RENEWABLES

104+

Country locations of UL renewable energy customers

55+

Years of combined experience in renewable energy industry

Independent / Owner's Engineer on

450+

wind & solar projects*

*since 2012

ADVISED

90%

of the industry's top PROJECT DEVELOPERS and PLANT OWNERS

500+ UL Renewable Energy Experts

200,000+ MW

Total renewable energy megawatts (MW) assessed

FORECAST PROVIDER for

60+ GW

of installed renewable energy projects

GLOBAL PRESENCE

143+
Countries with office locations

500+
Renewable energy experts

Layout Optimisation

Openwind is a software programme for the design and optimisation of wind farms.

Primarily designed to run on a desktop PC (MS Windows, Linux, Unix)

GIS-based (GDAL, PROJ4) and uses EPSG codes to specify projection and datum.

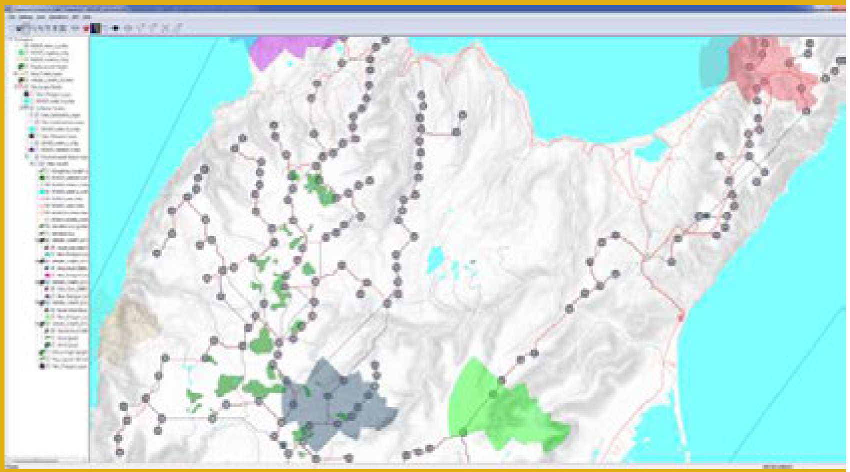
Variety of wake models – N.O. Jensen, Modified Park, Eddy Viscosity, DAWM

Layout Optimisation

Openwind®

Turbine layout optimisation can be carried out respecting:

- Vectors (+/- buffers)
- Raster-based spatial constraints (can be derived from shadow flicker risk)
- Noise limits at points
- Visual impact limits at points
- Constructability – crane pad tests
- Suitability – effective TI (as either strict limits or automated WSM for <3D, say)



Objective Functions

Turbine layout optimisation can be used to:

- Optimise (increase) net annual energy production
- Optimise (decrease) the levelized cost of energy (LCOE)
- Optimise (increase) the internal rate of return (IRR)

Models

To optimise for LCOE or IRR we need the following components:

- Financial model – to trade off one-time capital costs against recurring revenue
- Automated access road design to estimate balance of plant (BOP) costs
- Automated collector system design to estimate balance of plant costs
- Electrical loss model (single line DC analogue at nominal voltages)
- Variable component longevity driven by suitability (ideally – this is still in the works)

Inputs

To optimise for LCOE or IRR we need the following inputs to estimate BOP costs:

- Financial model (project life, taxes, debt, discount rate, incentives, etc)
- Cost estimates:
  - Per turbine cost (including transport, foundation, erection etc)
  - Road costs per km (new, existing – can be linked to vector attributes)
  - Costs of feeder bay, HV line per km and collector lines per meter (based on single line diagram)
  - Crossing costs: water courses, pipelines, wetlands, fences, etc.
  - Cost multipliers (roads, collectors, turbine foundation costs)
- Collector system resistances*
- Substation transformer losses*
- Turbine transformer losses*

*for use in single line DC analogue electrical loss model

BOP algorithms

To estimate BOP costs, we need to come up with an access road design and a collector system design for each candidate turbine layout

Road layout is determined using a custom directional form of A*

Collector system layout is determined using a mix of A*, Dijkstra and a form of multi-centre Esau-Williams (multi-centre allows us to have more than one substation) or Sharma for offshore

In the case of both the access roads and the collector system:

- Cost grids are assembled on an as needed basis and
- Initialised by drilling into the GIS data (attribute values can be queried, scaled and used)
- Cost grids can be re-used, once initialised, so that the optimisation speed increases after the first few iterations

Optimiser Modes

Desktop application optimising on a single PC

Scripted optimisations on a single PC

External optimisation
- Command-line interface (CLI)
- Text-based API
- Headless version available
- Openwind provides objective function (AEP, COE, IRR)
- For use on multiple nodes with bio-inspired optimisation algorithm

Questions

Does optimising for LCOE create layouts that are too compact?

Is IRR a better objective function?

- Higher energy price should allow layout to “chase the wind” more
- Potential for multiple solutions to IRR calculation

Does setting the discount rate to equal the desired IRR give us the best of both?

Test Site

Southern Ontario using publicly available GIS data and modelled wind data (WindNavigator) with default costings.

- Simple terrain
- Farmland

Results

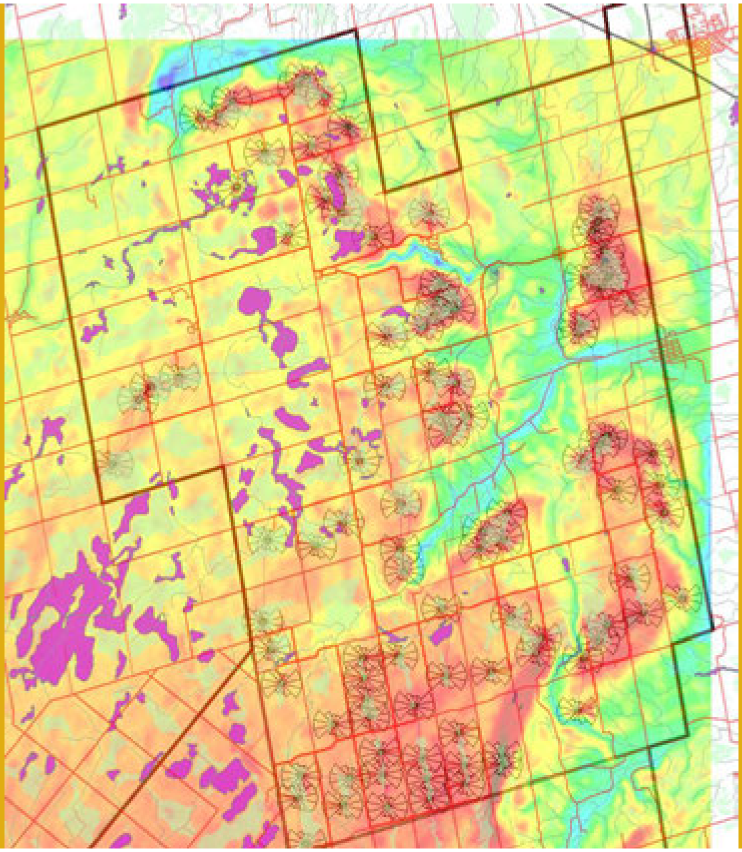
Nova Scotia site showed little difference between IRR and COE layouts

- Both cheaper than AEP optimised layout
- Inexpensive public roads make COE and IRR similar to AEP layout

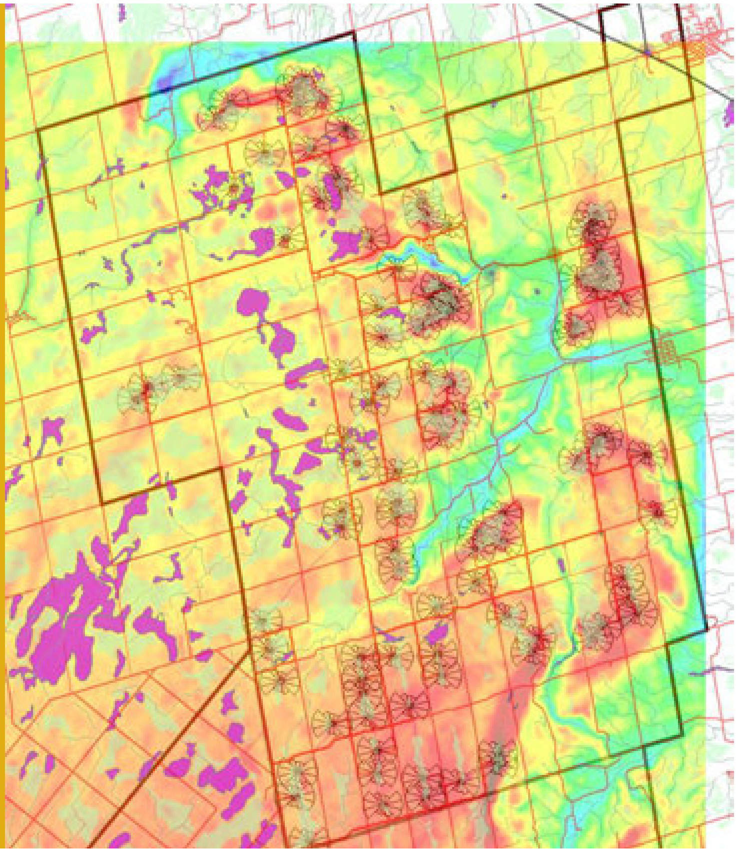
Objective Function	Net Energy [GW]	BOP Cost [$]	LCOE [$/MW]
AEP	1101 100%	51 100%	38.49 100%
COE	1096 99.6%	46 90.2%	38.3 99.5%
IRR	1094 99.4%	46 90.2%	38.38 99.7%
COE Turbines x 10	1099 99.8%	50 98%	38.45 99.9%

Results

AEP



COE



Answers?

It depends…

Undoubtedly, multiplying turbine costs 10 and optimising for COE will result in a layout which looks more like one optimised for AEP

Attempts to do something similar with energy price and IRR failed to optimise (multiple roots?)

However, using realistic values, it is hard to discern much difference between layouts optimised using COE and those optimised using IRR (at least in this case)

Hard to imagine there wont be some cases where one is superior to the other.

More research needed….