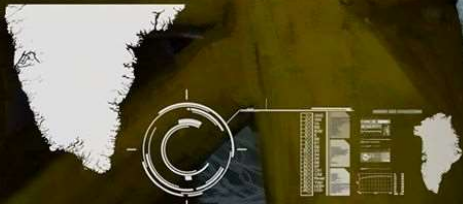




# Harvesting wind energy in Greenland: a project for Europe and a huge step towards the building a global electrical grid



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# The big fail

80% of primary energy is from fossil fuel.

This percentage has barely not changed in the last decade.

**And now?**

# Global grid: an answer to this big fail

**Fact 1:** Natural smoothing of renewable energy sources and loads in a global grid setting. Very little investment in storage needed.

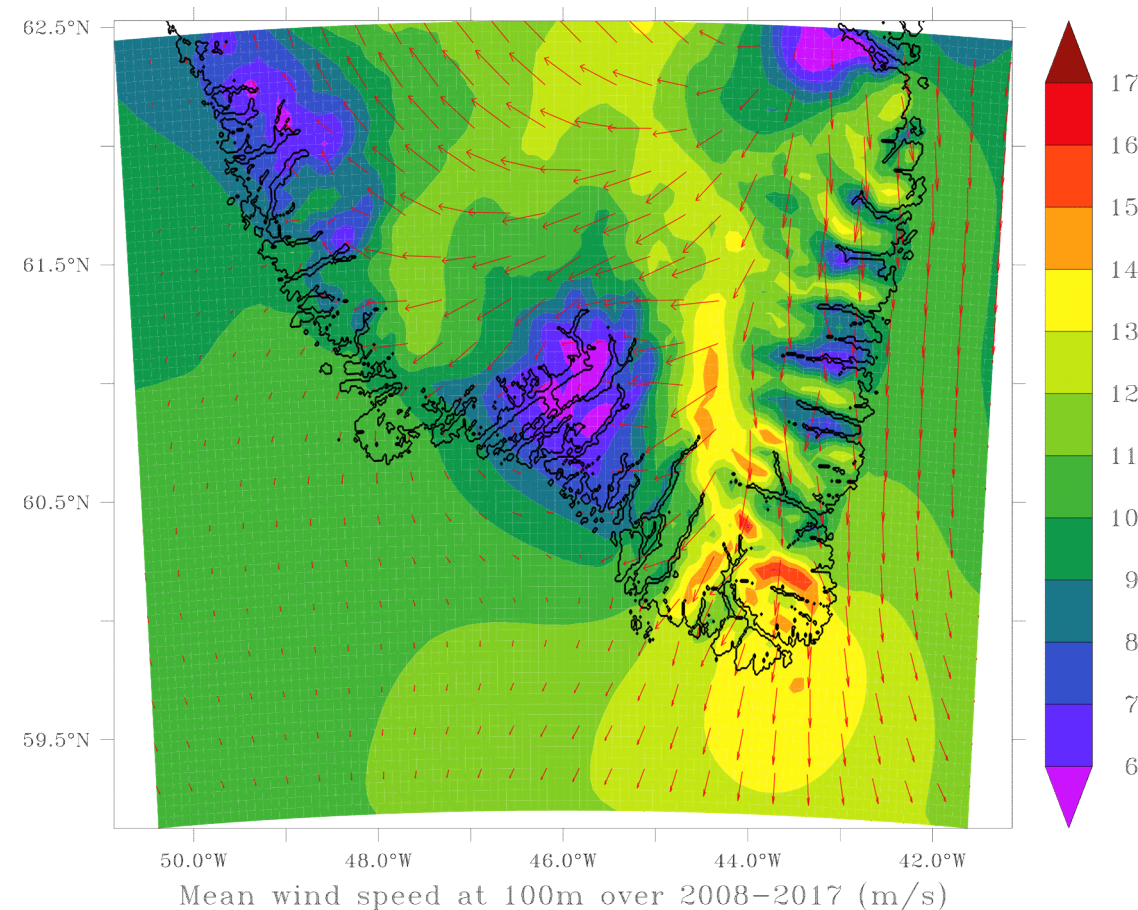
**Fact 2:** Renewable electricity – in €/MWh – is very cheap in high-density renewable energy fields (e.g., Atacama desert for solar energy, Greenland coast for wind energy).

**Fact 3:** Transporting electricity over long-distances is becoming cheap.

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**Fact 1 + Fact 2 + Fact 3** offer a true possibility for putting fossil fuels **out of business** for electricity generation (even without a CO2 tax) by building a global grid.

# Why harvesting wind energy in the southeast Greenland?

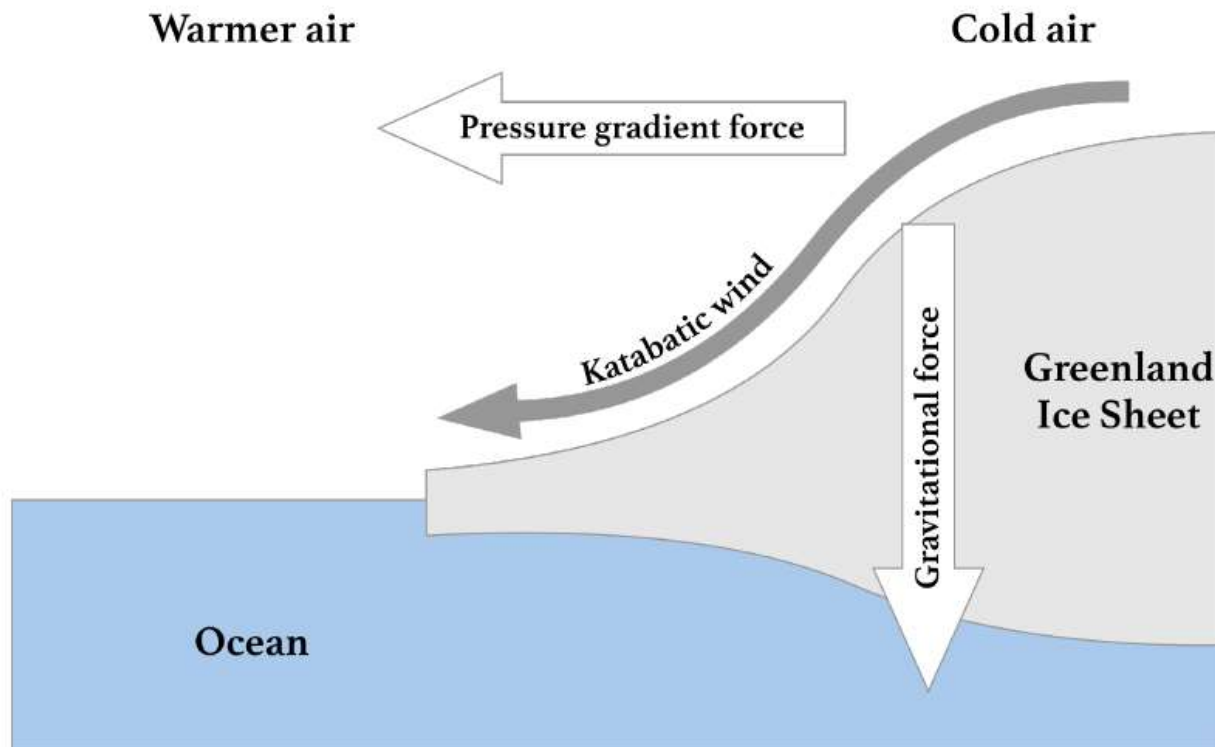


1. High winds.
2. Decorrelation with European wind patterns.
3. Huge areas. No NIMBY issues.
4. Half-way between Europe and the US.
5. Nice flagship project for accelerating the building of the global grid.



# Winds in the southeast Greenland

In the southeastern part of Greenland, general circulation winds (driven by the Sun's energy) add up to **Katabatic winds**.



Katabatic winds are the result of heat transfer processes between the cold ice cap and the warmer air mass above it.

When the air mass temperature is higher than that of the ice sheet, the former is cooled down by radiation, thus the air density increases forcing it down the sloping terrain.

The flow of katabatic winds is driven by gravity, temperature gradient and inclination of the slope of the ice sheet.

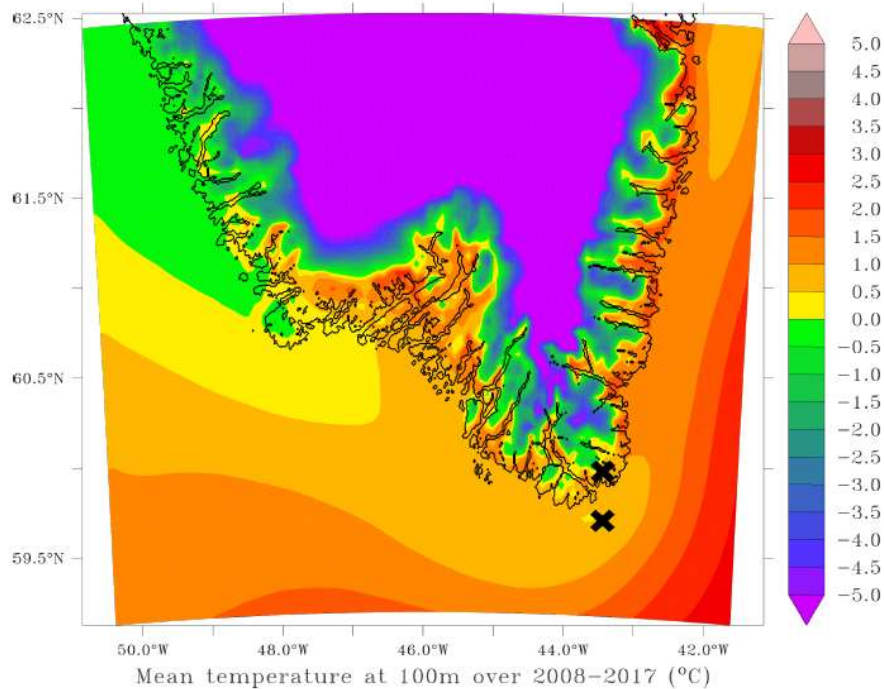
# Data acquisition for our analysis

We relied on data reanalysis to reconstruct wind signals from past in situ and satellite observations.

The regional **MAR** (Modèle Atmosphérique Regional) model was used for data reanalysis over Greenland. This model can represent well physical processes in Greenlandic regions, including Katabatic winds. Boundary conditions determined by the ERA5 reanalysis model.

Hourly values of wind speed at 100 meters above ground level are generated using the reanalysis models for the period 2008-2017.

# Regions selection for our analysis



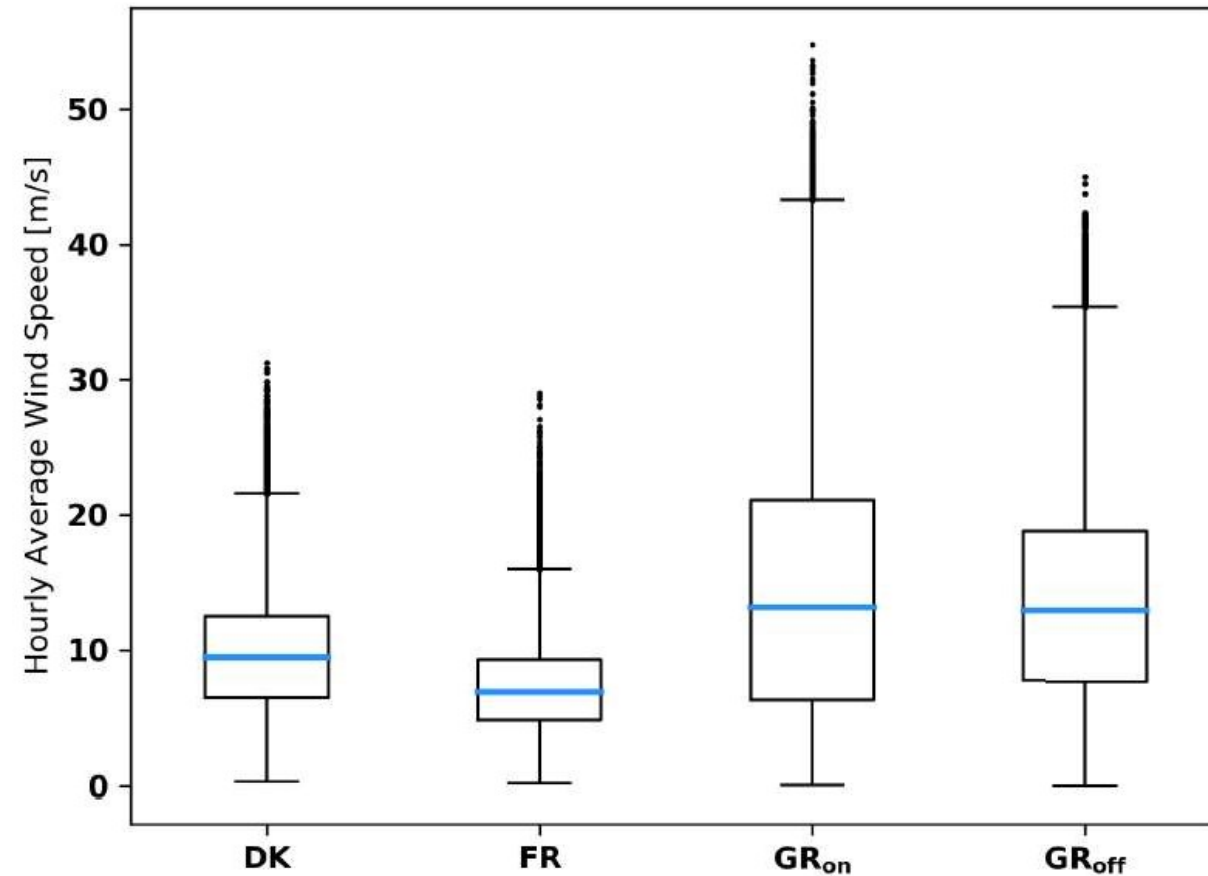
Two areas in Greenland: one offshore ( $GR_{OFF}$ ) and one onshore ( $GR_{ON}$ ).

Temperatures too mild to have a frozen sea or permanent ice onshore.



Two areas in Europe: one offshore wind farm in Denmark (DK) and one on-shore wind farm in France (FR).

# Wind ressource assessment



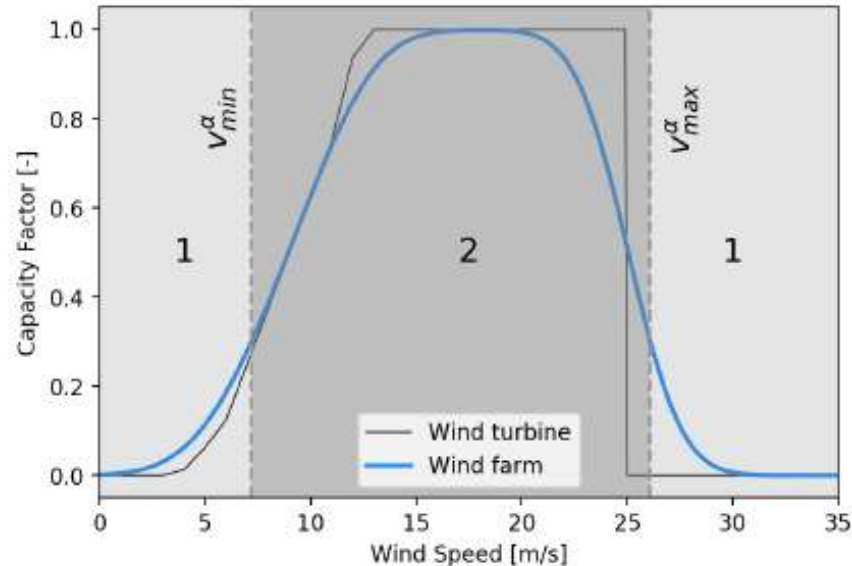
Higher mean wind speeds in Greenland than in the two European locations.

Distribution of wind speeds more assymetric for GR<sub>off</sub> and GR<sub>on</sub> than for DK and FR.

The high standard deviations of the wind speeds in Greenland do not correspond to a high turbulence intensity, but to the strong influence of seasonality of the local natural resource.



# Load factors of the wind farms



Single turbine and wind farm transfer functions. Example of wind farm power curve aggregation based on multiple aerodyn SCD 8.0/168 units.

DK	FR	GR <sub>on</sub>	GR <sub>off</sub>
0.55	0.32	0.50	0.59

Capacity factors for the different locations

$v_{cut}^{out}$ (m/s)	DK	FR	GR <sub>on</sub>	GR <sub>off</sub>	Capacity factors versus cut-out wind speed for the wind turbines.
25	0.55	0.32	0.50	0.59	
Highest wind speed observed	0.56	0.33	0.66	0.69	

Important remarks for manufacturers of wind turbines willing to tap into the Greenland wind energy market:

1. Wind turbines capable of operating with **higher cut-out speed** lead to significantly higher load factors in Greenland.
2. May also be interesting to design wind turbines which saturate in terms of power output for higher wind speeds (i.e., turbines having a **higher rated output speed**).

# Critical time windows for studying the complementarity of wind production

A window of duration  $\delta$  is said to be **critical** for a set of locations if the average power generated in those locations over the time window is below a fraction  $\alpha$  of the installed capacity.

Conjecture: The export of wind energy from Greenland to Europe would reduce to zero the number of these long critical periods of times during which Europe could not rely on wind energy to cover a significant amount of its energy needs (or more generally renewable energy - a phenomenon known as **Dunkelflaute** in German).

# Occurrence of critical time windows

$\delta \backslash \alpha$	20%	30%	40%	50%	60%	70%
1	0.11 <b>0.14</b> <i>0.02</i>	0.18 <b>0.19</b> <i>0.04</i>	0.27 <b>0.25</b> <i>0.07</i>	0.35 <b>0.30</b> <i>0.11</i>	0.44 <b>0.35</b> <i>0.17</i>	0.53 <b>0.42</b> <i>0.23</i>
6	0.10 <b>0.12</b> <i>0.01</i>	0.18 <b>0.18</b> <i>0.04</i>	0.27 <b>0.24</b> <i>0.07</i>	0.35 <b>0.30</b> <i>0.11</i>	0.45 <b>0.37</b> <i>0.17</i>	0.54 <b>0.44</b> <i>0.25</i>
24	0.08 <b>0.06</b> <i>0.01</i>	0.16 <b>0.12</b> <i>0.02</i>	0.26 <b>0.19</b> <i>0.06</i>	0.36 <b>0.28</b> <i>0.11</i>	0.48 <b>0.39</b> <i>0.20</i>	0.59 <b>0.53</b> <i>0.32</i>
168	0.01 <b>0.00</b> <i>0.00</i>	0.06 <b>0.01</b> <i>0.00</i>	0.18 <b>0.06</b> <i>0.01</i>	0.38 <b>0.18</b> <i>0.08</i>	0.58 <b>0.43</b> <i>0.26</i>	0.77 <b>0.75</b> <i>0.58</i>

« Probability » of occurrence of critical time windows when using as set of locations: the two European locations (black); the Greenland sites (**green**) and all the four locations (**blue**).

# Additional thoughts

Further research is needed to accurately estimate the costs (including the costs of transporting electricity) and revenues of a large wind farm in Greenland.

The main competitors of a global electrical grid are not stationary batteries and microgrids, but hydrogen as an energy carrier.

What about using metrics related to the amount of raw materials used for identifying the best future green energy system?



# References

Berger, M., Radu, D., Fonteneau, R., Henry, R., Glavic, M., Fettweis, X., Le Du, M., Panciatici, P., Balea, L., Ernst, D. (2018). *Critical Time Windows for Renewable Resource Complementarity Assessment*. Available at <https://arxiv.org/abs/1812.02809>

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