Wake effects

The experiences of an offshore developer

Leo E. Jensen

EWEA Resource Assessment 2013
Dublin

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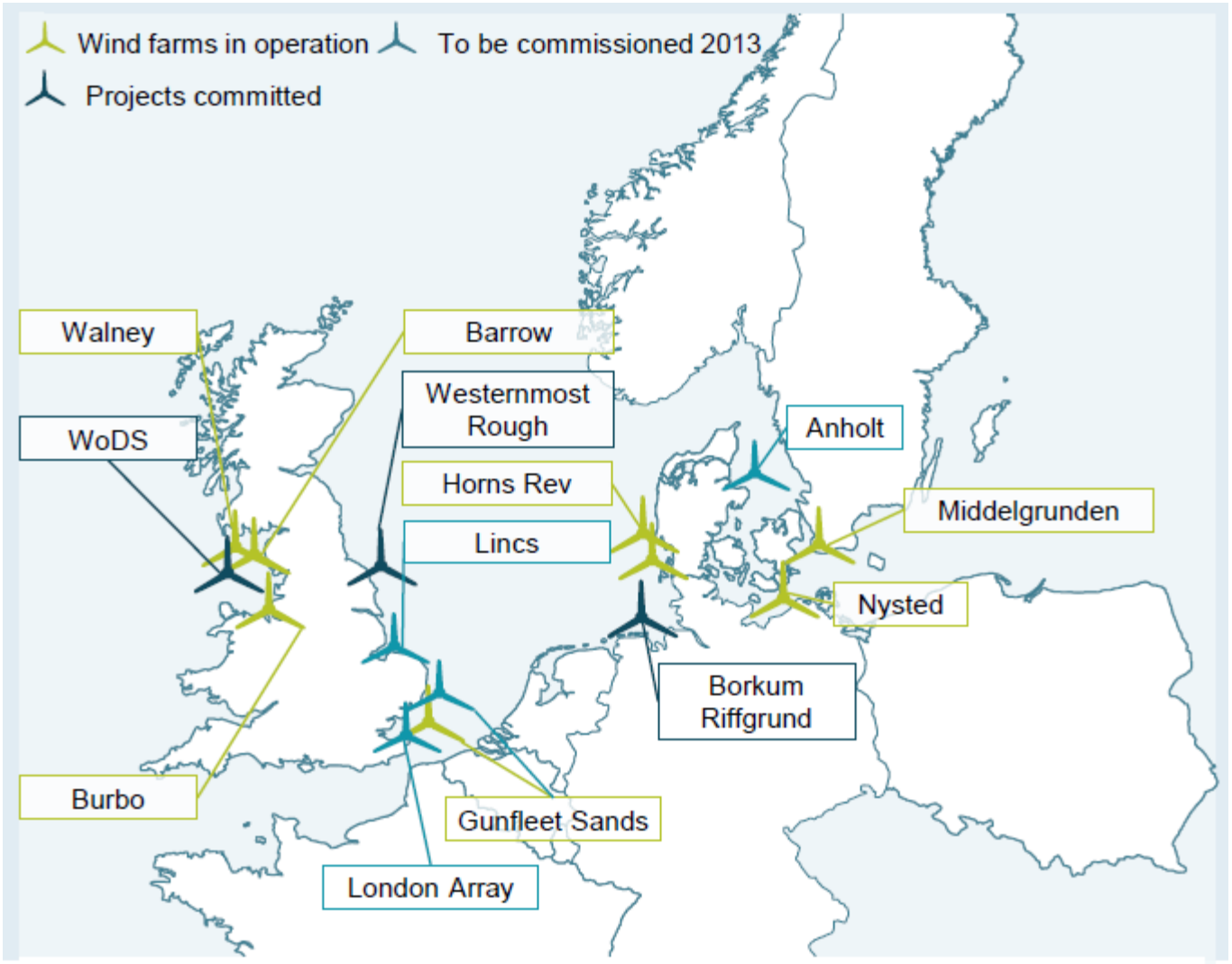
DONG Energy: An OFFSHORE wind developer



Portfolio	Year	Installed
Vindeby	1991	5
Tuno Knob	1996	5
Middelgrunden	2000	40
Frederikshavn	2001	11
HR1	2002	160
Nysted	2003	165
Burbo	2006	90
Barrow	2007	90
HR2	2009	209
GFS	2010	172
Walney 1	2011	184
Avedøre	2011	11
Walney 2	2011	184
Anholt	2013	400
London Array	2013	630
GFS 3	2013	12
Lincs	2013	270
Total		**2637**
Owner share		**53%**
O&M share		**84%**

(status end of 2012)

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Agenda

- How did we get where we are
- Present development
- Present challenges
- Future opportunities

Who am I?

Name:	Leo Enrico Jensen
Education:	M.SC. Mech. Eng., Aalborg 1989
Specialization:	Energy and fluid dynamics
Experience:	Has been working with wind power since 1989: 10 year at Elsam Projekt 3 years at LM Glasfiber 11 years at DONG Energy
Family:	Married, 4 children
Position:	Chief Specialist in "Wind Power Technology"

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Nibe turbines

- Wake effects measured

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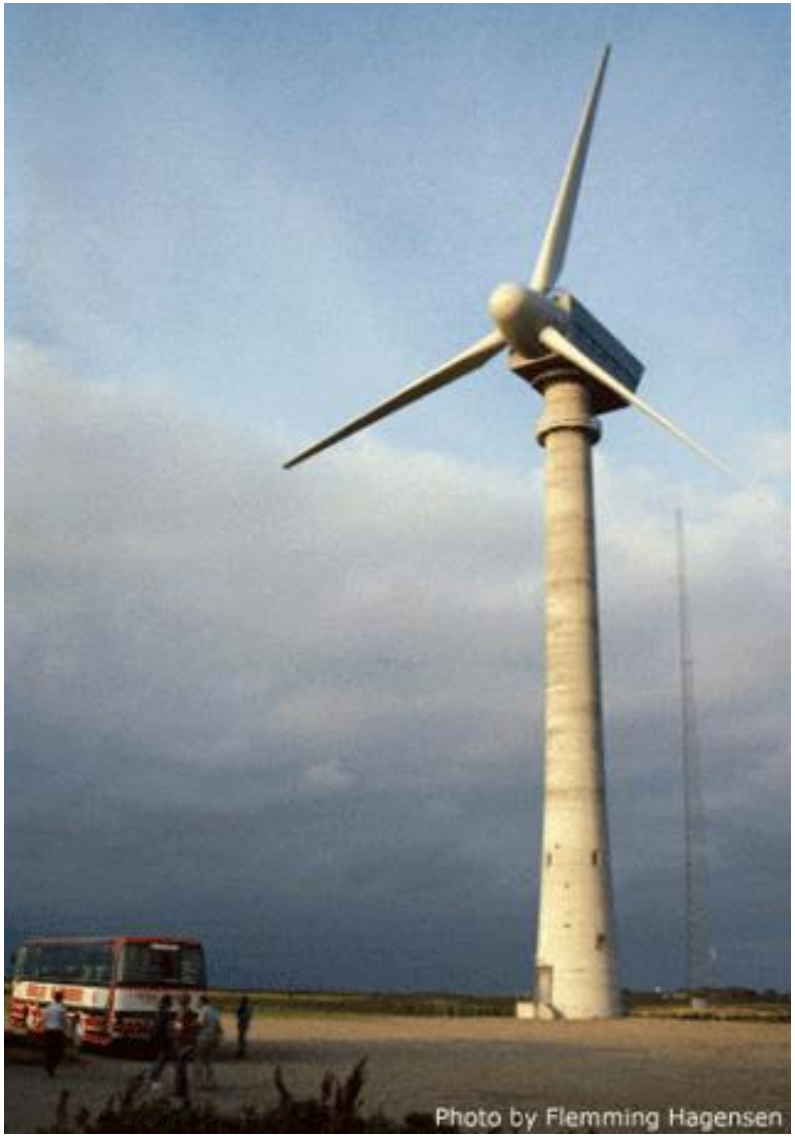
Tjæreborg wind turbine



- Dynamic wake effects measured

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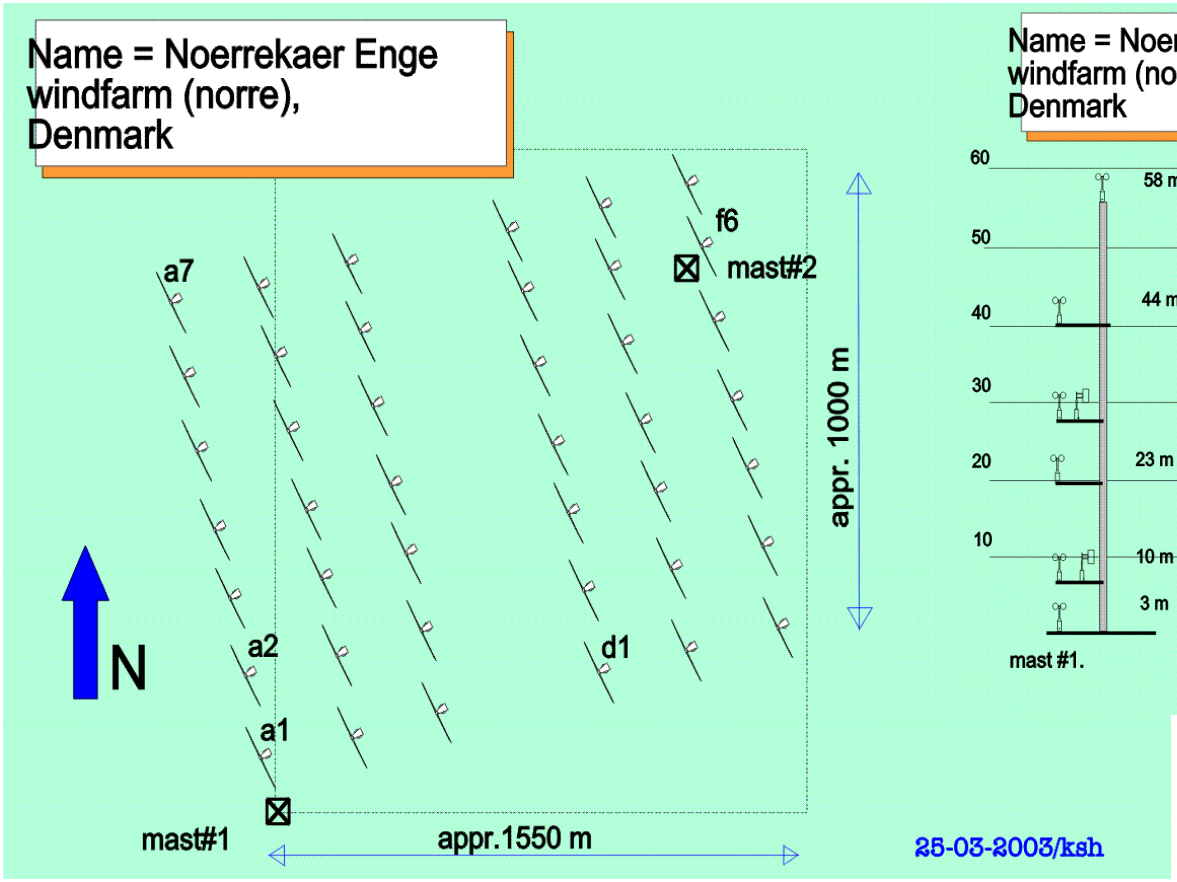
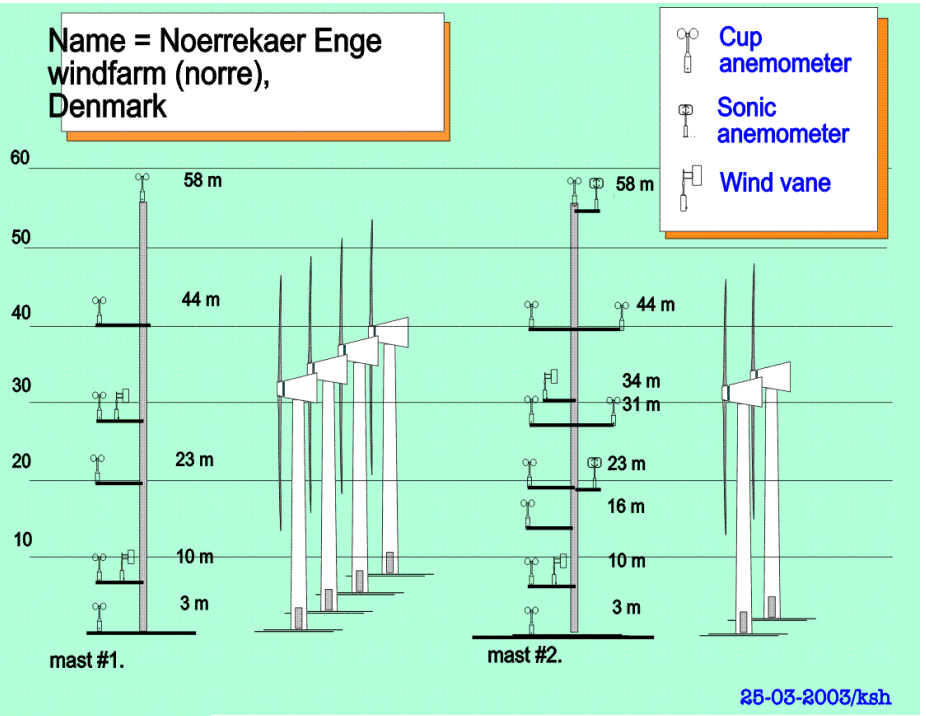
Nørrekær enge





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Nørrekær Enge

Full Scale Measurements in Wind-Turbine Arrays. Nørrekær Enge II. CEC/JOULE

Risø-I-684(EN)

J. Højstrup, M.S. Courtney, C.J. Christensen, P. Sanderhoff

Department of Meteorology and Wind Energy

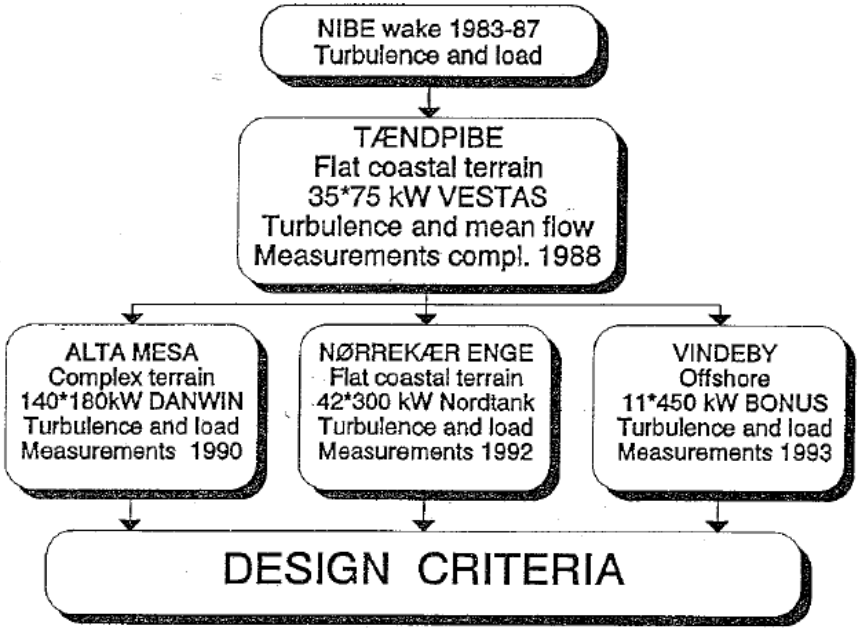


Figure 1 Overview of Risø windfarm and wake measurements programme.

PARK is surprisingly good at its job.

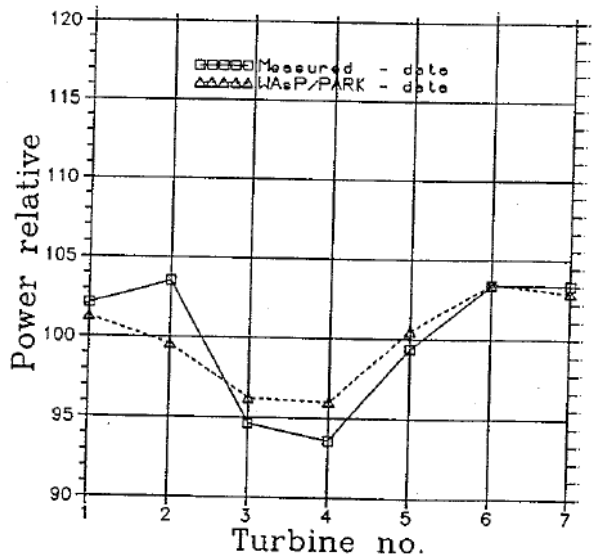
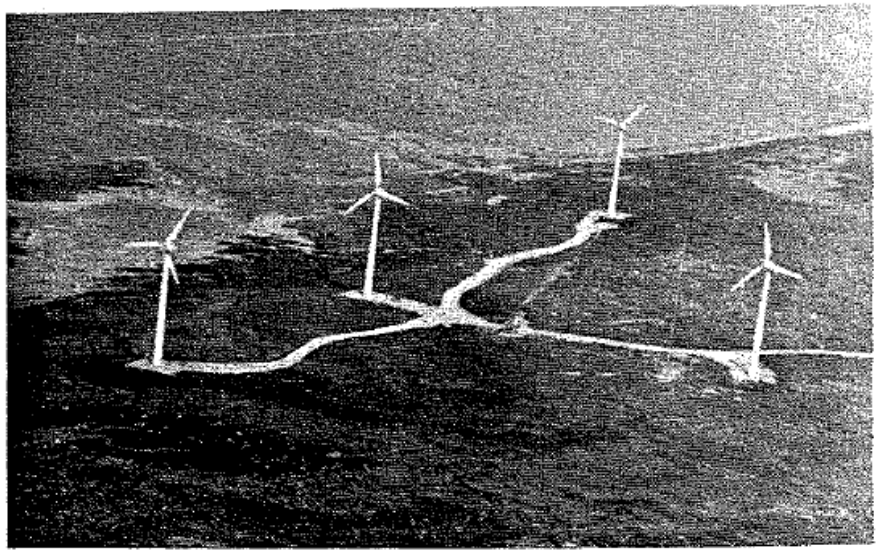


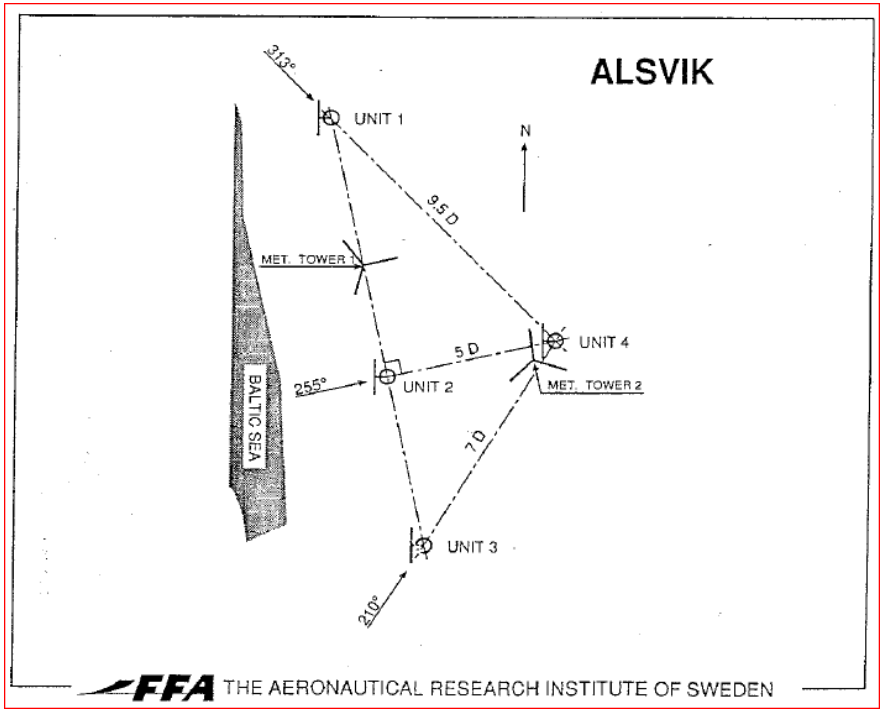
Figure 7 Relative power output, of turbines in row A, for wind from sector 9 (225-255°).

Alsvik

Fatigue loads on wind turbine blades in a wind farm

Maria Poppen, Jan-Åke Dahlberg





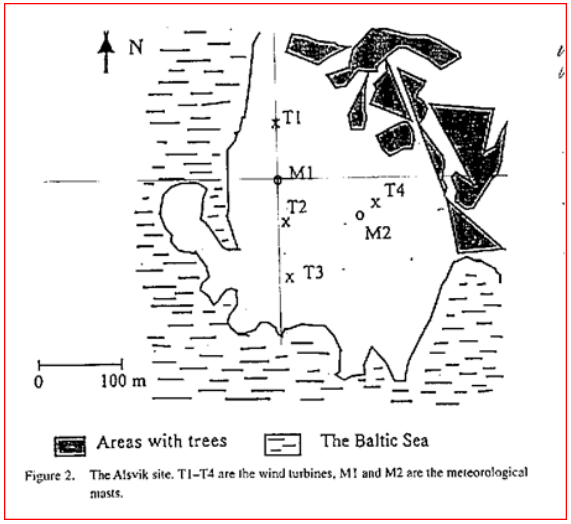


Figure 2. The Alsvik site. T1–T4 are the wind turbines, M1 and M2 are the meteorological masts.

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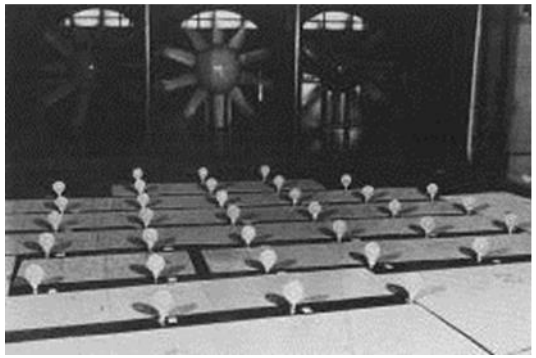
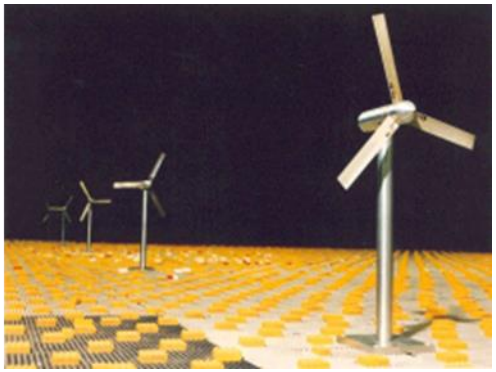
Wind tunnel investigations





[7] **Hassan U.,** (1993) *A wind tunnel investigation of the wake structure within small wind turbine farms,* Rep. ETSU W N 5113.

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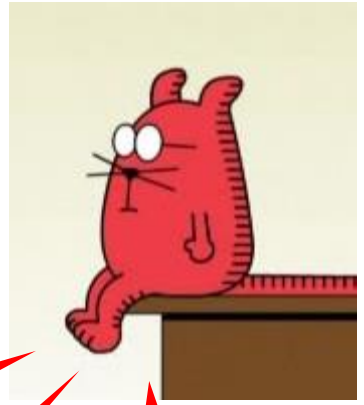
Horns Rev 1

Wake effects are important. Please calaculate

That's not too bad !

What ! That's bad !

OK wake effect 94%



Remember: Offshore wake decay is different

Low turbulence: Probably 0.04

OK – what is it?

OK wake effect 88%

Compromize: Wake induced turbulence included Wake decay 0.05

OK wake effect 90%

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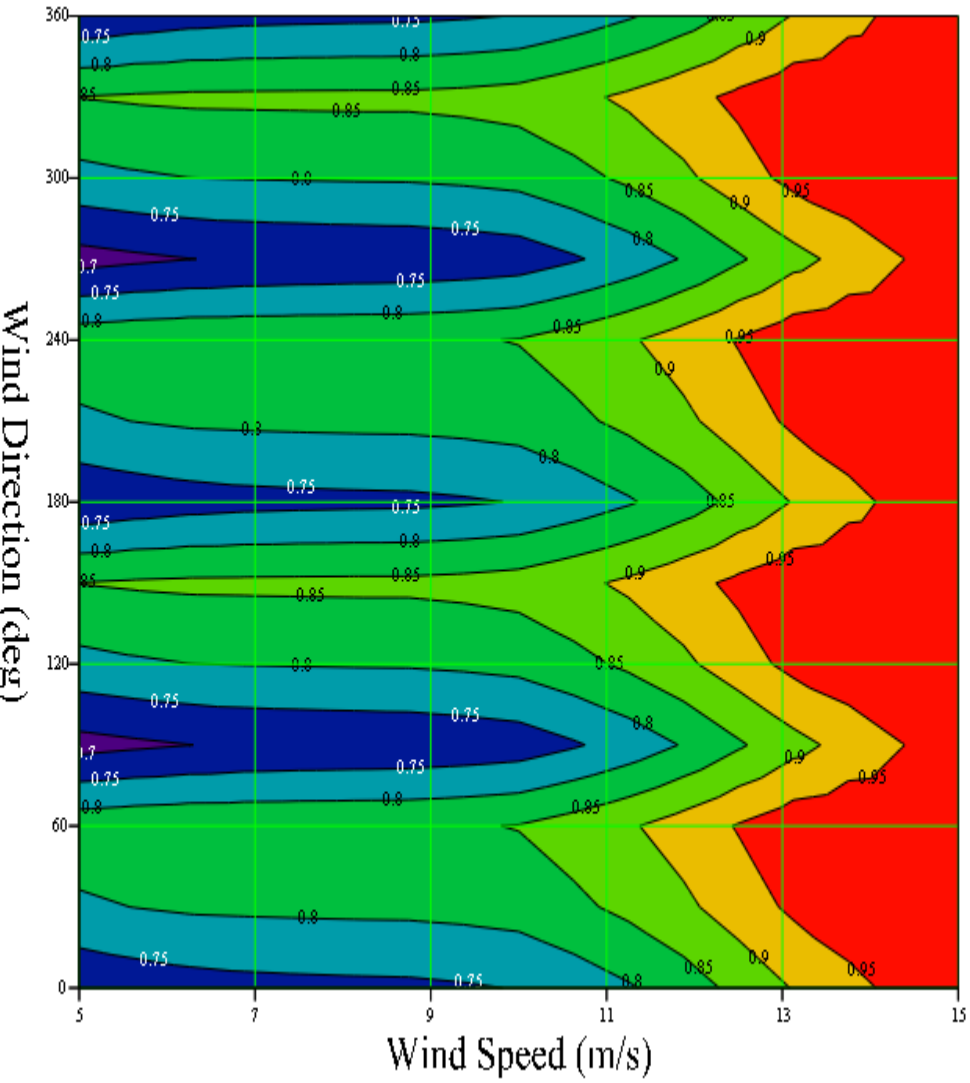
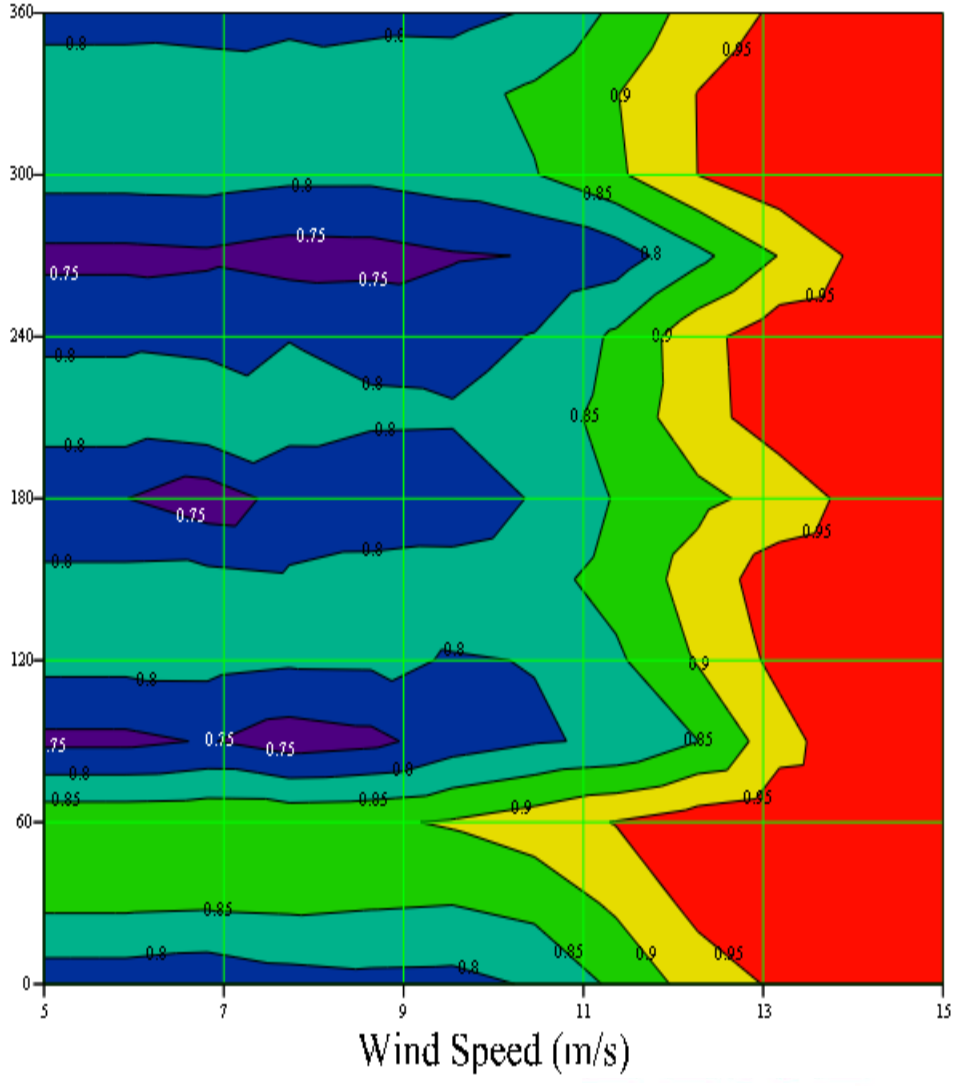
HR1: Measured array efficiency



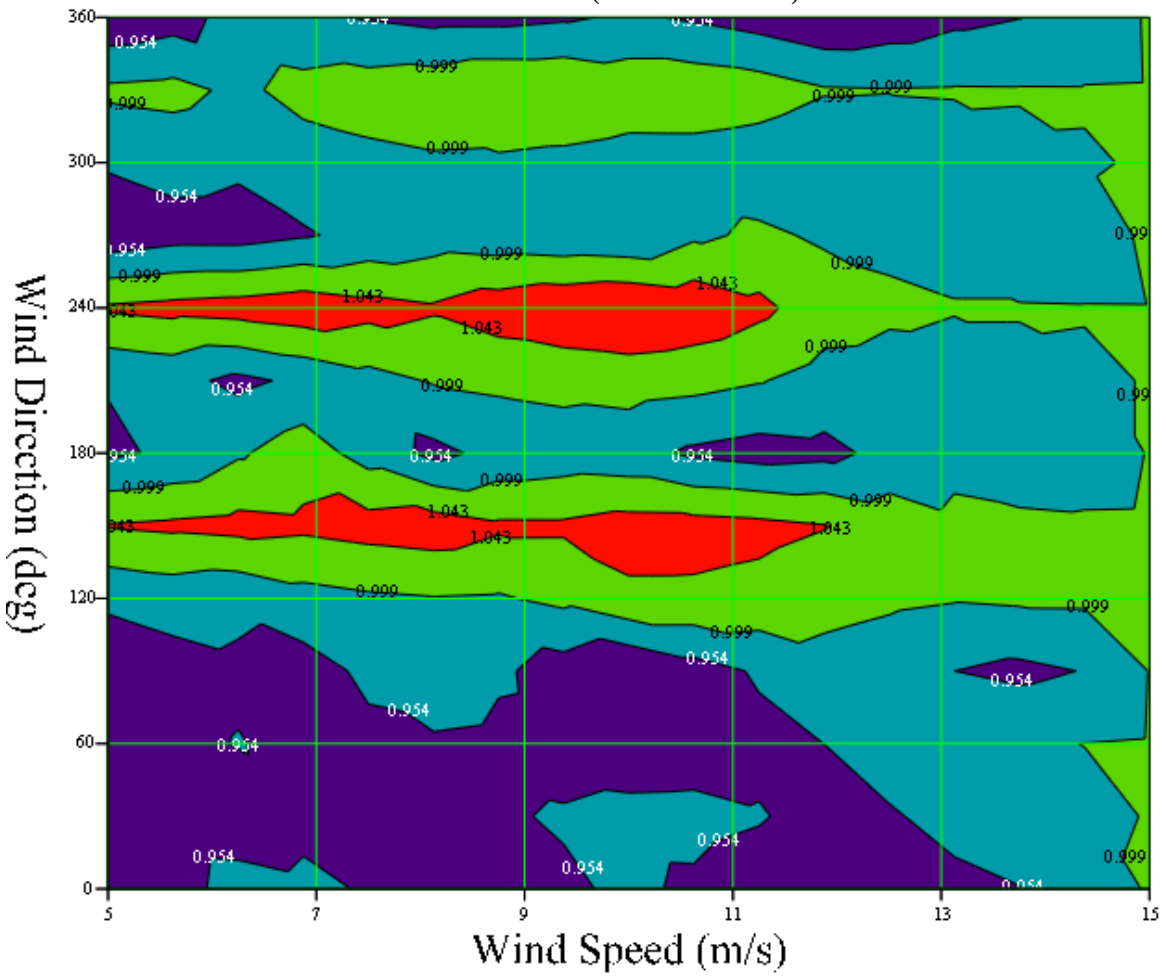
Estimated



Measured

Measurement & Calculated Efficiency Comparison

Model overestimation (estimated/measured)



Comparison
1.043
0.999 - 1.043
0.954 - 0.999
0.954

GetRel

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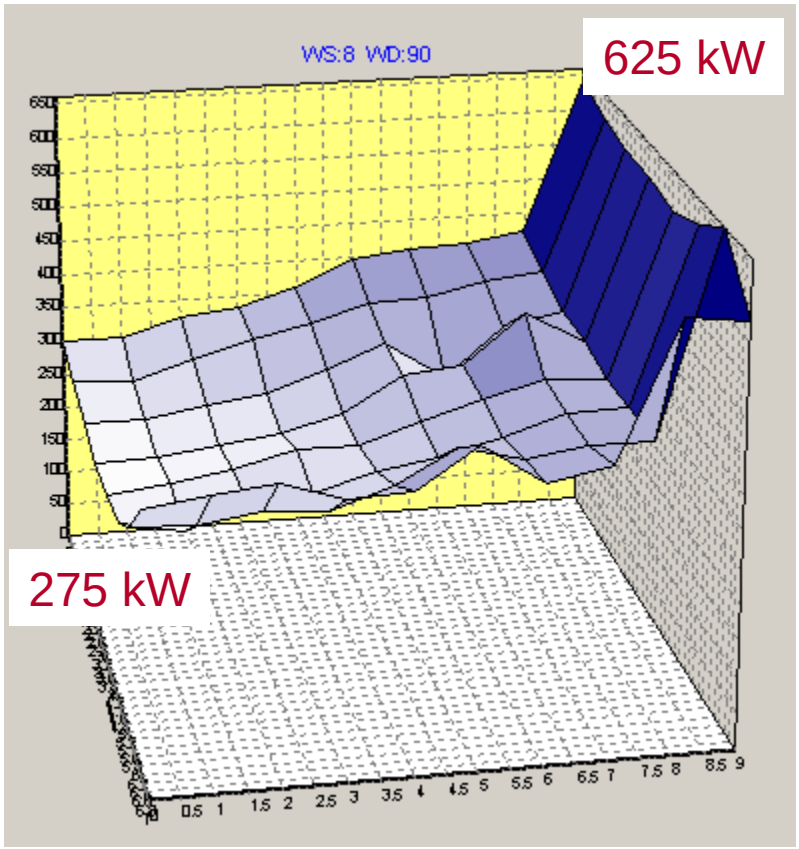
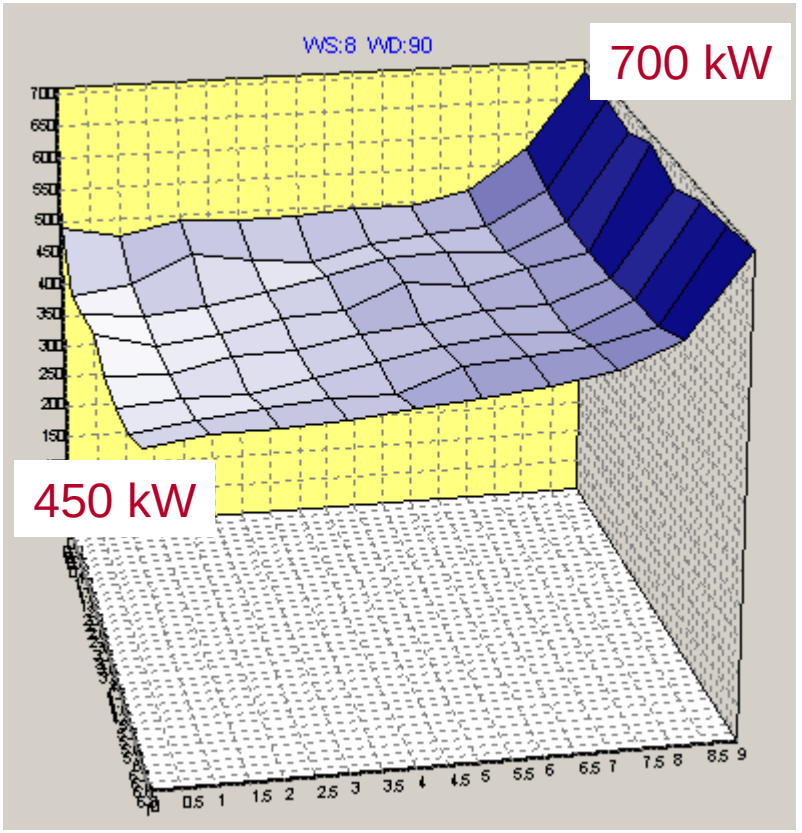
The effect of stability discovered

Only stable data



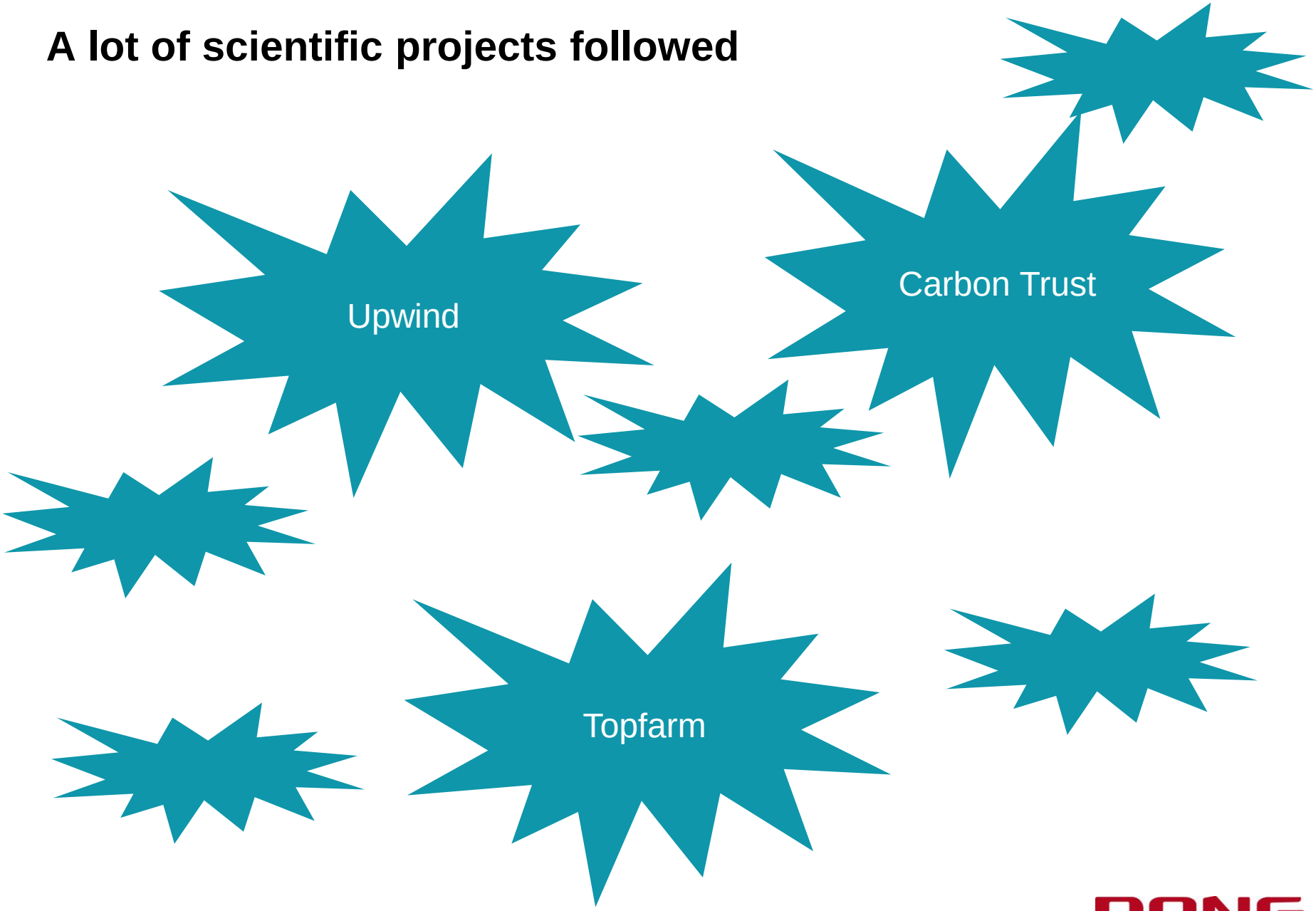
Array Efficiency 61 %

Only unstable data

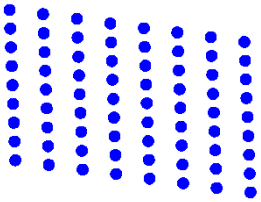


Array Efficiency 74 %

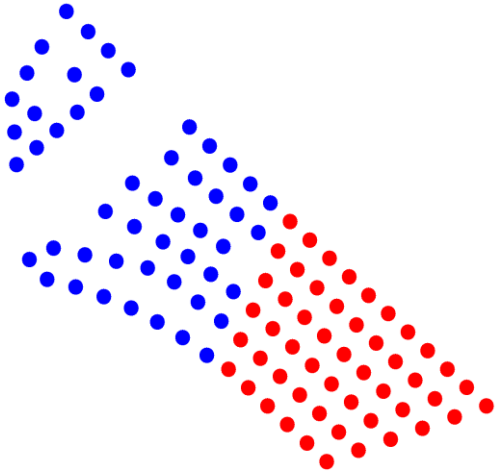
A lot of scientific projects followed



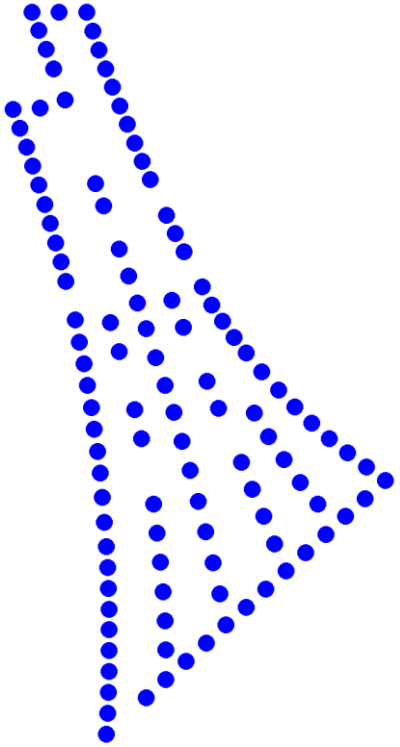
Wake optimized layouts starts popping up



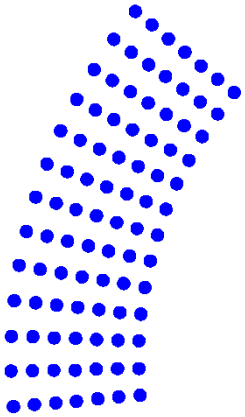
Nysted (NHP)
72x2.3 MW
Hub height: 68 m
Rotor diameter: 82 m



Walney 1&2 (WOW)
2x51x3.6 MW
Hub height: xx&yy m
Rotor diameter:
107&120 m



Anholt (ANH)
111x3.6 MW
Hub height: YY m
Rotor diameter: 120 m



Horns Rev 2 (HR2)
91x2.3 MW
Hub height: 68 m
Rotor diameter: 93 m

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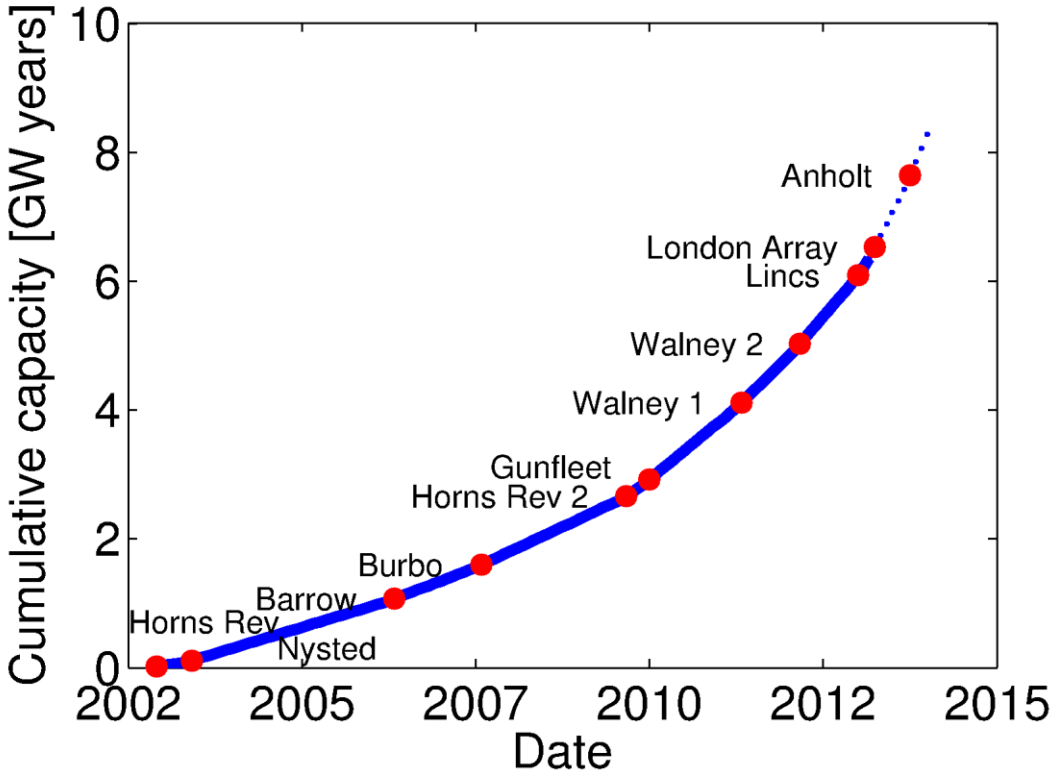
The accumulated pool of knowledge



Then we hired Nicolai

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Validation of the N. O. Jensen wake model

Wind Farm	Capacity [MW]	Data Range	Model Error [%]
HR1	160	Jan 2005-Jan 2008[1]	0.25%
NHP	165.6	Feb 2008-Mar 2010[2]	[illegible]
BOW	90	Jan 2007-Jan 2011[3]	[illegible]
BBW	90	Jan 2009-Mar 2013	[illegible]
HR2	209.3	Oct 2009-Jun 2011[4]	[illegible]
GFS	172.8	Jun 2010-Mar 2013	[illegible]
WOW01	183.6	Jan 2011-Nov 2011[5]	[illegible]

1) Available data range
2) NHP shadowed by Rødsand 2 after March 2010
3) BOW shadowed by WOW after January 2011
4) Aerodynamic upgrades installed on HR2 June 2011. New power curve means altered wake losses
5) WOW01 shadowed by WOW02 after November 2011. Limited data set

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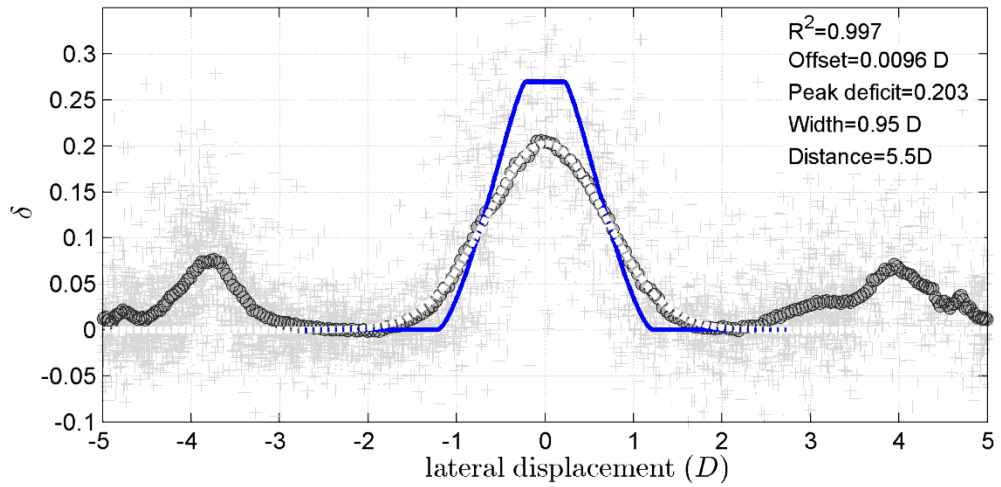
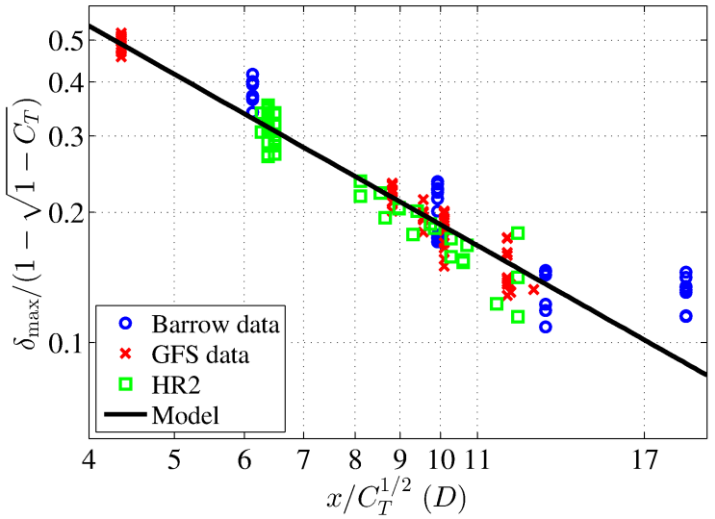
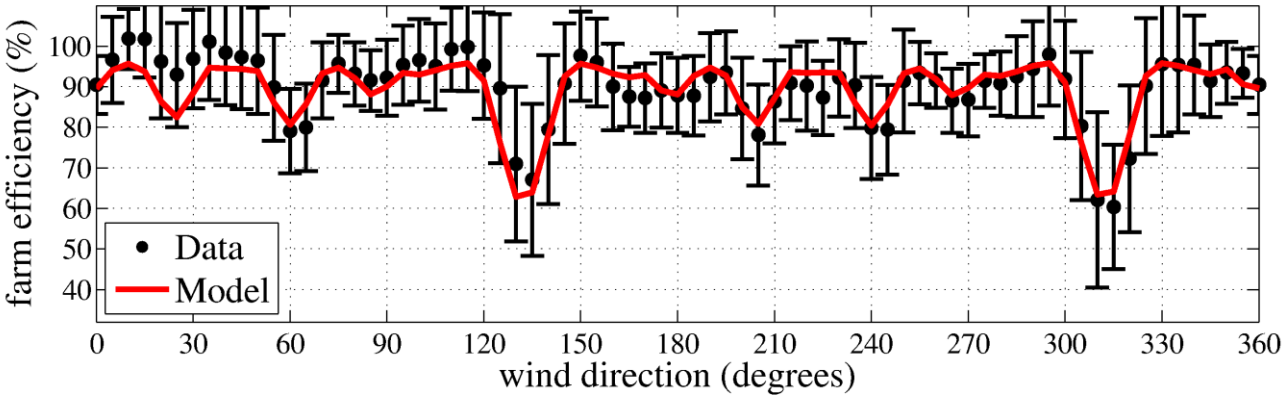
DEWaM – DONG Energy Wake Model



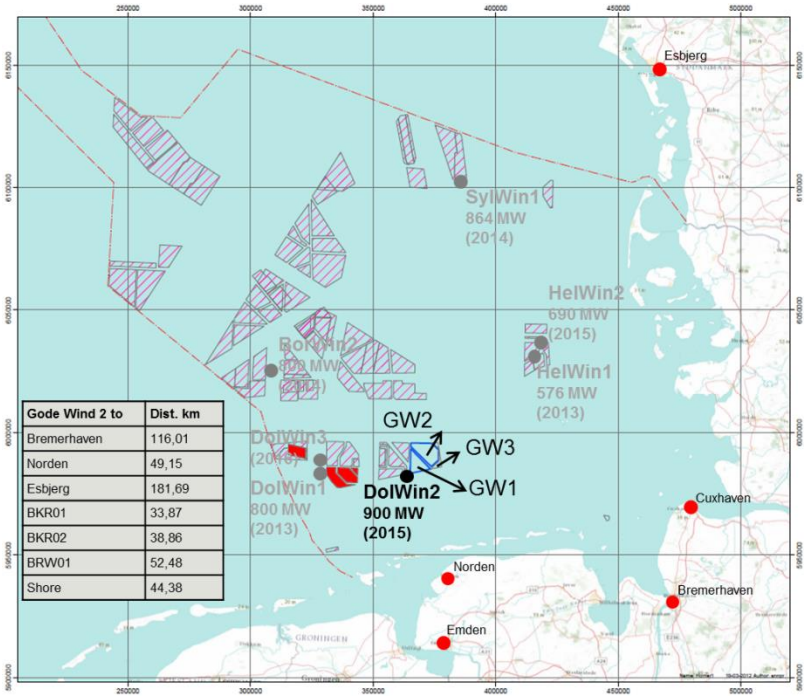




Build model on the data

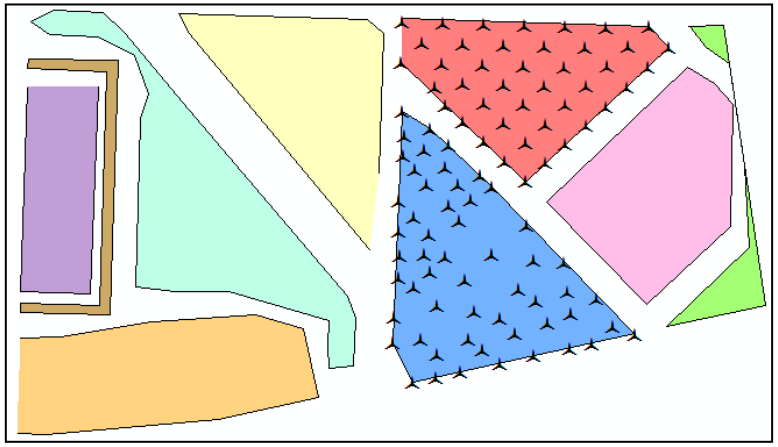
Please refer to : Nicolai Gayle Nygaard, ICOWES 2013

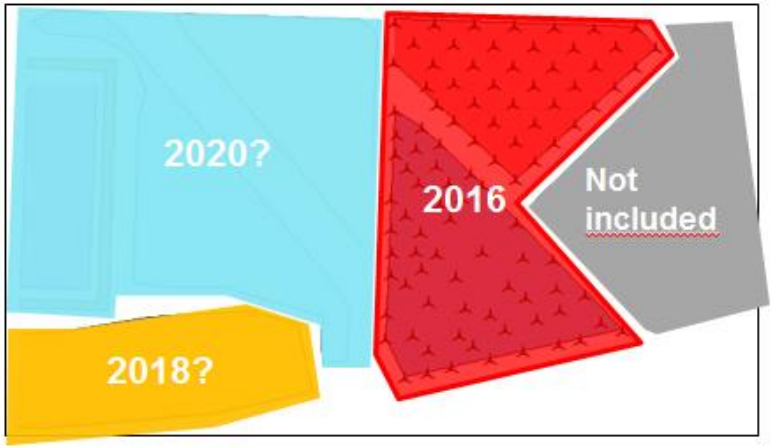
Present challenges 1



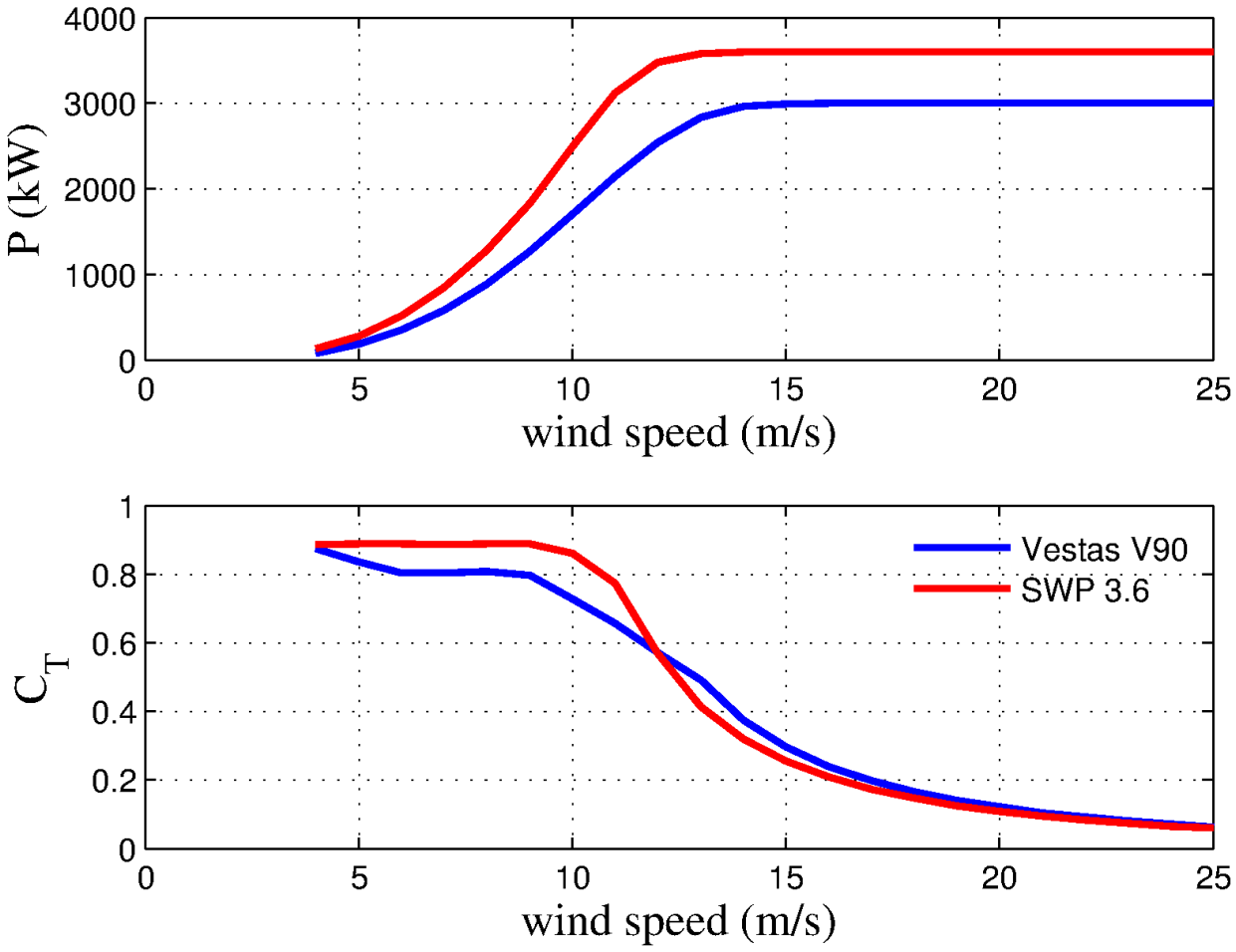
Gode Wind 2 to	Dist. km
Bremerhaven	116,01
Norden	49,15
Esbjerg	181,69
BKR01	33,87
BKR02	38,86
BRW01	52,48
Shore	44,38

Neighbouring wind farms





Present challenges 2



Ct-curves are changing – can we thrust them?

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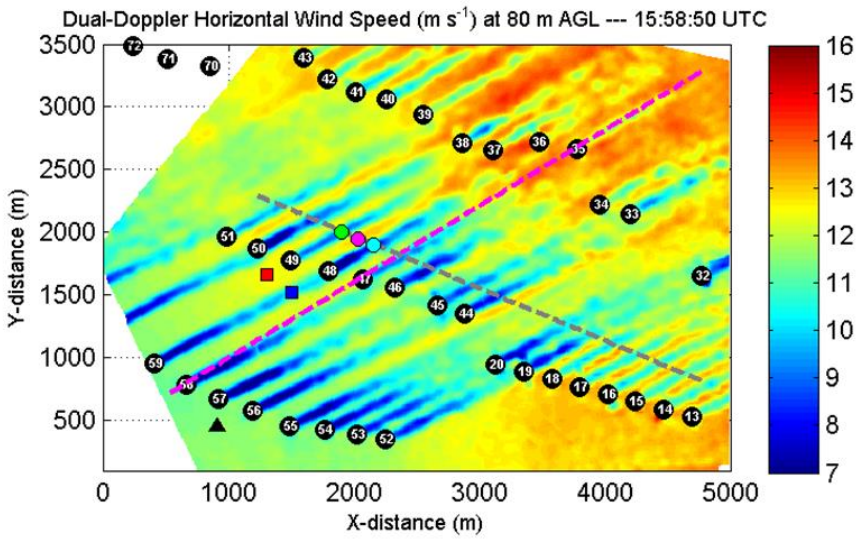
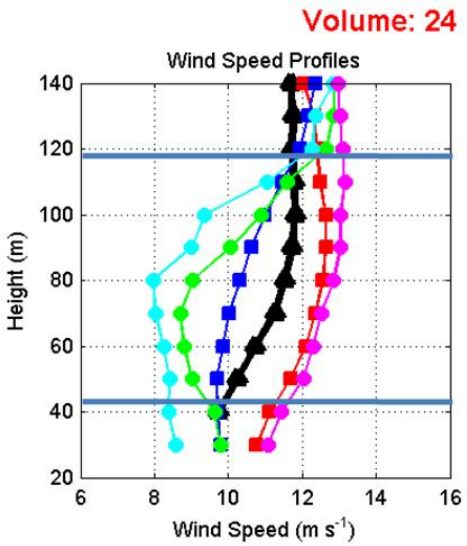
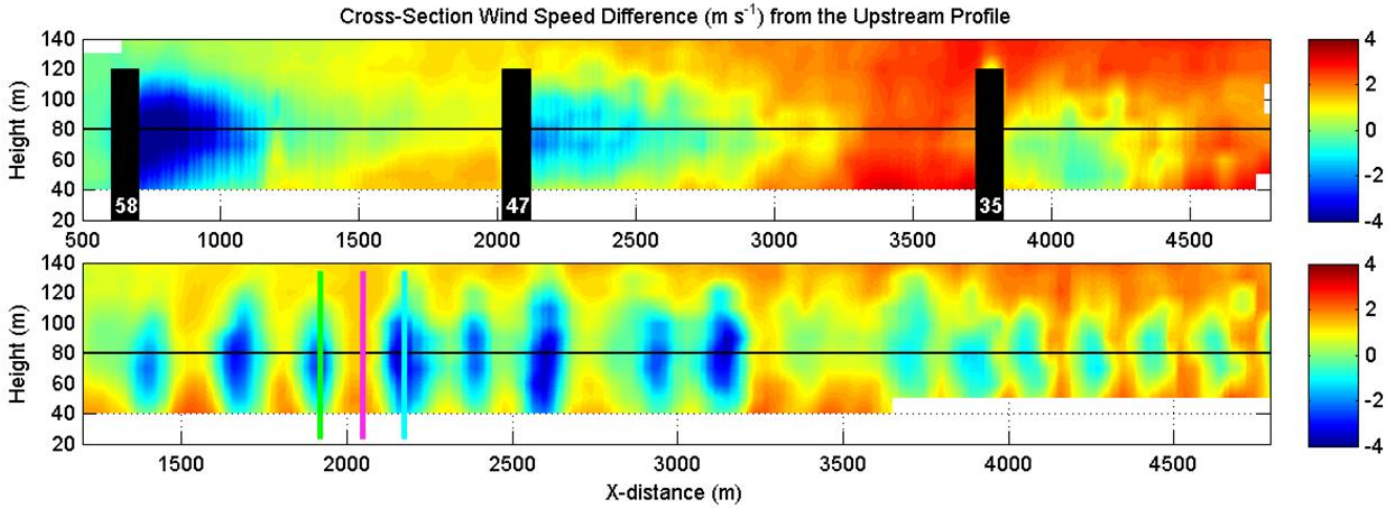
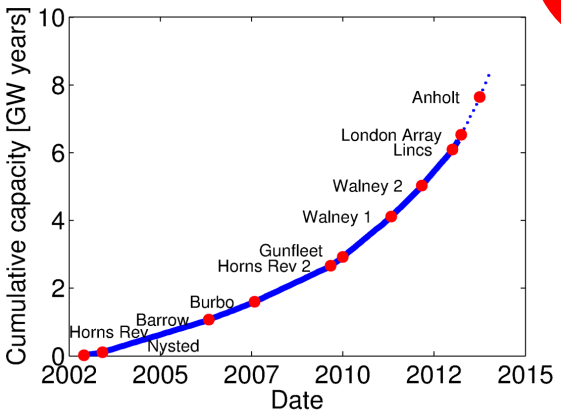
Future Oportunities
From know-how to know-why

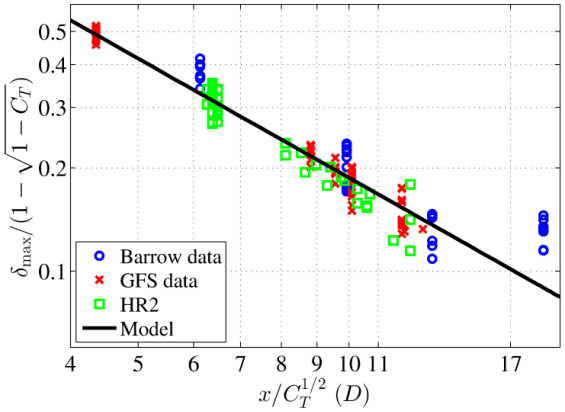






Q&A


Cumulative capacity [GW years]
Date
Horns Rev
Nysted
Barrow
Burbo
Horns Rev 2
Gunfleet
Walney 1
Walney 2
Lincs
London Array
Anholt


Barrow data
GFS data
HR2
Model