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Park optimization using IEC constraints for wind quality

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Abstract

Park Optimizer processes WindSim results to map exclusion areas of turbulence, flow inclination, speed and extreme wind as defined by the IEC 61400-1 standard. With this information, you can design IEC compliant park layouts from the start on and choose the appropriate turbine class.

Park Optimizer uses innovative optimization algorithms to find optimal turbine layouts, taking the IEC exclusion areas as constraints.

Park Optimimizer provides not only one but a whole range of optimal layouts for each project size, which allows you to perform technoeconomic optimization that maximises the profits of your projects.

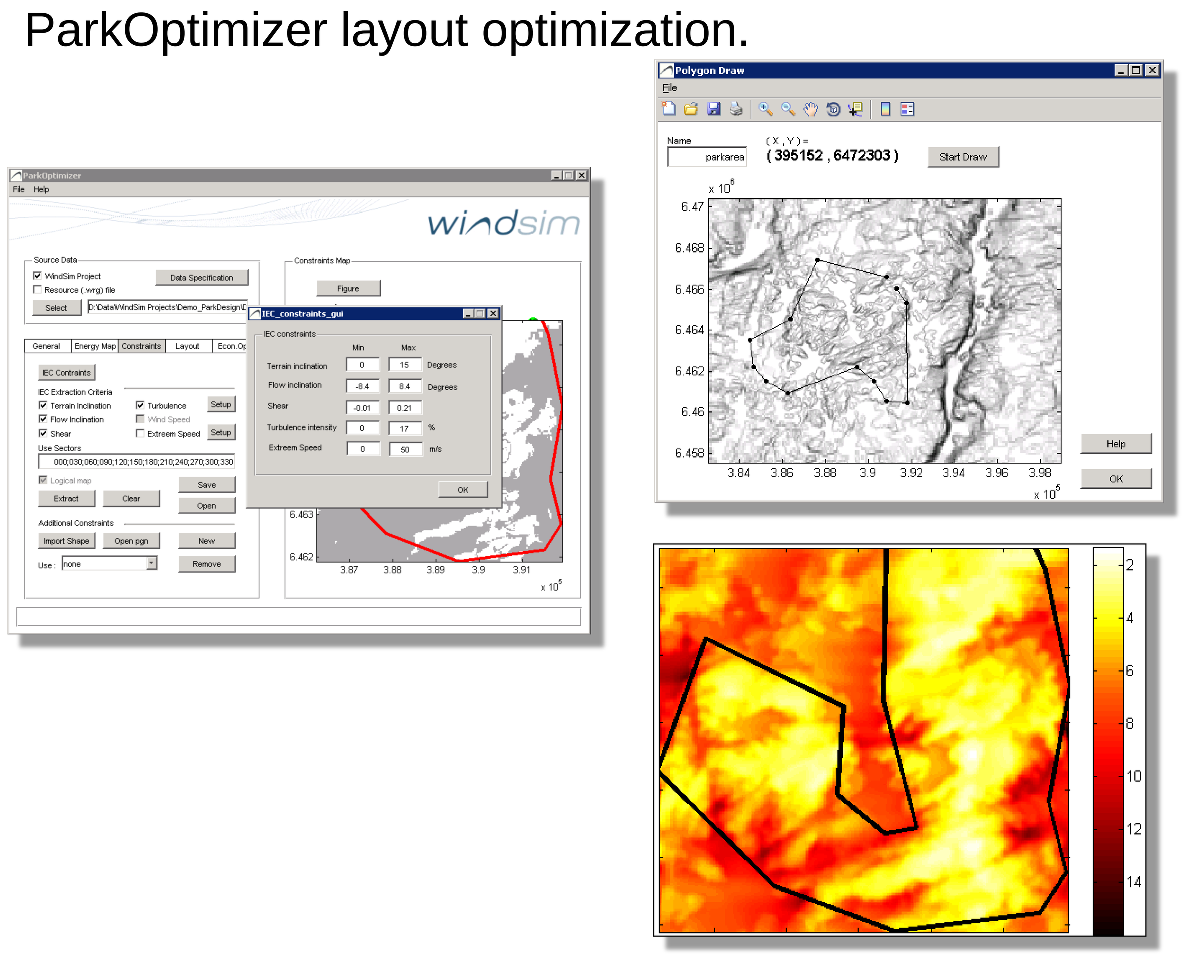
IEC exclusion areas

WindSim simulation results provide all the necessary information:

- Shear
- Flow inclination
- Turbulence
- Extreme wind
- Terrain inclination

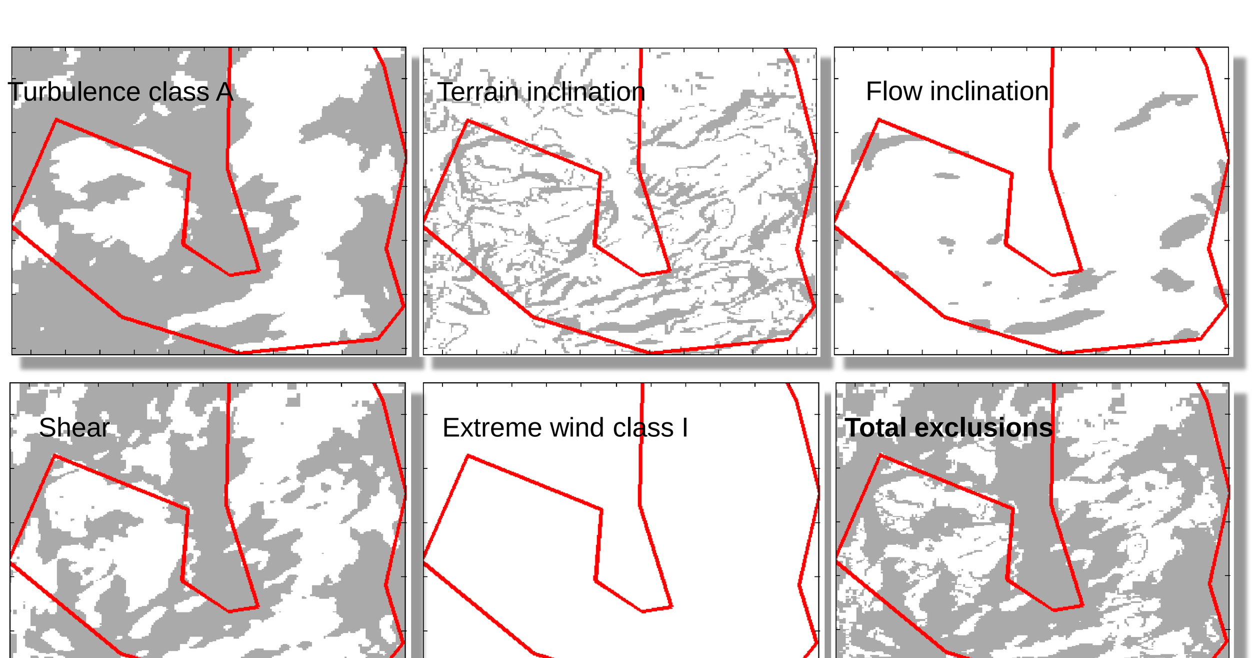
The ParkOptimizer module processes WindSim results in order to create maps of exclusion areas that do not comply with the IEC 61400-1 – standard.

These areas are used as constraints in the ParkOptimizer layout optimization.



Above: Screenshot from ParkOptimizer, showing settings for calculating IEC exclusion areas (left); Drawing editor for including other exclusion areas manually, or as shape- or text files (upper right); Turbulence intensity shown as continuous values (lower right).

Below: IEC exclusions shown as gray areas for turbulence (class A), flow inclination, shear and extreme wind (class I). White zones within the planning area in the lower right graph indicate areas for IEC class IA compliant layouts.



Extreme wind maps

Extreme wind estimation in ParkOptimizer is done by the method of *Independent Storms,* as described in [1] and [2]. Comparisons with WindPro shows similar results when on site measurement periods are long, but yields lower extreme wind speeds and more robust results for few years of measurements.

The estimated extreme wind estimates are then extrapolated across the park area based on WindSim results taking speedup and direction into account for each sector.

Turbulence maps

Ambient turbulence

WindSim calculates turbulent kinetic energy, which can be used as an approximation of turbulence intensity [3,4]. Our tests show that WindSim's turbulent kinetic energy correlates well with on site turbulence measurements, but must be calibrated with turbulence measurements from masts. *ParkOptimizer* uses on site measurement together with turbulence kinetic energy results from WindSim to calculate turbulence maps for reference wind speeds at 15 m/s.

Effective turbulence, I_{eff}

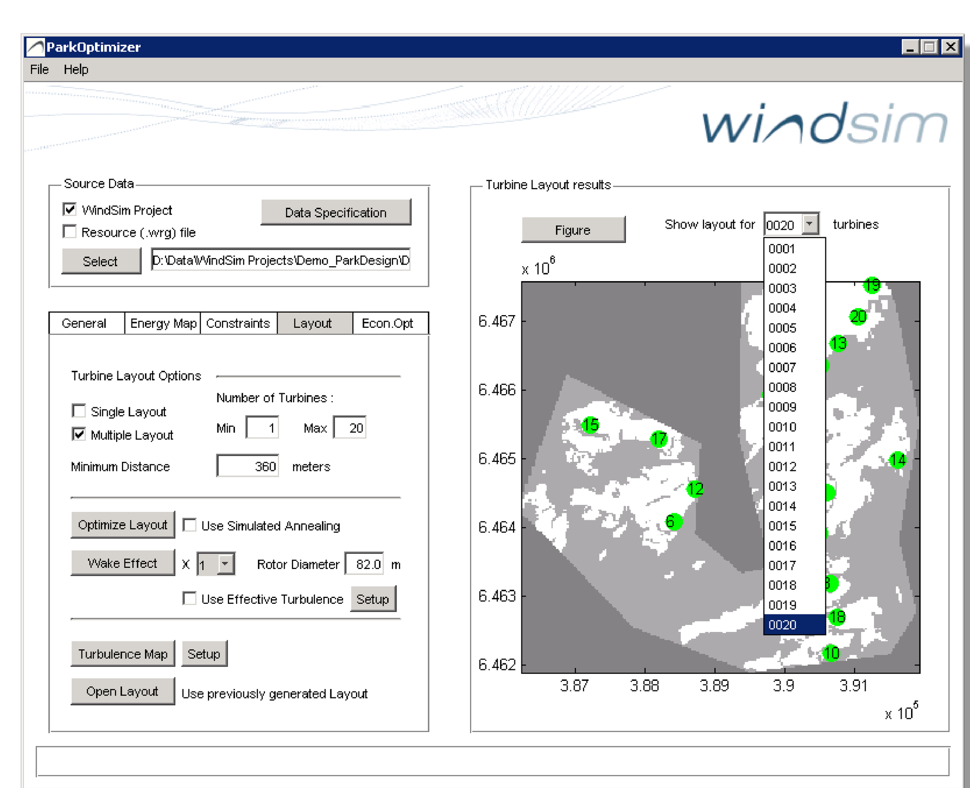
Wake induced turbulence as defined by IEC 61400-1 3rd ed. can be computed for proposed layouts. ParkOptimizer can even take effective turbulence into consideration as part of the layout optimization process.

Turbine	x utm	y utm	z m	Terrain Incl. degr.	Flow Incl. degr.(max)	Shear (mean)	Ambient turbulence % (mean)	Effective turbulence %	Extreme speed m/s
1	322702.0	6504138.0	478.0	6.91	6.73	0.11	8.66	11.02	36.39
2	323362.0	6502018.0	491.0	8.83	5.95	0.08	9.25	11.28	34.19
3	321142.0	6504018.0	467.0	2.39	5.44	0.07	8.47	11.68	36.43
4	319902.0	6503178.0	415.0	2.75	3.20	0.14	9.48	11.42	34.97
5	322862.0	6502318.0	503.0	10.64	4.93	0.14	9.06	11.00	35.76
6	323382.0	6503378.0	544.0	2.07	2.75	0.09	7.96	11.42	57.23
7	321662.0	6503878.0	447.0	6.41	2.56	0.06	9.20	11.77	34.84
8	322282.0	6504178.0	452.0	9.39	7.85	0.08	9.40	11.58	37.68
9	322582.0	6503798.0	500.0	5.95	5.91	0.09	8.65	11.61	48.17
10	323322.0	6502958.0	543.0	7.92	5.16	0.09	8.47	11.36	54.67
11	324702.0	6501438.0	458.0	7.09	6.90	0.12	9.90	11.65	35.60
12	324862.0	6503098.0	506.0	7.50	5.65	0.10	8.76	12.81	51.28
13	322522.0	6502478.0	485.0	9.34	7.35	0.14	9.47	11.47	35.91
14	324002.0	6504038.0	464.0	5.56	6.10	0.12	9.11	10.94	45.16
15	324342.0	6502858.0	529.0	4.29	1.83	0.13	9.16	12.30	50.62
16	320002.0	6502718.0	395.0	0.00	2.13	0.15	9.52	11.08	35.14
17	321662.0	6502958.0	443.0	8.06	5.16	0.12	9.06	11.52	42.79
18	324042.0	6501778.0	480.0	0.00	4.55	0.11	9.47	12.27	43.59
19	320882.0	6504398.0	402.0	11.40	7.46	0.11	9.71	11.80	35.85
20	324362.0	6501558.0	454.0	7.43	6.17	0.14	10.23	12.16	34.82
21	320642.0	6502858.0	402.0	2.76	2.94	0.17	9.87	11.46	32.71
22	321002.0	6502958.0	400.0	0.00	3.29	0.16	9.61	11.89	31.80
23	323102.0	6504218.0	464.0	9.39	7.28	0.11	9.50	11.85	37.06
24	321502.0	6504318.0	405.0	11.29	7.47	0.11	9.93	11.87	35.47

IEC compliance for turbine layouts: The table shows values for terrain inclination, flow inclination, shear, extreme speed and ambient and effective turbulence for the optimized layout

Layout Optimization

ParkOptimizer comes with several optimization algorithms for park layouts that maximize energy yield for a defined range of 1..N turbines



Above: Screenshot of layout optimization, providing one optimal layout for a range of layouts for 1 to N number of turbines. Optimization options include minimum distance constraint, choice of optimization algorithm and inclusion of wakes and effective turbulence in the optimization.

The optimization procedures are differentiated by *fast layouts* and an additional *wake adjustment algorithm*.

Fast layouts include:

- A heuristic algorithm using simulated annealing. Provide good results, but does not guarantee optimum.
- A more sophisticated algorithm employs a mixed integer relaxation algorithm that *guarantees global optimum.* This algorithm is not part of the standard ParkOptimizer, but can be obtained as a special edition.

Wake adjustment

The fast layouts do not consider wake effects.

The simulated annealing algorithm can be run with the N.O Jensen wake model, taking wake effects into account. The method does not guarantee global optimum, but benchmarking against other industry standard tools such as WindPro shows results that are at least as good.

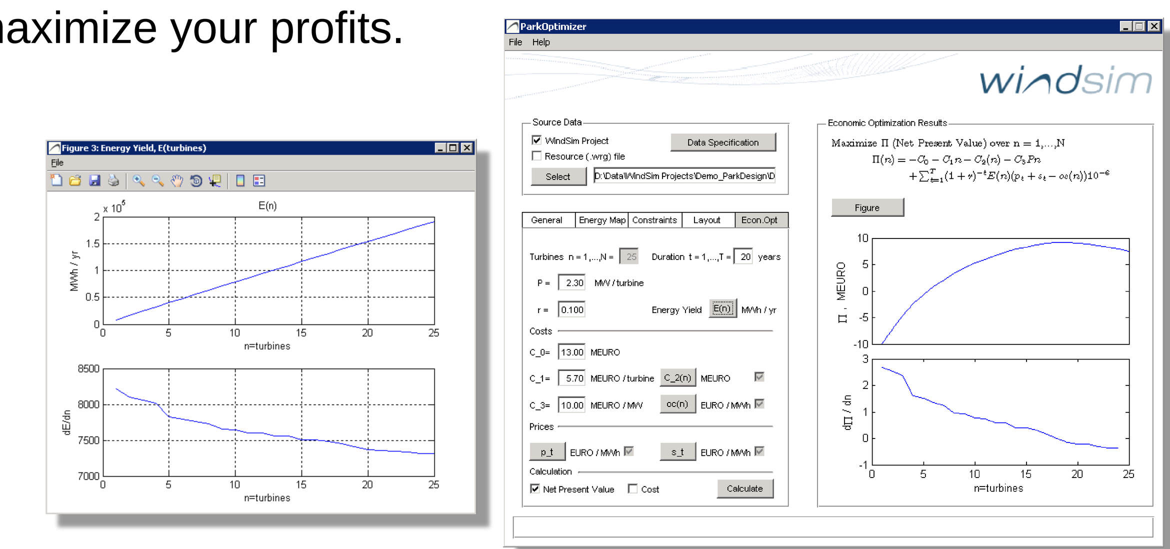
In addition, ParkOptimizer optionally can include effective turbulence I_{eff}, as a constraint.

We are now improving ParkOptimizer to be able to guarantee global optimum.

Economic optimization

According to our experience, project size highly influences the profitability in complex terrain [6,7]. Wind conditions vary significantly within the planning area. More turbines reduces unit costs, but increases wake losses.

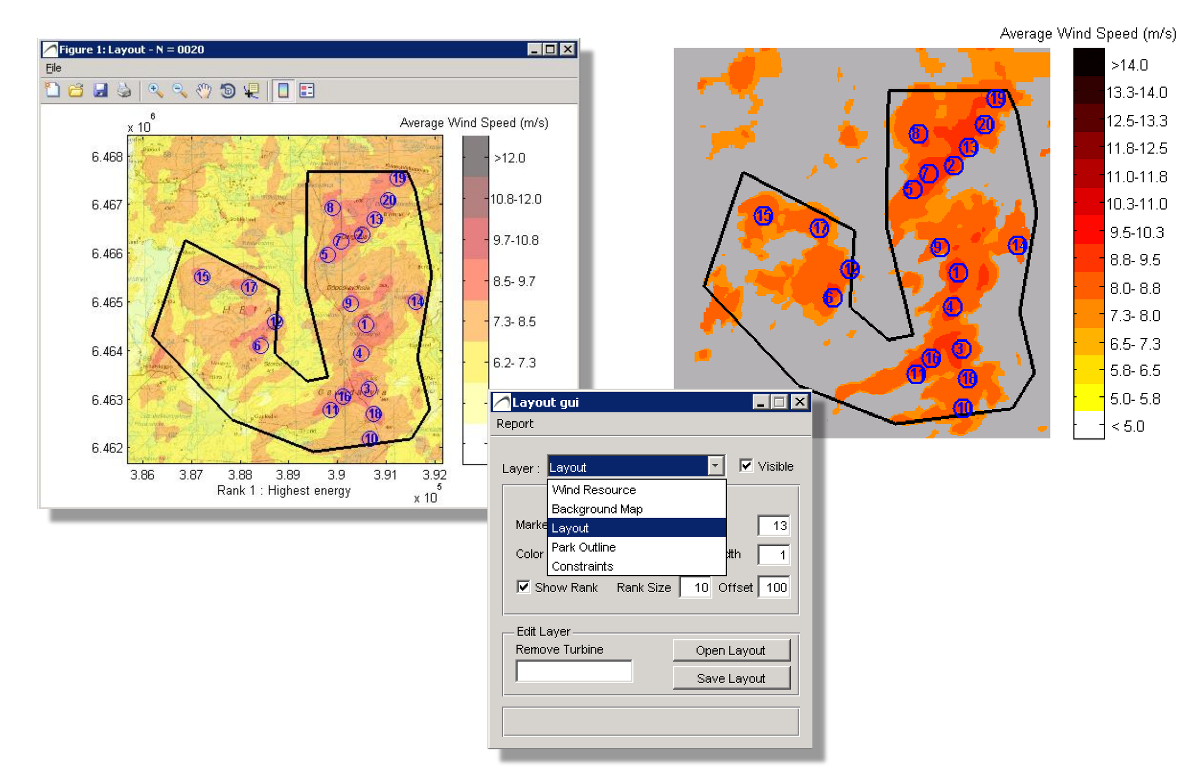
Using results from the layout optimization and financial data, ParkOptimizer helps you select the park size that maximize your profits.



Above: Economic optimization of the park size. Using results from the layout optimization, we establish an energy curve E(n) for each layout n= 1..N , where N corresponds to the number of turbines of each optimized layout. The energy curve E(n) represents the energy output as function of project size, and is used as input to NPV calculations. As seen by the above graphs, there is a defined optimum at around 20 turbines.

Editing layouts

After selecting the optimal size, we can move on and perform the final manual adjustments to the layout. ParkOptimizer provides tools for manual adjustments.



Above: ParkOptimizer can show a set of various layers including energy and wind maps; constraints and background maps

Validation

ParkOptimizer is an ongoing development of Agder Energi Wind & Site group in collaboration with WindSim and represents state of the art wind & site assessment in complex terrain. During the last two years, we have analyzed more than 60 sites in highly complex terrain, and the methods have been tested against measurement data in more than 25 locations.

Conclusions

ParkOptimizer provides new tools and methods for wind and site assessment in complex terrain. ParkOptimizer extends the value of WindSim results and sets a new standard for wind & site by:

➢Including IEC standards from the beginning of project development

➢Introducing new techniques for layout optimization

➢Helping you to maximize profits by selecting the optimal park size.

References

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