Wind resources in the North Sea

and the optimal spot for wind power

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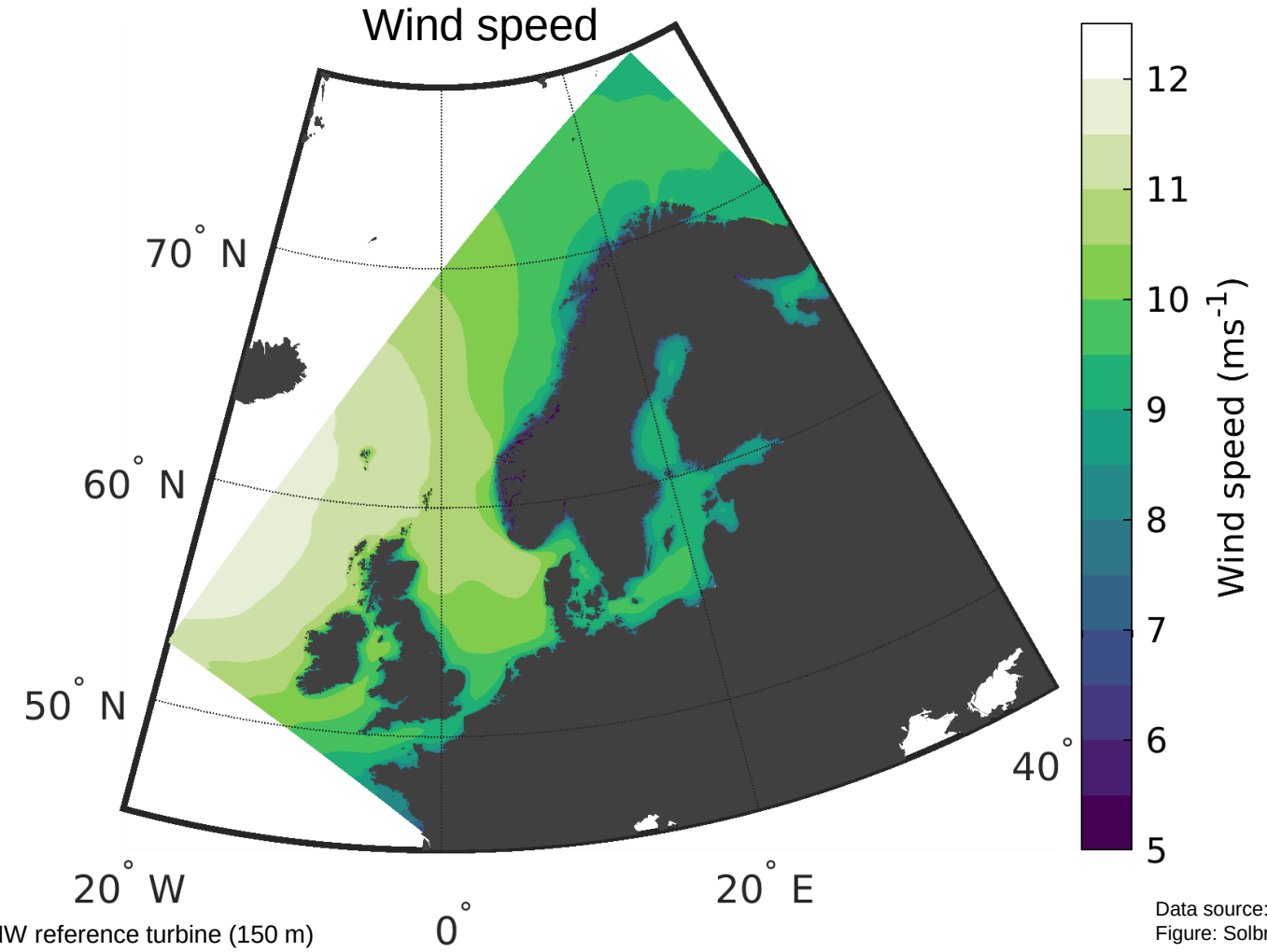
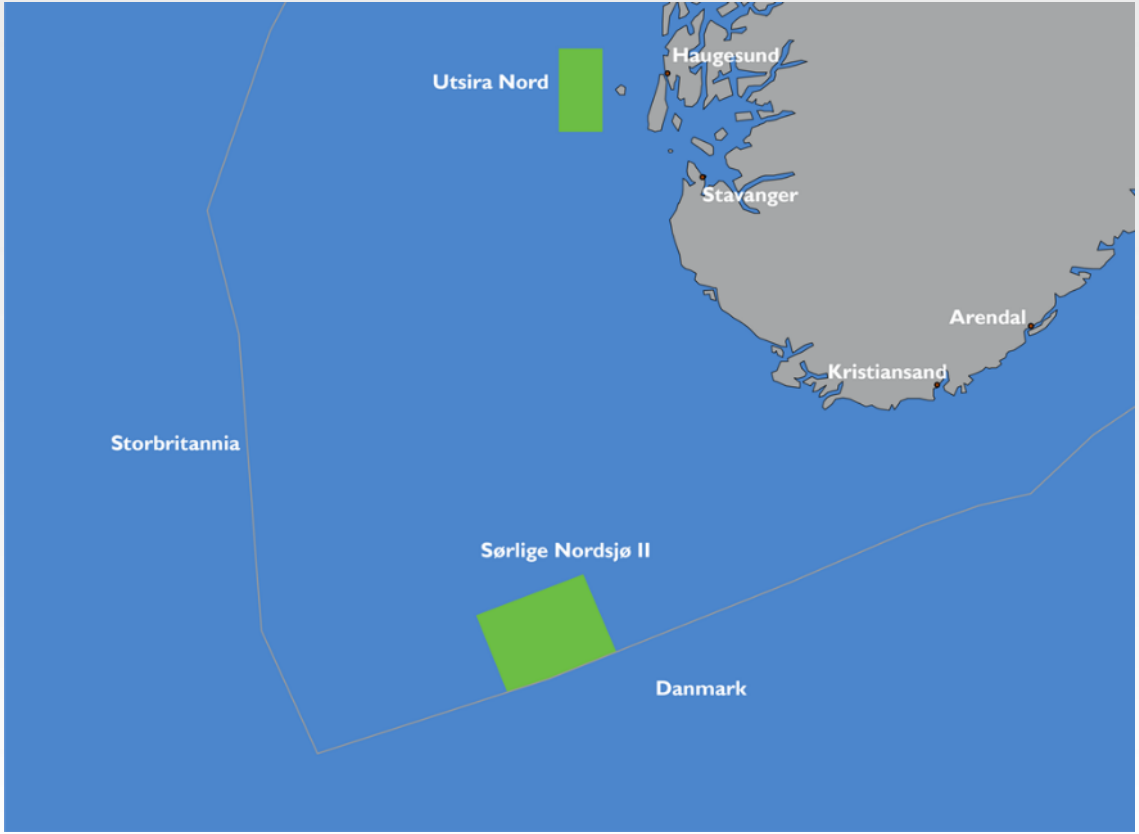
Enorm interesse for
havv
— Det perfekte
Europa
energi fra havvind
Bedriftene strømmer til Nordsjøen for å bygge havvind
ore vind i
Stor interesse for havvindmølleparker i områdene Utsira Nord og Nordsjø II



Turbine: IEA 15MW reference turbine (150 m)

Data source: NORA3-WP
Figure: Solbrekke & Sorteberg 2021



What's next?

Figure: NVE

NORA3 - Wind Power (N3-WP)

- N3-WP: created to facilitate for wind power stakeholders and decision makers
- N3-WP: is based on the newest hindcast data set from the Norwegian Meteorological inst.
- N3-WP: is an open access climatological offshore wind resource data set
- N3-WP: monthly data (u and P are available as hourly data) from 1996-2019
- N3-WP: 7 wind resource and 18 wind power related variables
- N3-WP: 3 heights/turbines
  - Siemens 6 MW, hub = 101 m
  - DTU ref turb 10 MW, hub = 119 m
  - IEA ref turb 15 MW, hub = 150 m

NORA3 - Wind Power (N3-WP)

- NORA3-WP: 7 wind resource variables

Wind speed

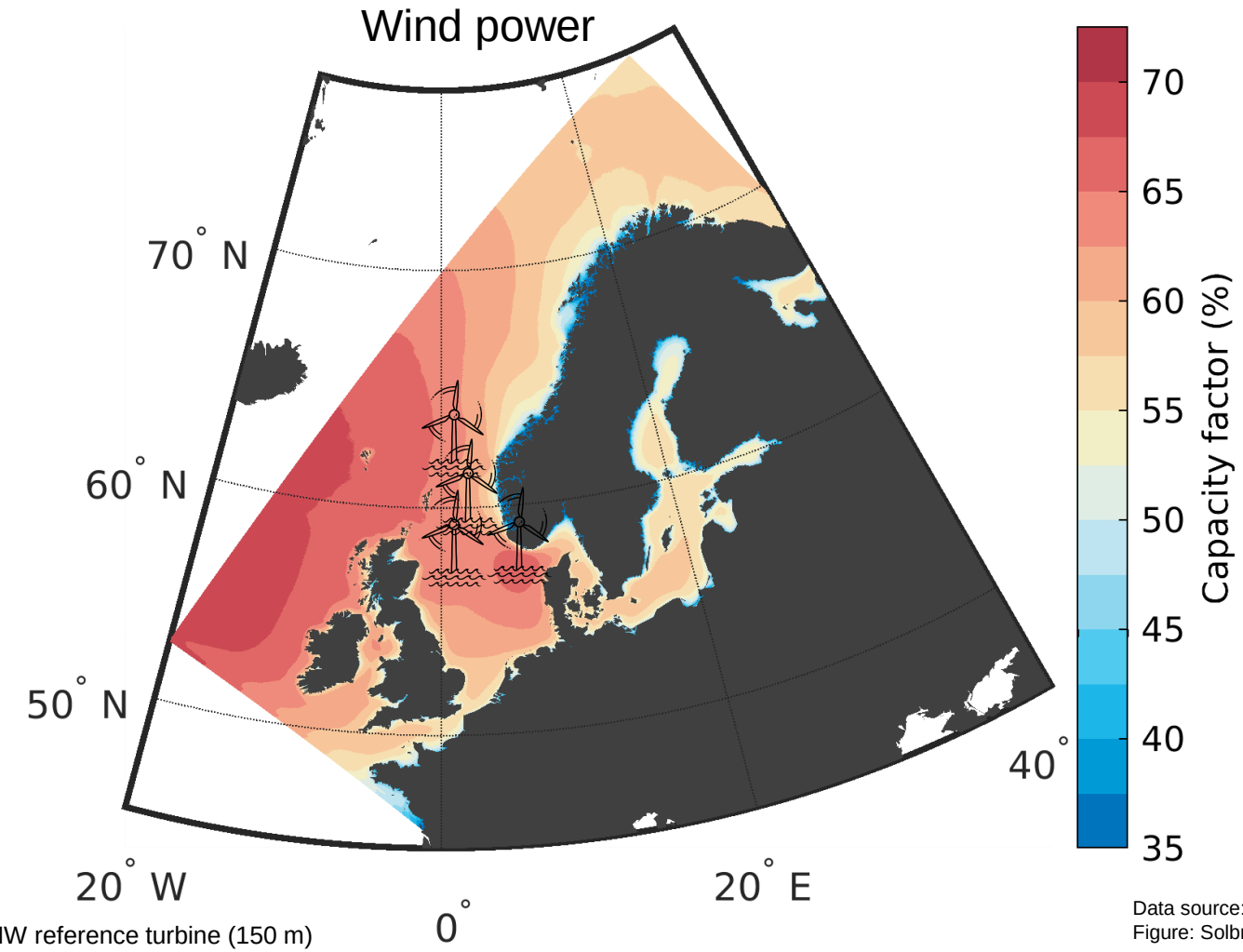
Variable	Stat	unit	X grid x Y grid x time	height (m)
Hourly wind speed	-	ms^{-1}	652 x 1149 x h_{month}	hh 1, hh 2, hh 3
Wind speed	Mean, 25-, 50-, 75-, 95-percentile, std, max	ms^{-1}	652 x 1149 x 1	hh 1, hh 2, hh 3
Exponential power law coefficient (α)	Mean	-	652 x 1149 x 1	10-100, 50-100, 100-250
Weibull wind speed parameters	a, b	-	652 x 1149 x 1	hh 1, hh 2, hh 3
Prevailing wind direction sector	mean	degrees	652 x 1149 x 1	100
Vertical wind shear	Mean, max	ms^{-1}	652 x 1149 x 1	50-100, 100-250
Wind speed absolute ramp-rate (ARR)	Mean, max	ms^{-1}	652 x 1149 x 1	hh 1, hh 2, hh 3

NORA3 - Wind Power (N3-WP)

- NORA3-WP: 18 wind power related variables

Wind power

Variable	Stat	unit	X grid x Y grid x time	height (m)
Power density, P_d	Mean	Wm^{-2}	652 x 1149 x 1	hh 1, hh 2, hh 3
Power capture, P_c	Mean	$Warea^{-1}$	652 x 1149 x 1	hh 1, hh 2, hh 3
Hourly generated power, P_w	-	W	652 x 1149 x h_{month}	hh 1, hh 2, hh 3
Power generated, P_w	Mean, 25- , 50-, 75-percentile	W	652 x 1149 x 1	hh 1, hh 2, hh 3
Power generated, density correction	Mean	W	652 x 1149 x 1	hh 1, hh 2, hh 3
Power generated, SC1 $P_{w,SC1}$	Mean	W	652 x 1149 x 1	hh 1, hh 2, hh 3
Power generated, SC2 $P_{w,SC2}$	Mean	W	652 x 1149 x 1	hh 1, hh 2, hh 3
Power capture coefficient, P_{cc}	Mean	%	652 x 1149 x 1	hh 1, hh 2, hh 3
Generated power absolute ramp-rate (ARR)	Mean, max	W	652 x 1149 x 1	hh 1, hh 2, hh 3
Cubed generated power ($u_{ci} \leq u < u_r$)	-	%	652 x 1149 x 1	hh 1, hh 2, hh 3
Rated generated power ($u_r \leq u < u_{co}$)	-	%	652 x 1149 x 1	hh 1, hh 2, hh 3
No generated power ($u < u_{ci}, u \geq u_{co}$)	-	%	652 x 1149 x 1	hh 1, hh 2, hh 3
No generated power, SC1 ($u < u_{ci}, u \geq u_{co}$)	-	%	652 x 1149 x 1	hh 1, hh 2, hh 3
No generated power, SC2 ($u < u_{ci}, u \geq u_{co}$)	-	%	652 x 1149 x 1	hh 1, hh 2, hh 3
Capacity factor	-	%	652 x 1149 x 1	hh 1, hh 2, hh 3
Full load hours	-	h	652 x 1149 x 1	hh 1, hh 2, hh 3
Full load hours, SC1	-	h	652 x 1149 x 1	hh 1, hh 2, hh 3
Full load hours, SC2	-	h	652 x 1149 x 1	hh 1, hh 2, hh 3



Turbine: IEA 15MW reference turbine (150 m)

Data source: NORA3-WP
Figure: Solbrekke & Sorteberg 2021

Where is the optimal spot for wind power production?

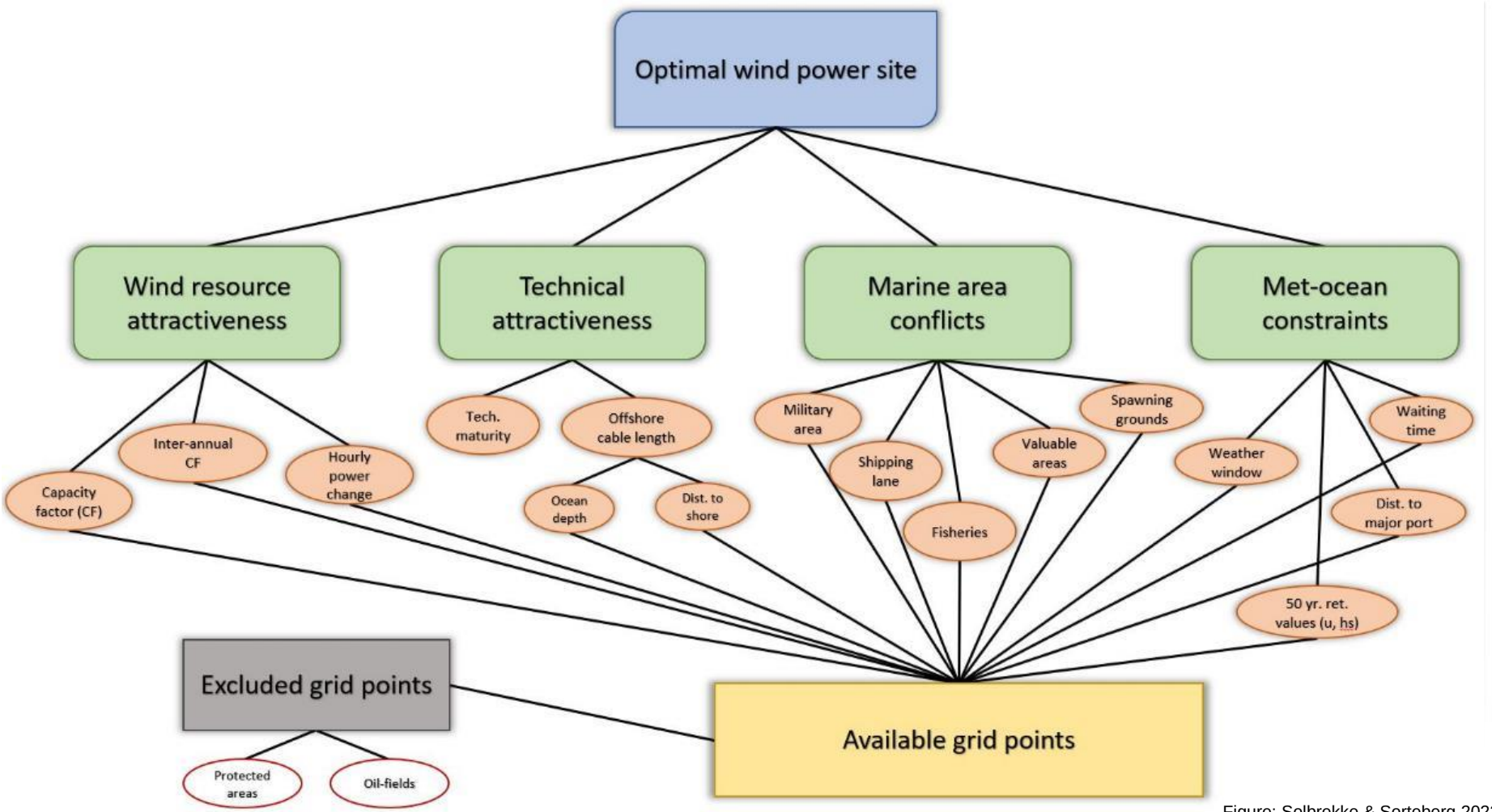


Figure: Solbrekke & Sorteberg 2022

The wild forest of criteria

Many (conflicting) criteria

How can we know the importance of each criteria?

Analytical hierarchy process ?

Analytical hierarchy process

What and why

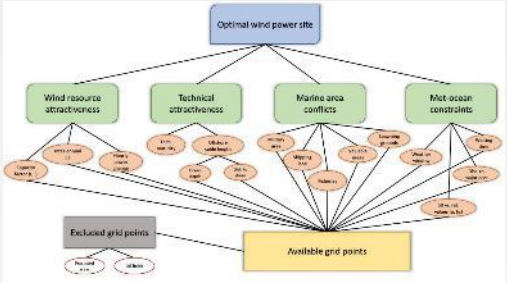
A method to handle complex decision making:

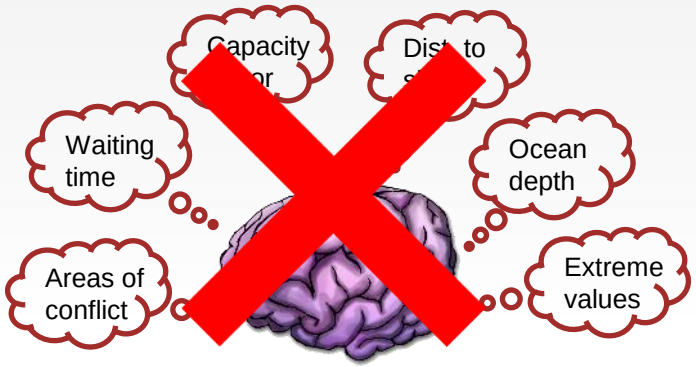
- Pin-point the optimal spot in the Norwegian economical zone for offshore wind power installation

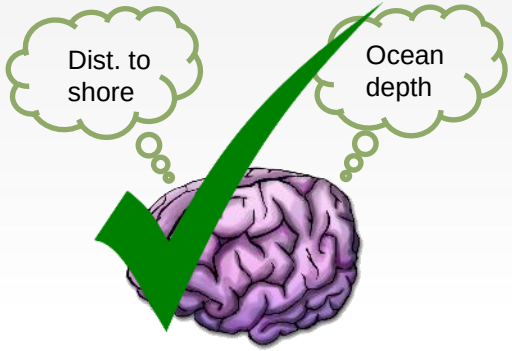
The goal is split into goal-influencing criteria

The criteria is further divided into sub-criteria -> HIERARCHY

Criteria in the same branch are pair-vise compared

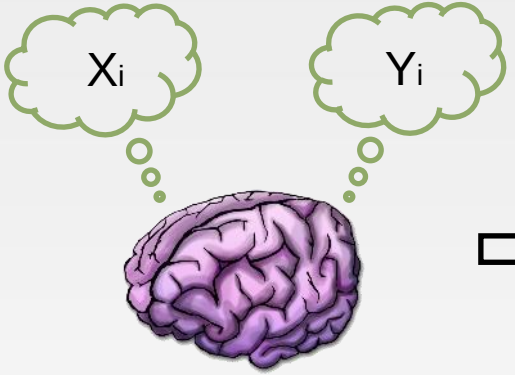






Analytical hierarchy process

What and why



Comparison matrix

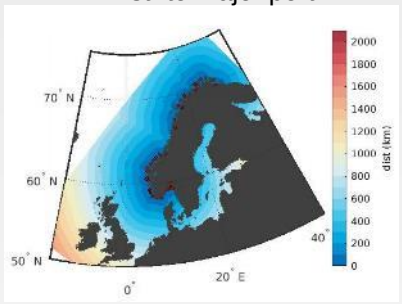
$$\begin{pmatrix} 1 & z_{12} & \cdot & \cdot & \cdot & z_{ij} \\ 1/z_{12} & 1 & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & 1 & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & 1 & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & 1 & \cdot \\ 1/z_{ij} & \cdot & \cdot & \cdot & \cdot & 1 \end{pmatrix} \Rightarrow \begin{pmatrix} W_1 \\ \cdot \\ \cdot \\ \cdot \\ W_j \end{pmatrix}$$

The weight of each criteria is found by calculate **eigenvalues/geometric mean** of the comparison matrices.

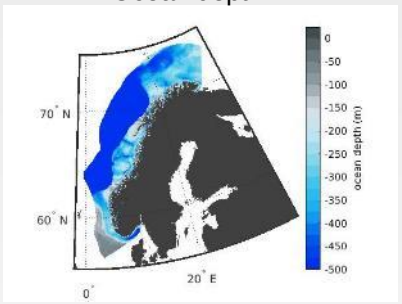
Analytical hierarchy process

What and why

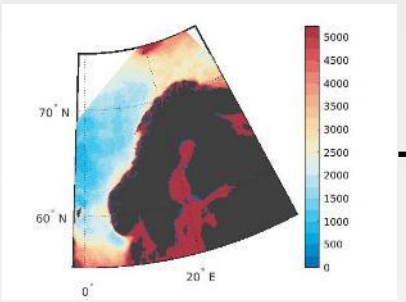
Dist. to major port

$W_1 *$ 

Ocean depth

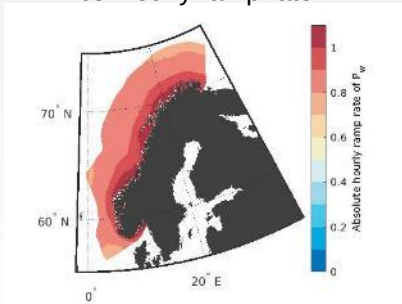
$+ W_2 *$ 

Weather window

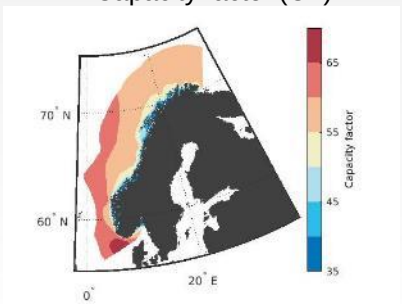
$+ W_3 *$ 

$+$

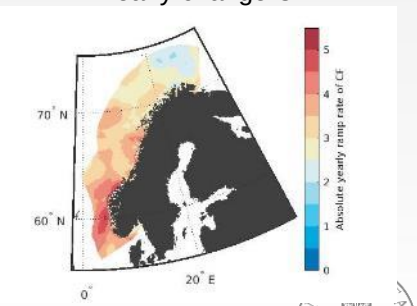
Abs. hourly ramp rate P

$W_4 *$ 

Capacity factor (CF)

$+ W_5 *$ 

Yearly change CF

$+ W_6 *$ 

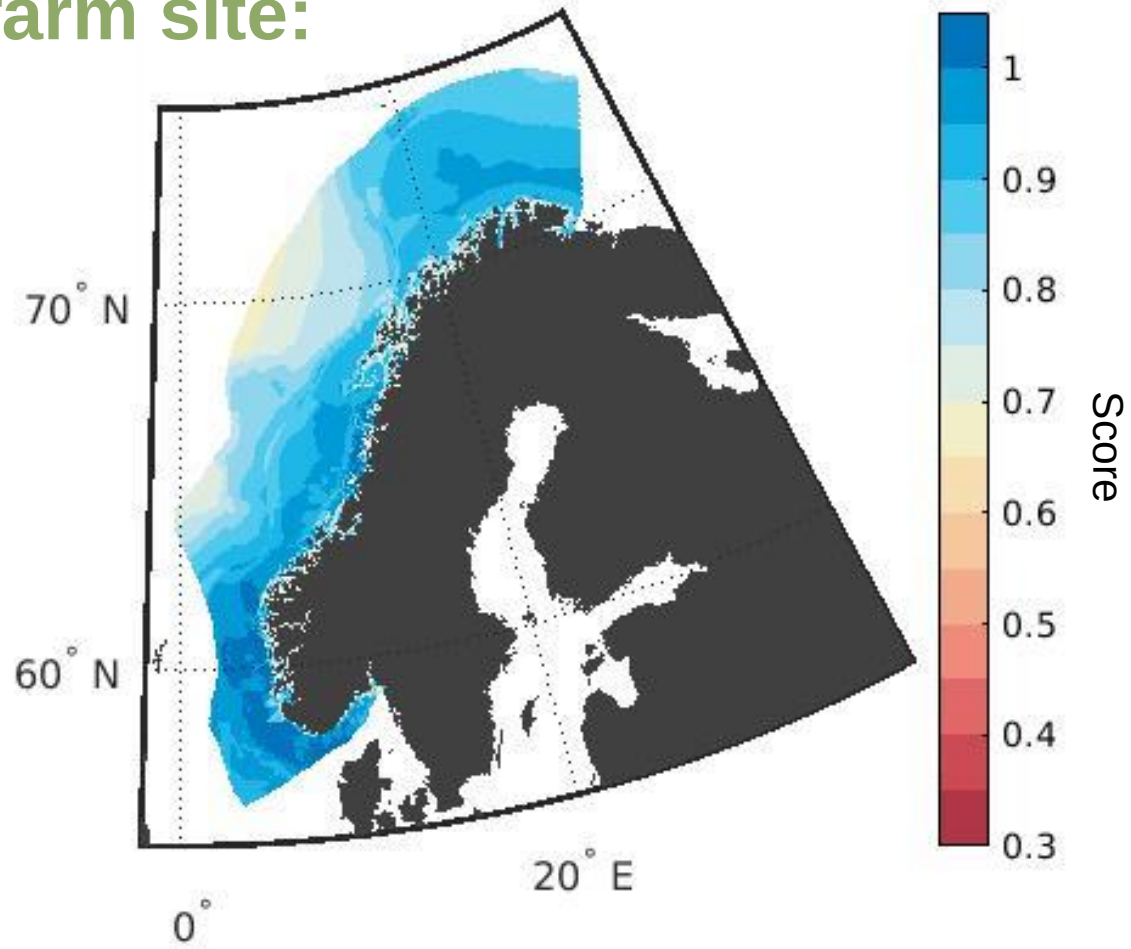
The optimal wind farm site:

Wind resource +

Technical considerations +

Marine area conflicts

(excluded areas,
met-ocean constraints)



References

1) Solbrekke, Ida Marie and Sorteberg, Asgeir. “NORA3-WP: NORwegian hindcast Archive's offshore Wind Power data set”, submittet to *Scientific data – Nature* (2021)

2) Solbrekke, Ida Marie and Sorteberg, Asgeir. “Optimal wind farm siting using an Analytical Hierarchy Process approach: A case-study of the Norwegian economical zone. In preparation for *Renewable Energy* (2022)

3) Haakenstad et al. “NORA3: A non-hydrostatic high-resolution hindcast for the North Sea, the Norwegian Sea and the Barents Sea”. *Journal of Applied Meteorology and Climatology,* Vol 60, 1443-1464 https://doi.org/10.1175/JAMC-D-21-0029.1

Thank you for your attention!

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