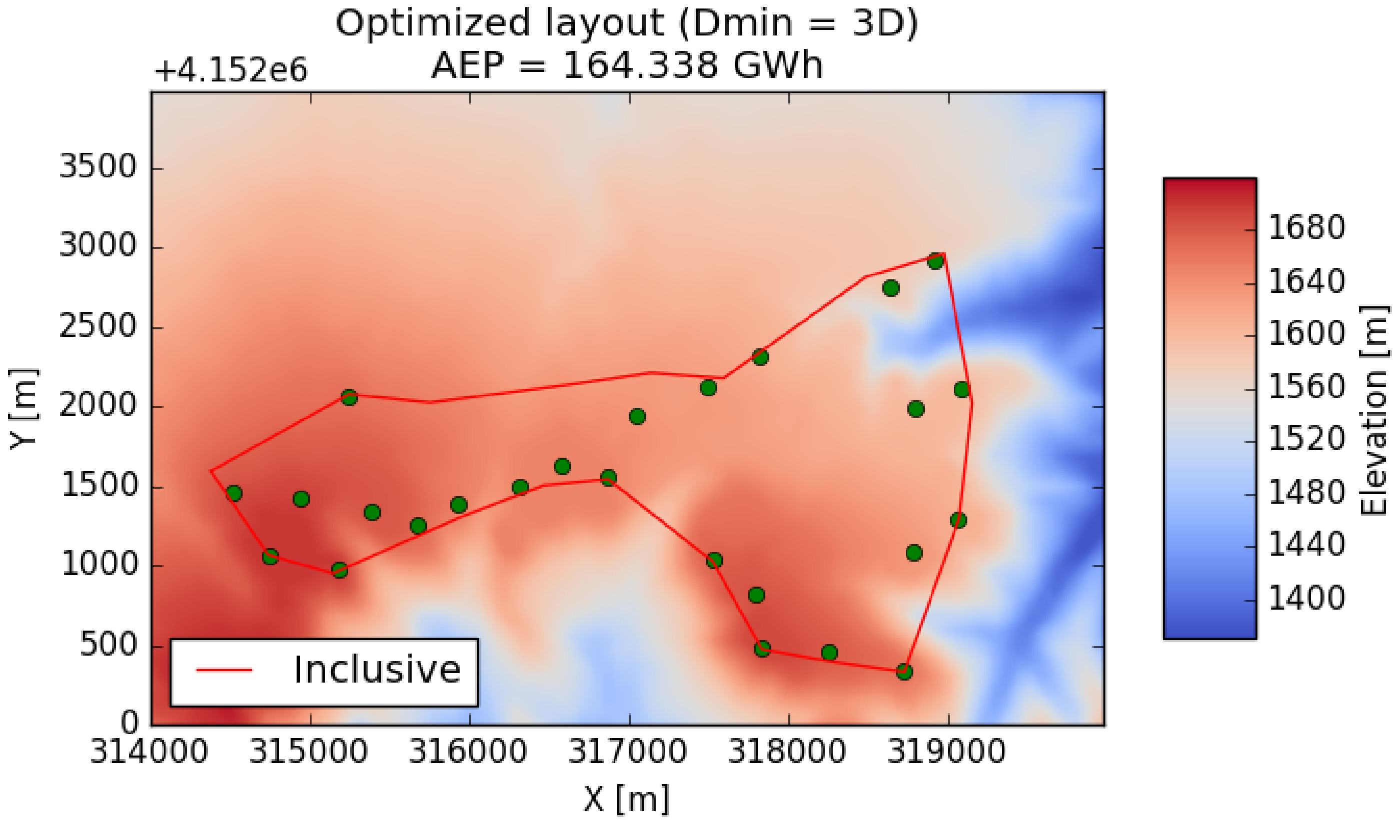
Optimized layout: scenario 1



- Constraints: Umean >= 6 m/s, RD <= 0.08, Dmin = 3D
- No inclusive boundary
- Net AEP improvement: 161.839 GWh to 168.136 GWh **(+3.89%)**
- Number of evaluations: 1000, cpu time: 12300 s.

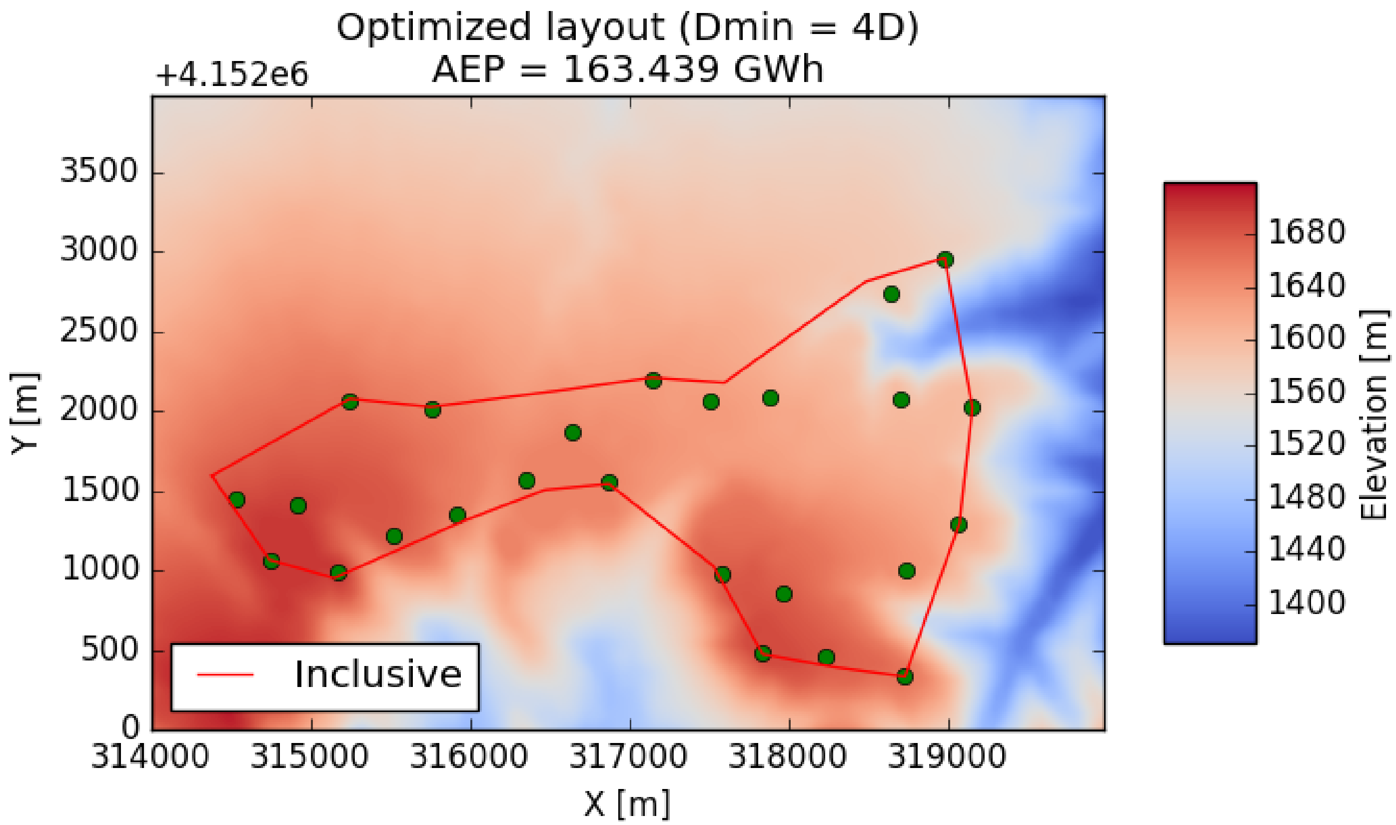
[Time as running on a 5 year old Dell laptop with intel i5-2520M CPU]

Optimized layout: scenario 2



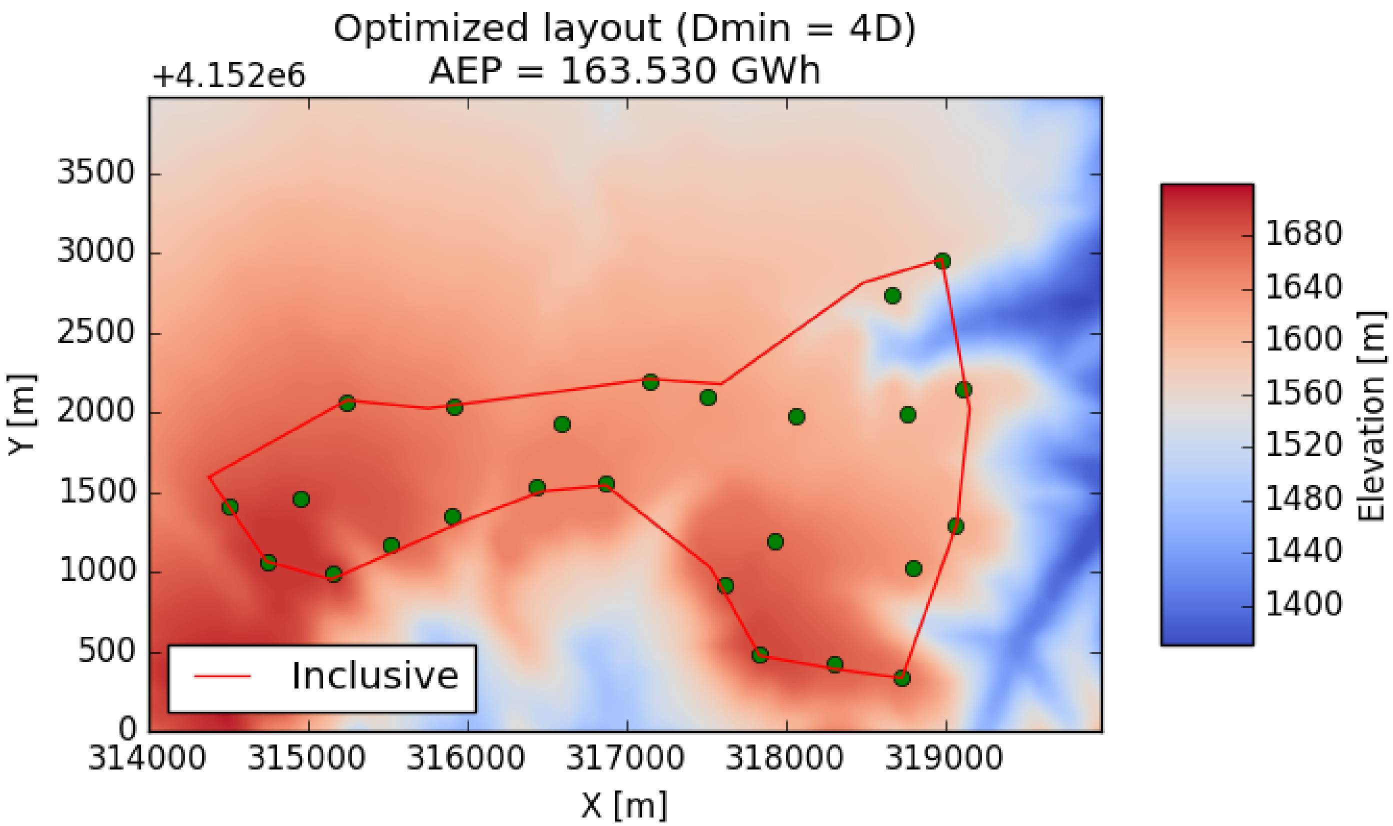
- Constraints: Umean >= 6 m/s, RD <= 0.08, Dmin = 3D
- With inclusive boundary
- Net AEP improvement: 161.839 GWh to 164.338 GWh **(+1.54%)**
- Number of evaluations: 1000, cpu time: 11257 s.

Optimized layout: scenario 3



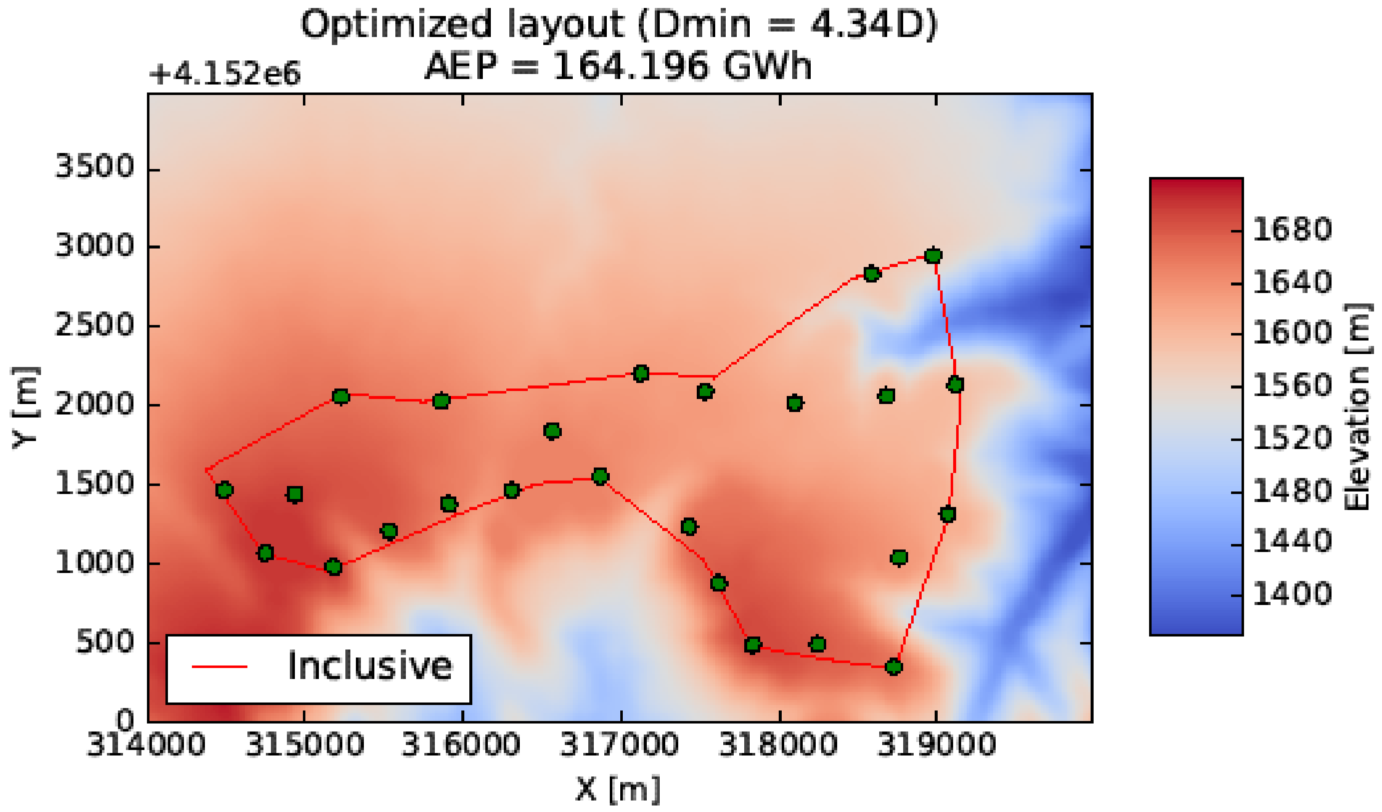
- Constraints: Umean >= 6 m/s, RD <= 0.08, Dmin = 4D
- With inclusive boundary
- Net AEP improvement: 161.839 GWh to 163.439 GWh **(+0.99%)**
- Number of evaluations: 1000, cpu time: 11264 s.

Optimized layout: scenario 4



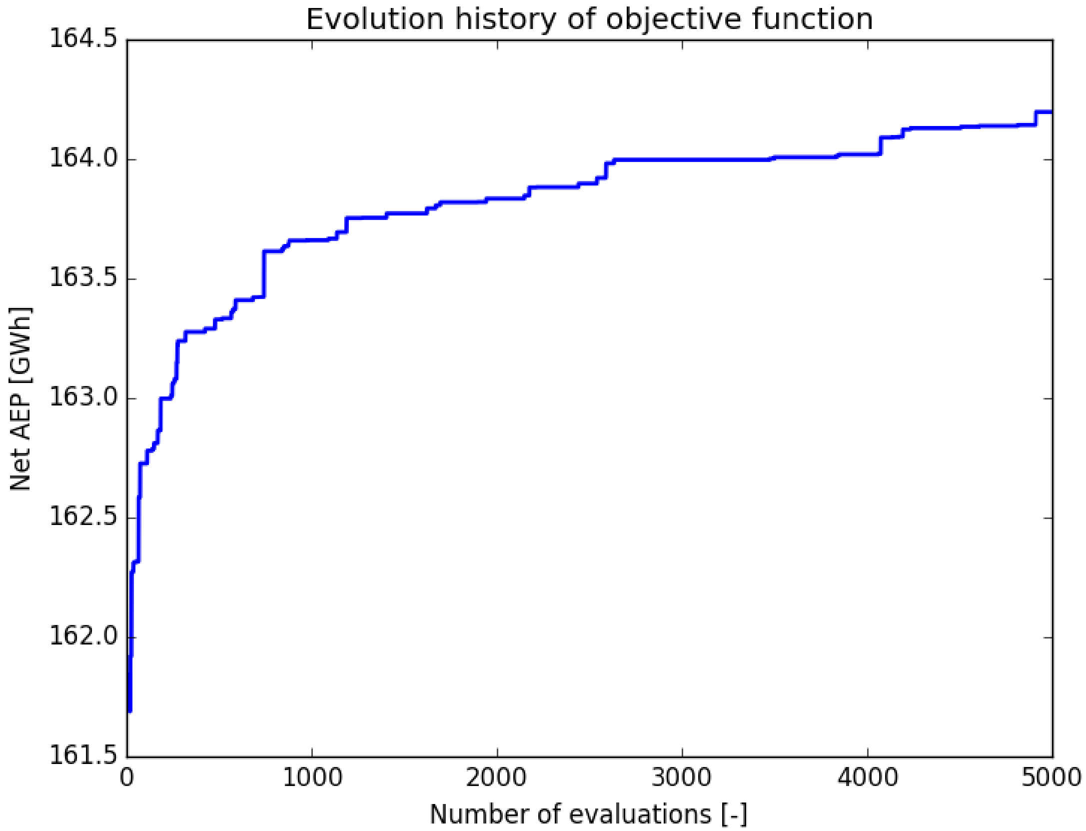
- Constraints: Umean >= 6.5 m/s, RD <= 0.06, Dmin = 4D
- With inclusive boundary
- Net AEP improvement: 161.839 GWh to 163.530 GWh **(+1.05%)**
- Number of evaluations: 1000, cpu time: 12099 s.

Optimized layout: scenario 5



- Constraints: Umean >= 6.5 m/s, RD <= 0.06, Dmin = 4.34D (current min.)
- With inclusive boundary
- Net AEP improvement: 161.839 GWh to 164.196 GWh **(+1.46 %)**
- Number of evaluations: 5000, cpu time: 63278 s.

Optimized layout: scenario 5



- Constraints: Umean >= 6.5 m/s, RD <= 0.06, Dmin = 4.34D (current min.)
- With inclusive boundary
- Net AEP improvement: 161.839 GWh to 164.196 GWh **(+1.46 %)**
- Number of evaluations: 5000, cpu time: 63278 s.

5. Conclustions & Future Developments

- FarmOpt: a valuable tool for wind farm design
- On-going developments
  - More accurate wake model by considering streamlines
  - Parallization and optimization for faster computation
- Planned developments
  - Overall design optimization
  - Integrated optimization of wind farm design and control
- A member of the synchronized DTU wind energy toolbox ...

Data tools	WAsP	WEng	WAT	CFD	Fuga	FarmOpt
Data & tools for wind and site data analysis	Wind resources for wind turbine production	Wind conditions for wind turbine loads	Site suitability for wind farm assessment	Model for complex and steep terrain	Wake model for large offshore wind farms	Wind farm design optimization

Thanks for your attention!

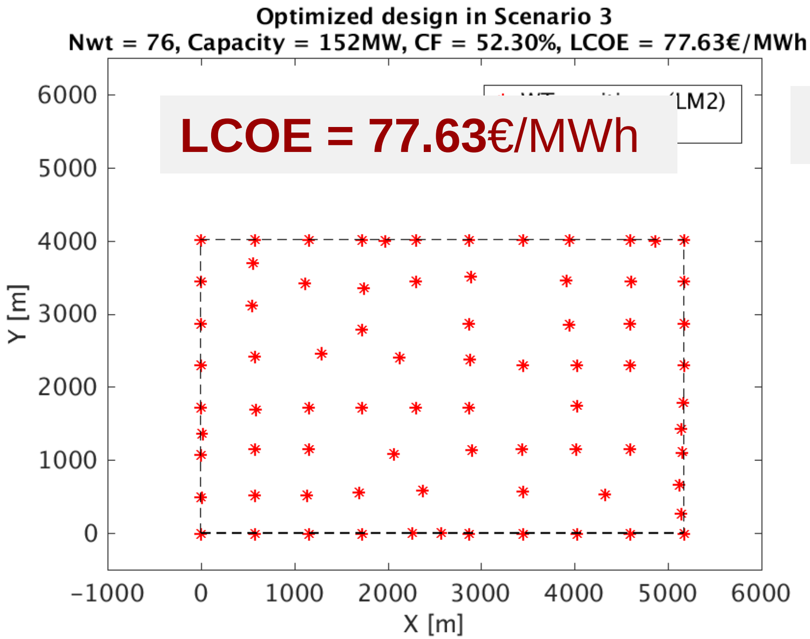
DTU Wind Energy
Department of Wind Energy

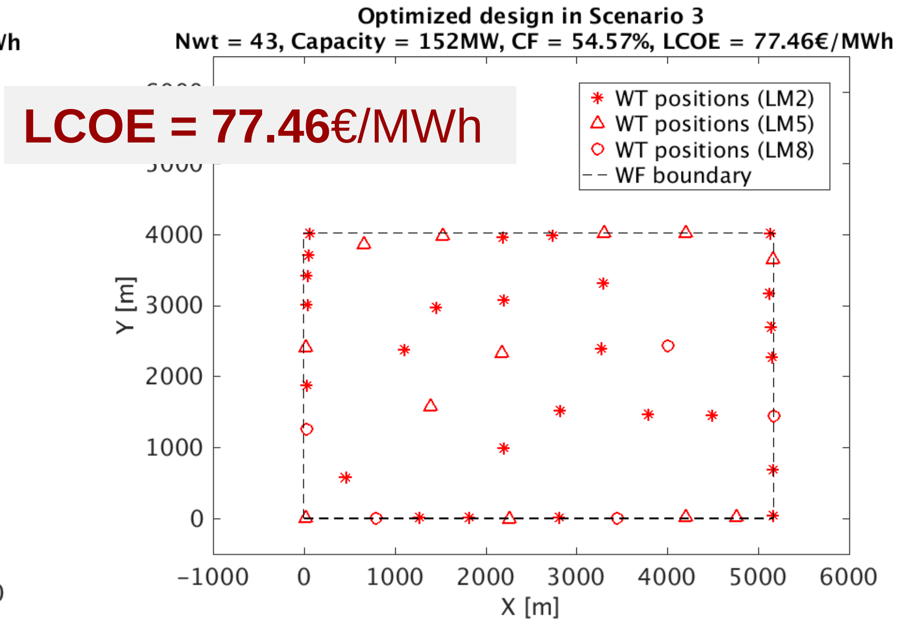
Appendix

❑ Overall design optimization:

optimizing number, configurations, locations of turbines, electrical cables, access road to min. LCOE or max. IRR with more realistic constraints, such as fatigue/extrem loads, noise, etc.

Design optimization of non-uniform wind farm (number, configurations, locations of turbines)





[Ref] Feng, J., & Shen, W. Z. (2017). Design optimization of offshore wind farms with multiple types of wind turbines, Applied Energy 205, 1283–1297.

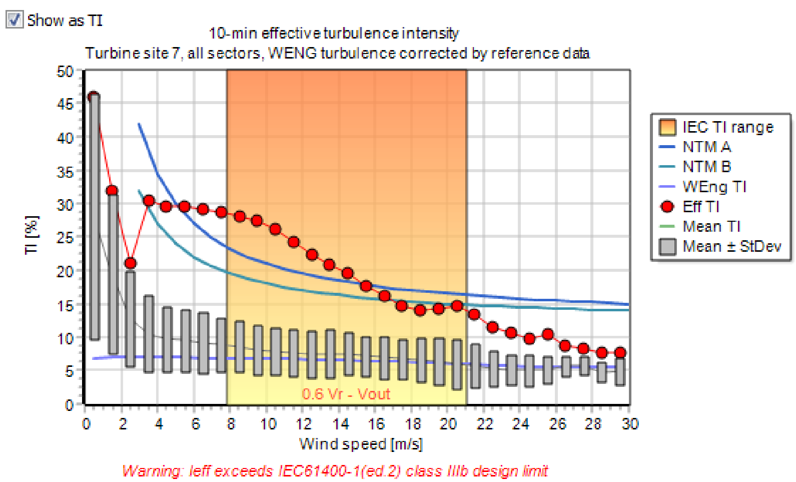
❑Integrated optimization of wind farm design and control:

including wind farm control strategies as optimization variables.

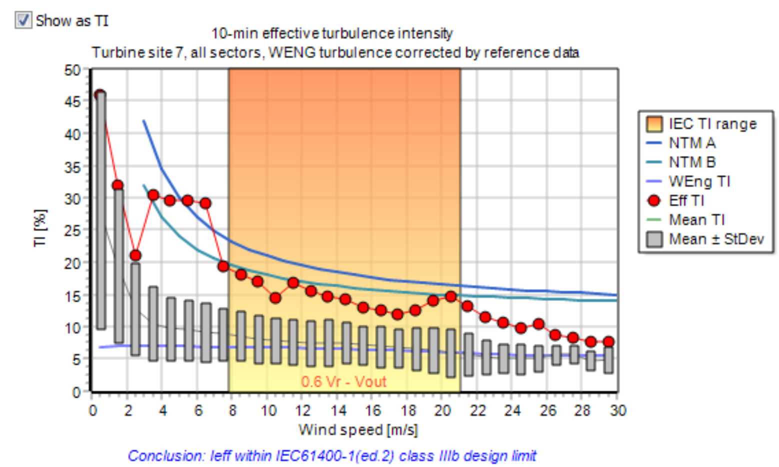
Automatic optimal sector management combined with design optimization

Allowing turbines placed closer to utilize limited high wind sites, and deal with excessive loads for certain wind directions by optimally stopping or derating certain turbines, to comply with IEC requirements on TI. The net AEP could be increased while constraints on loads satisified.

Effective TI, no management



Effective TI with management



Check WAT for sector management: http://www.wasp.dk/wat