Wind Farm Design

A focus on real world development and constraints

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Overview

Design goal

- Turbine locations that maximize energy production within the project temporal & spatial development constraints.

Traditional approach

- Qualitatively arrange turbines by rotor diameter considering both
  - Terrain
  - Primary wind direction
  - Approximate turbine spacing
- Quantify net energy production and wake effects
- Iterate, deploying additional instrumentation where necessary

Example Iberdrola Renewables

Wind Farm (WF)

Example WF

- Development is dynamic in both time & space
  Lots of stakeholder with different agendas

- Length scale range from meters to 100 km
  Numerous analysis tools available
    - Linear flow models
    - CFD
    - Other custom spatial models

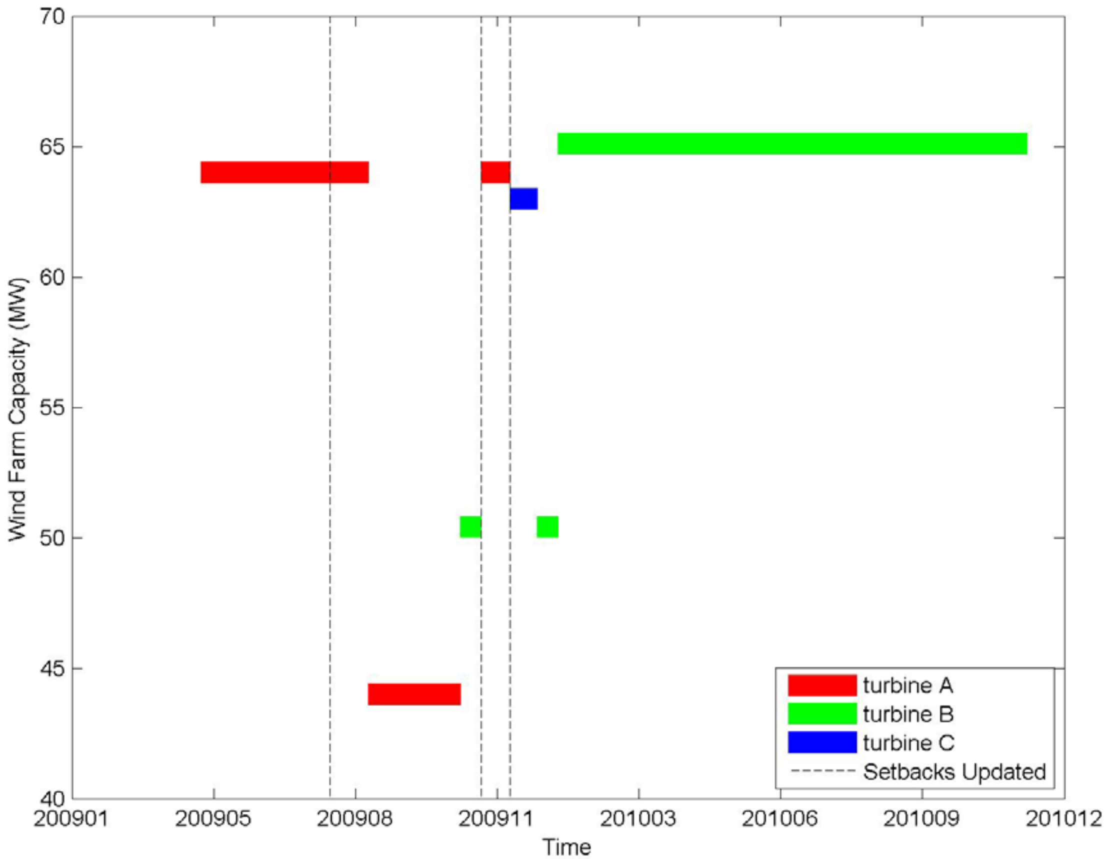
  Iteration is labor intensive

- Time scale range from weeks to decades
  Wildlife & environmental – annual time scales
  Local & State government – monthly time scales (sometimes)

Temporal Evolution of WF

Example WF (1.58 years)

- Power purchasing client drives WF capacity
- Three different turbines, four different WF capacities
- Spatial constraints updated 3 times
- Minimum time scale 15 days



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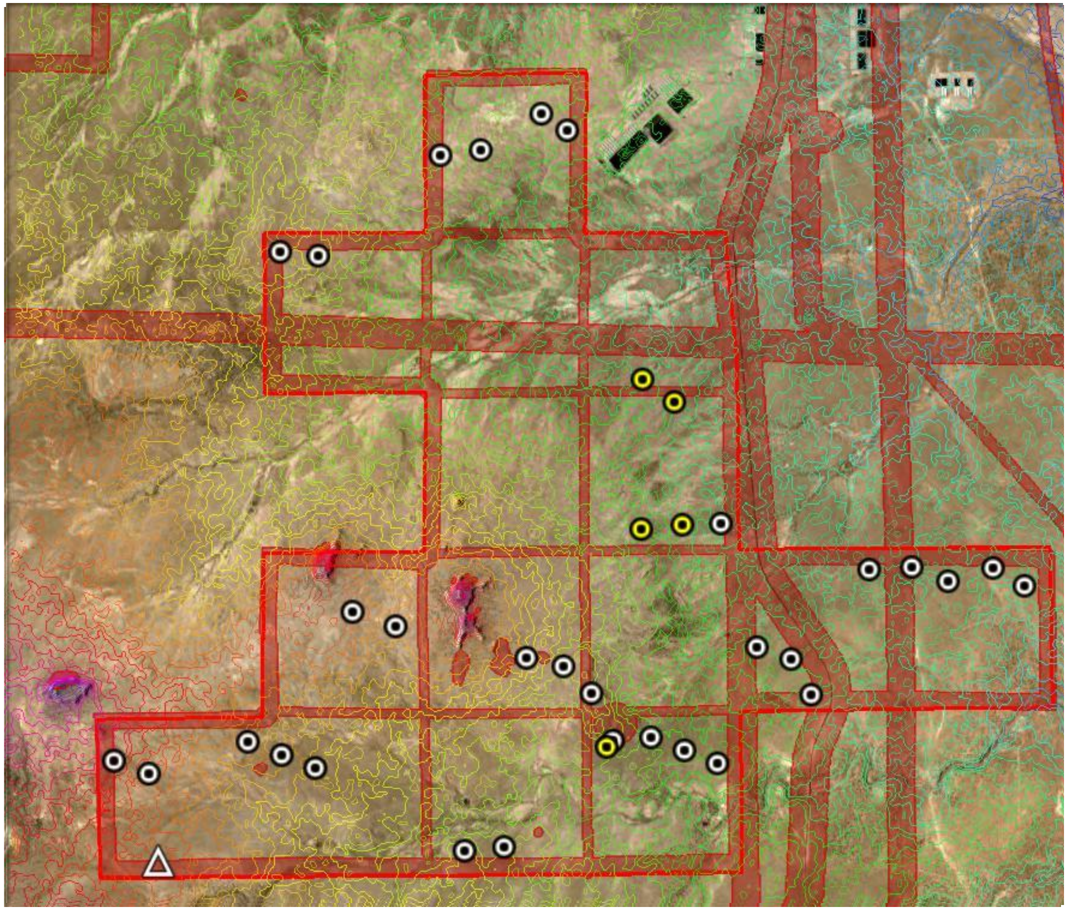
Spatial Design of WF

Example WF

- Based on property boundaries.
- Environmentally sensitive areas & wildlife
- Turbine fall down distances
- Government regulation & permitted constraints
- Other internal guidelines

As built



What is industry doing as a whole?

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Obstruction Evaluation / Airport Airspace Analysis (OE/AAA)

Database of tall structure maintained by the FAA

https://oeaaa.faa.gov/oeaaa/external/portal.jsp

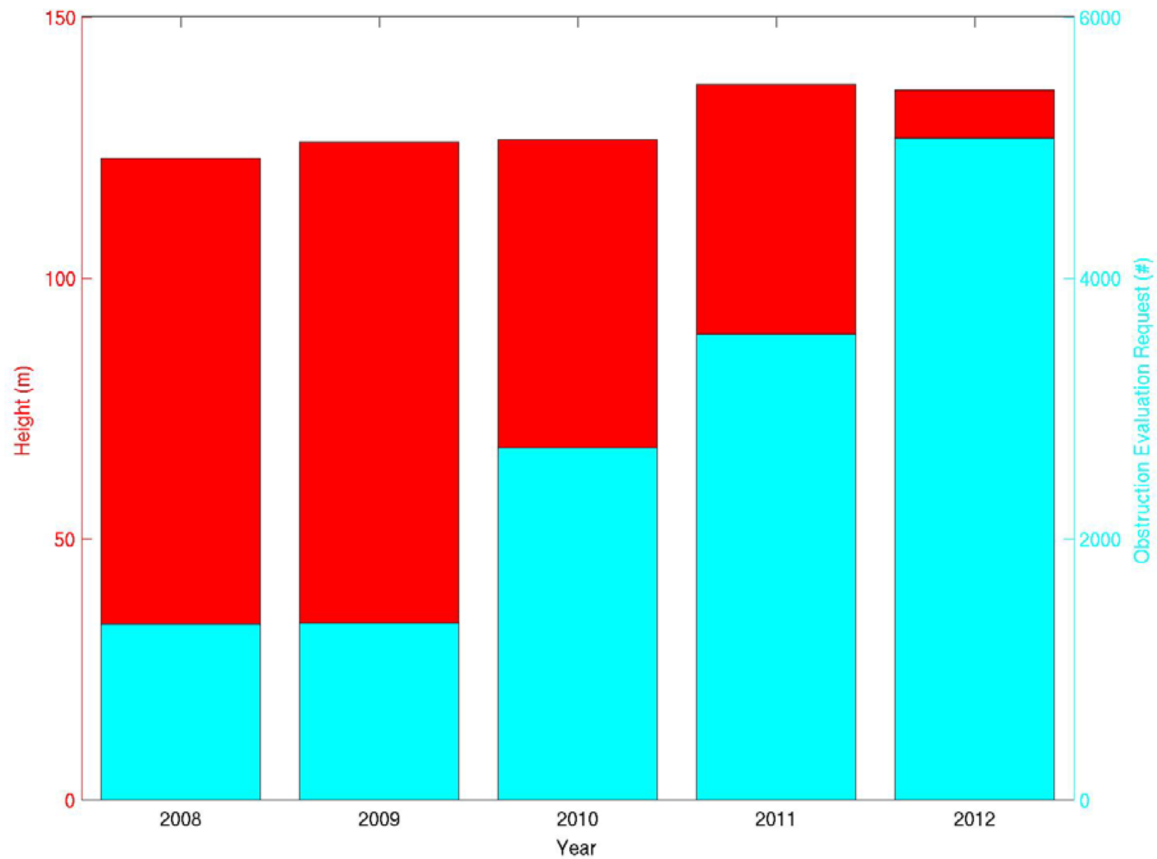
- Nationwide
- Source of wind turbine locations from 2008 to present
  - Both operational WFs & WFs under development
  - Including many failed developments & other relics

Analysis

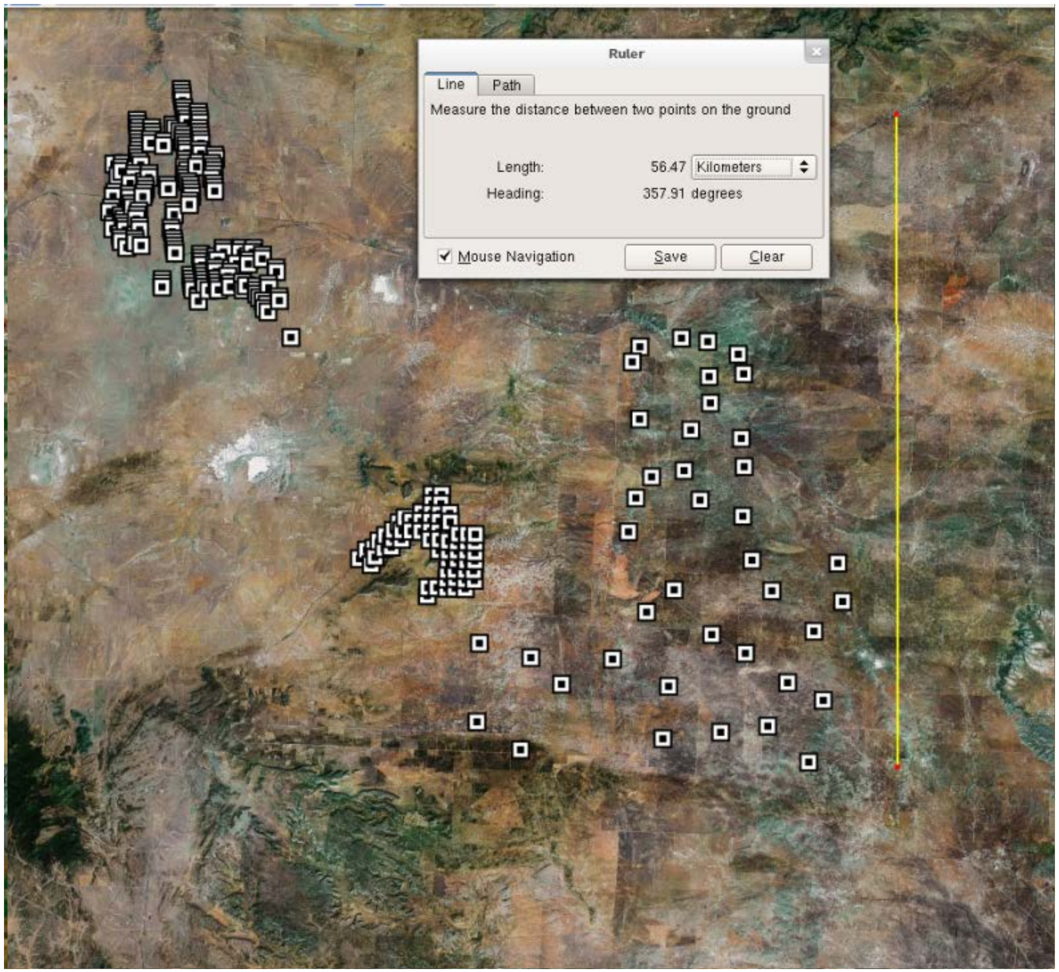
- Extract design parameters
  - Crosswind spacing, downwind spacing and row orientation
- Focus on TX (lat/long bounds N25.36, W108.45 & N37.23, W93.30 NAD83)

Overview OE/AAA WF data

- 14,036 turbines in search domain of OE/AAA – as of mid Dec 2012
- Mean increase of 930 evaluation/yr
- Mean height
  - suggest 2.X MW turbines primarily
  - 70 < RD < 100



Example, OE/AAA WF



Side by side WFs

- Very different design choices

Quantifying WF spacing

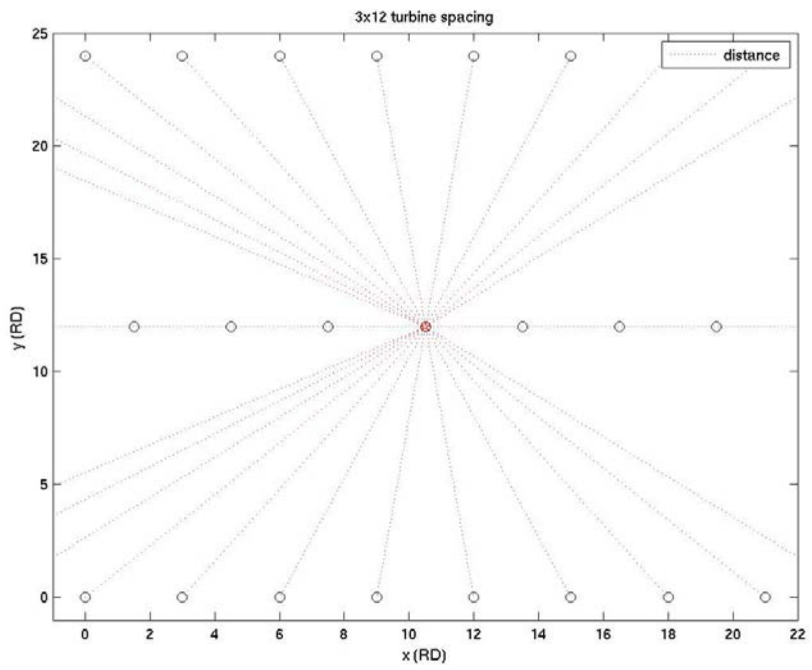
Crosswind spacing and row orientation

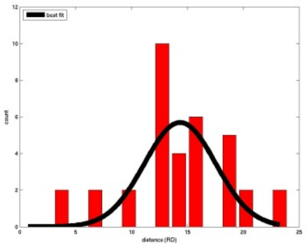
- nearest neighbor

Downwind spacing

- approximated using best fit normal PDF to distance between turbines

- **Mean from Best fit 14.33 (actually 12)**

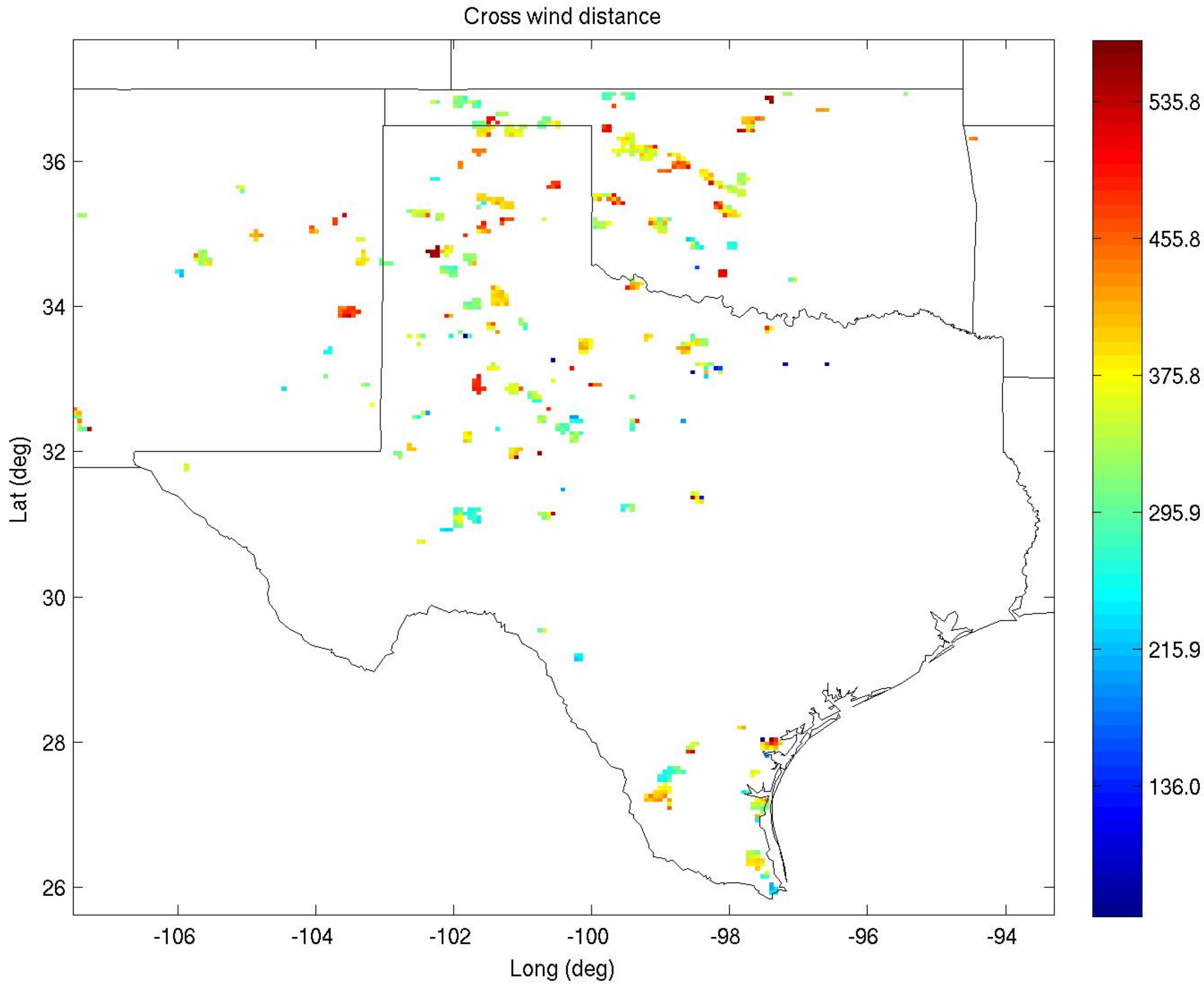




WF spacing

- **Row orientation**
  Lots of EW rows (TSR?)
- **Downwind spacing**
  1651.58 ± 501.62 m ~1 mile (or section TSR?)
- **Crosswind spacing**
  351.05 ± 74.57 m

No clear crosswind/downwind spatial patterns



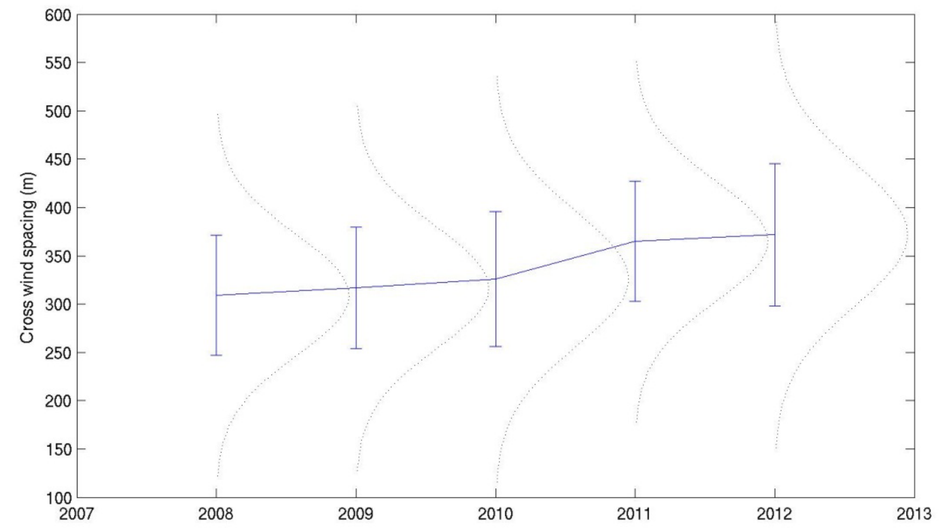
WF spacing over time

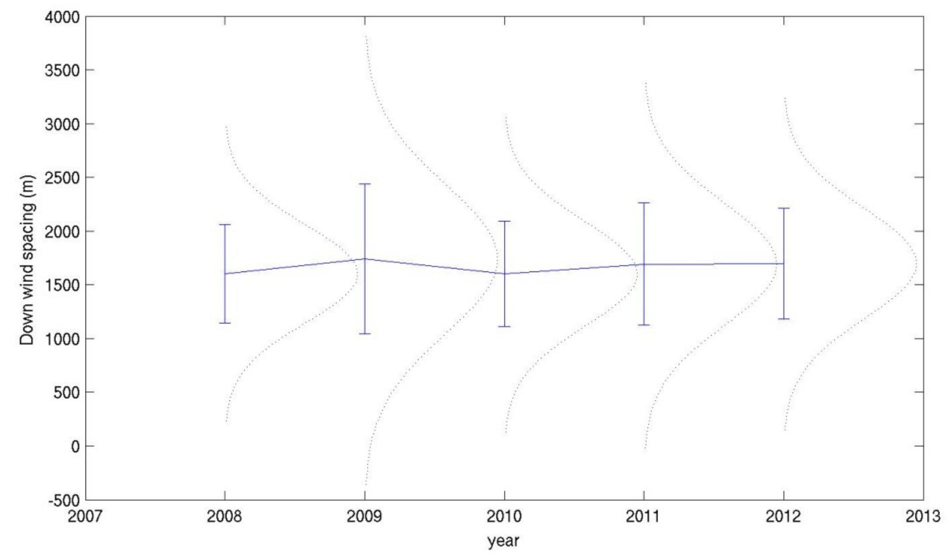
Crosswind spacing

- **Increasing between 6 & 40 m/yr**
- **2012 crosswind spacing** 371.90 ± 73.62 m

Downwind Spacing

- **Constant around 1650 m (approximated)**
- **Scale associated with TSR land ownership patterns**





Conclusions

- Temporal development constraints requiring rapid turnaround could prove challenging
- OA/AAA examples confirm there is a need for more sophisticated WF design
    - Current industry standards likely based on landownership not wind characteristics
    - This implies operators & developers are leaving money on the table due to un-optimized design
- No doubt WF design can benefit a great deal from systems engineering holistic approach

Questions