Big infrastructures for fighting climate change

Prof. Damien ERNST

LIÈGE université

80% of our primary energy comes from fossil fuels.

This percentage has hardly changed in the past decade.

CO_2 concentrations are climbing at a record pace.

And now? Well just read this presentation.

Global grid: one answer to this big fail

Fact 1: Natural smoothing of renewable energy sources and loads variability 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.

Fact 1 + Fact 2 + Fact 3 offer a true possibility for putting fossil fuels out of business for electricity generation (even without a CO_2 tax) by building a global grid.

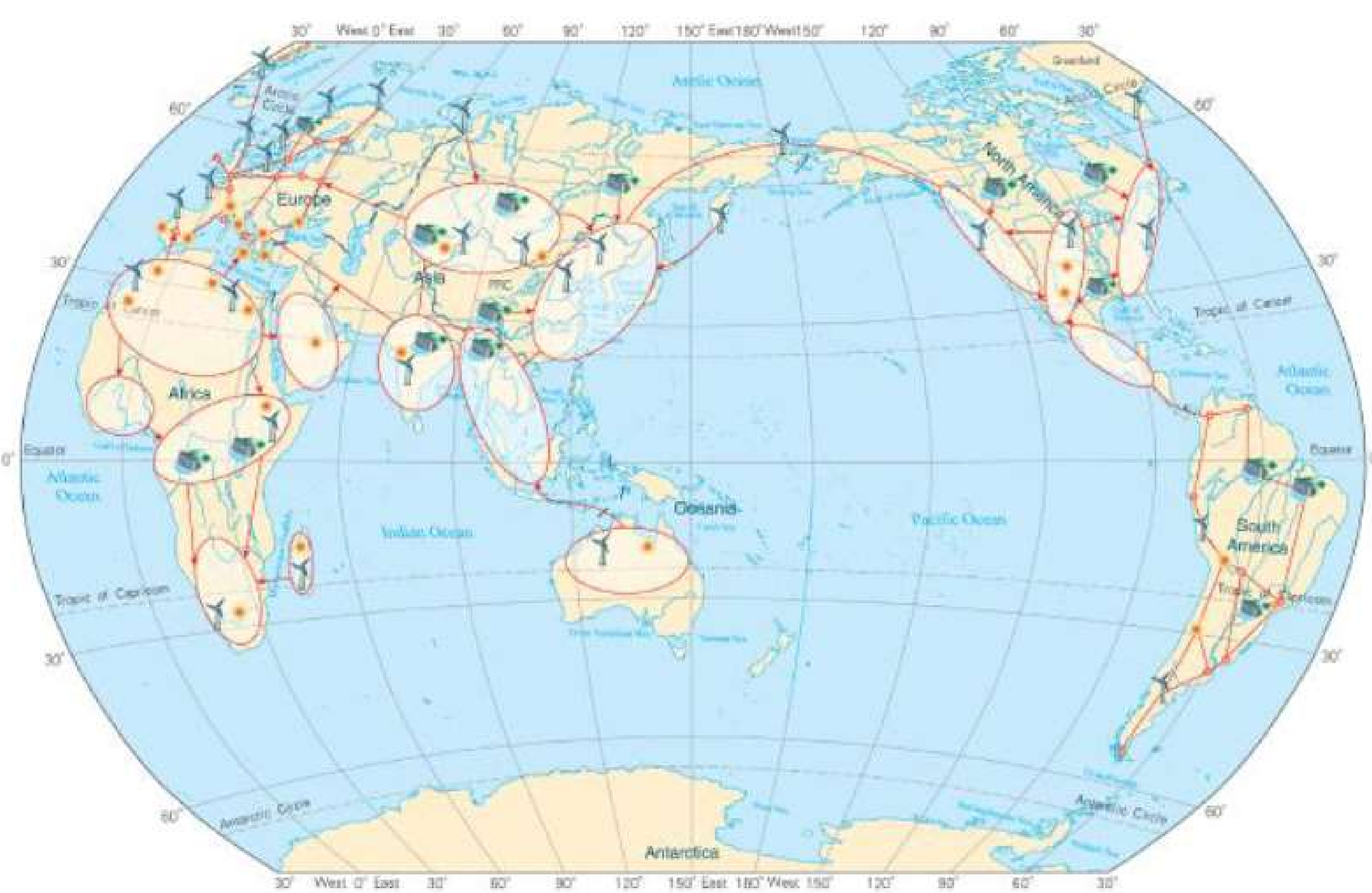
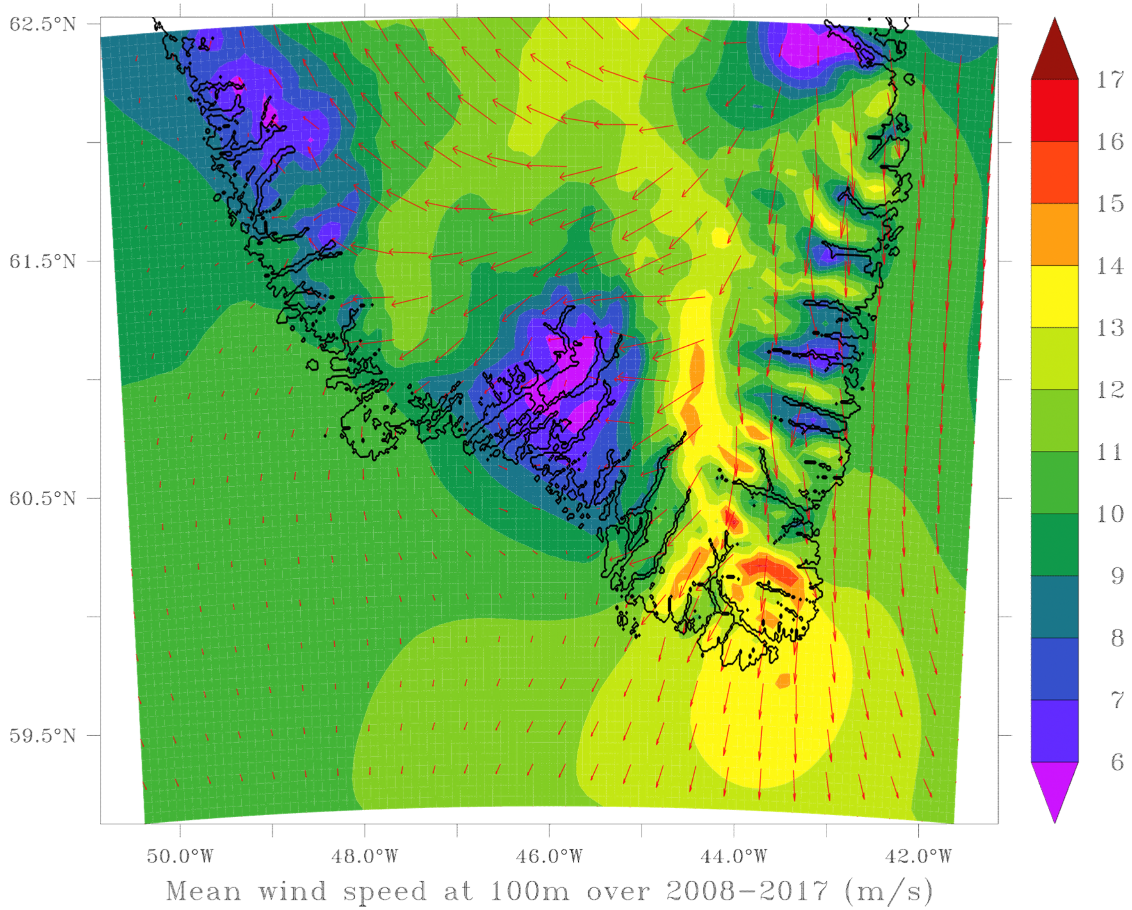


Figure 2-3. Schematic representation of the backbone electricity interconnection

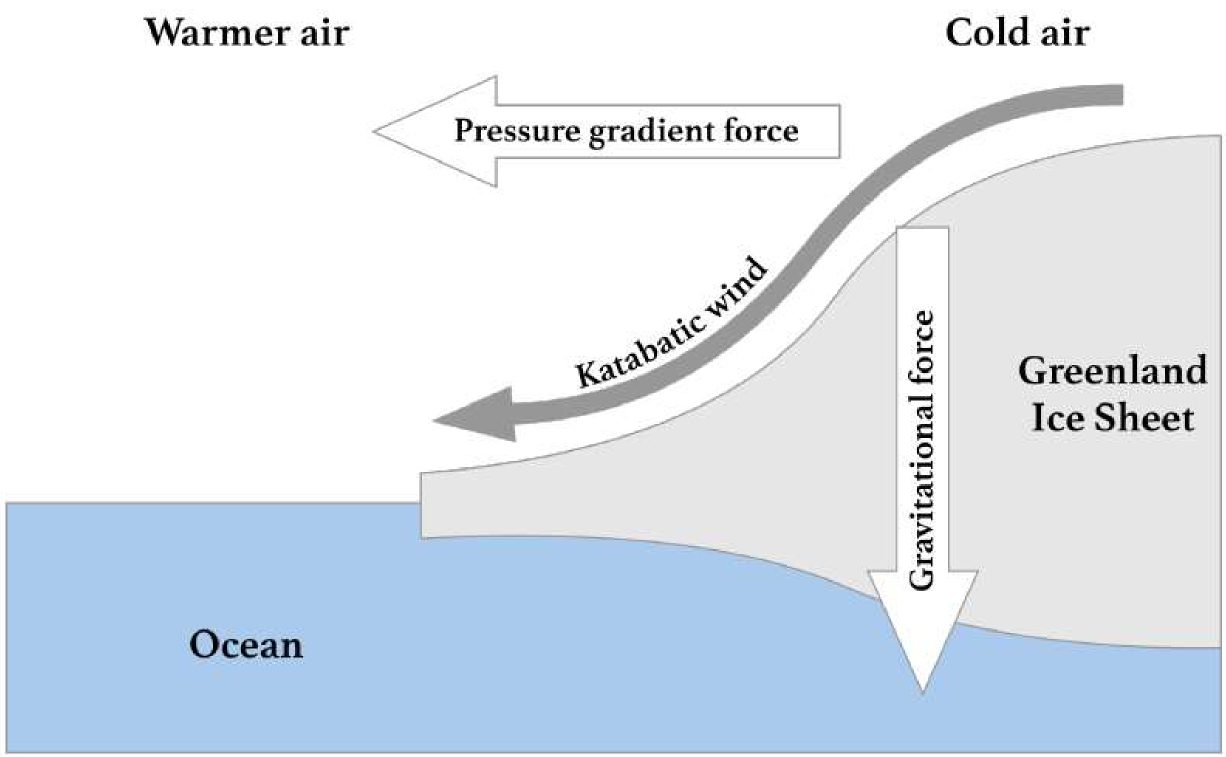
Why should Europe harvest wind energy in Southeastern Greenland?



1. High wind speeds.
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 Southeastern 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.

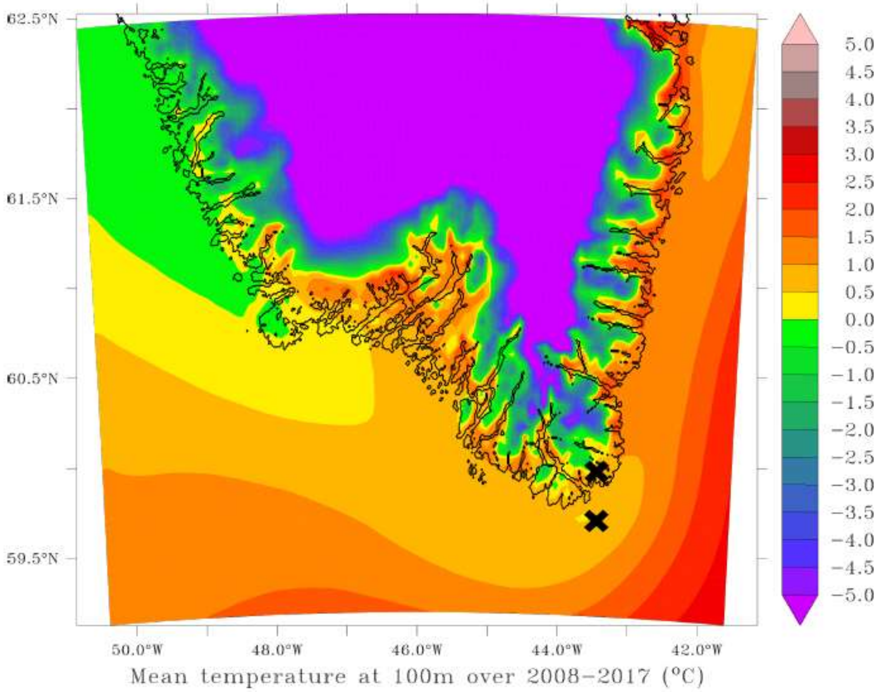
Data acquisition for our analysis

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

The regional MAR (Modèle Atmosphérique Regional) model was used to simulate the weather over Greenland. This model can accurately represent physical processes in polar regions, including Katabatic winds, and has high spatial and temporal resolutions. 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

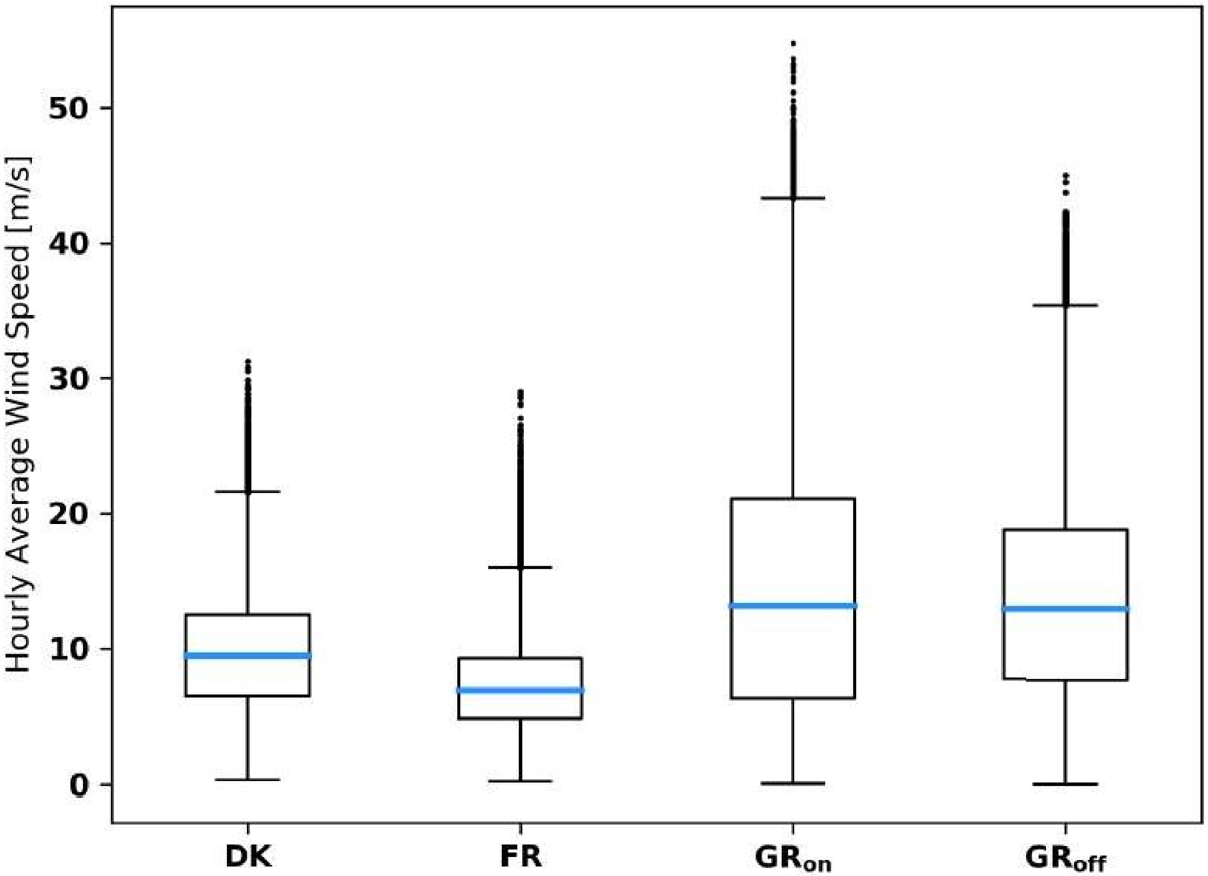


Two areas in Greenland: one offshore (GR_{OFF}) and one onshore (GR_{ON}).

Temperatures too mild to have a frozen sea or permanent ice on-shore.

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

Wind ressource assessment

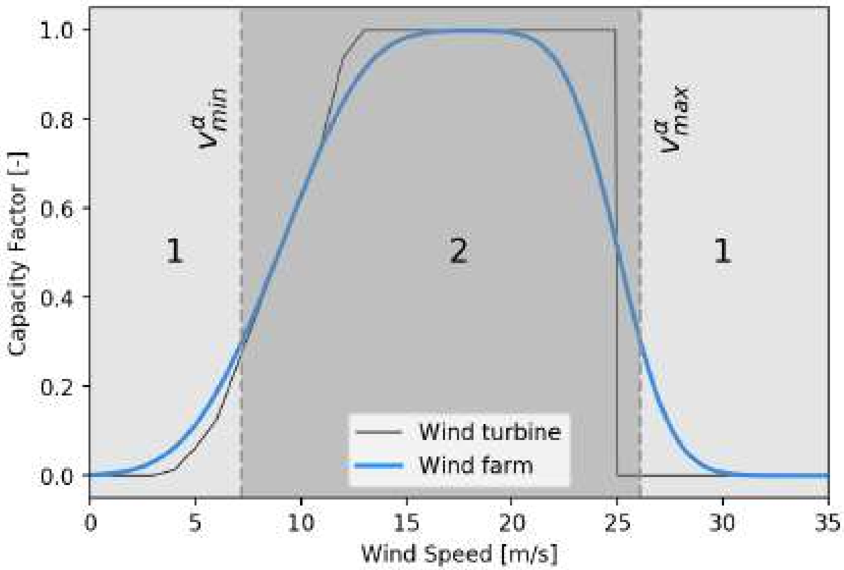


Higher mean wind speeds in Greenland than in the two European locations.

Distribution of wind speeds more asymmetric for GR_{off} and GR_{on} 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_{on}	GR_{off}
0.55	0.32	0.50	0.59

Capacity factors for the different locations

v_{cut}^{out} (m/s)	**DK**	**FR**	**$\mathbf{GR_{on}}$**	**$\mathbf{GR_{off}}$**
25	0.55	0.32	0.50	0.59
Highest wind speed observed	0.56	0.33	0.66	0.69

Capacity factors versus cut-out wind speed for the wind turbines.

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 capacity 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 δ 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 α of the installed capacity.

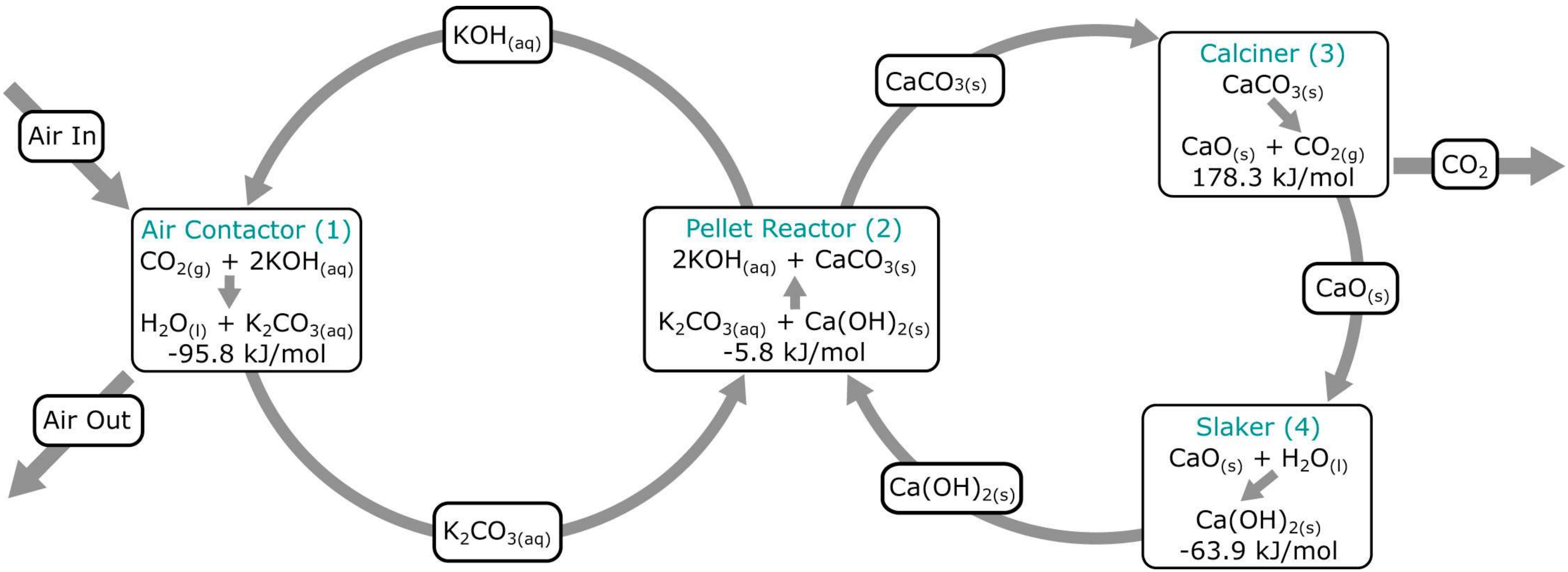
Conjecture: The export of wind energy from Greenland to Europe would reduce to zero the number of these long critical periods of times during which Europe could not rely on wind energy to cover a significant amount of its energy needs (or more generally renewable energy - a phenomenon known as Dunkelflaute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

Occurrence of critical time windows

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

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

Direct air CO_2 capture



Process commercialized by Carbon Engineering for capturing CO_2. Air exits with a CO_2 concentration of around 110 ppm. Energy required per ton of CO_2 captured and compressed at 150 bars: around 1.4 MWh of heat (at a temperature of more than 600 °C for the calciner – provided now by burning natural gas) and 0.4 MWh of electricity.

Source: https://carbonengineering.com/

What can be done with this CO_2?

1. Storing CO_2 underground.

2. Synthesize synthetic green fuels with high energy density using hydrogen produced from water electrolysis and renewable electricity.

Example: the Sabatier reaction for producing CH_4

$$CO_2 + 4\,H_2 \xrightarrow[\text{pressure}]{400\ ^\circ C} CH_4 + 2\,H_2O \qquad \Delta H = -165.0\ \text{kJ/mol}$$

Let us compute how much this green CH_4 would cost!

For 1 ton of liquefied synthetic green methane, you would need:

- Half a ton of H_2 that has an energy of 33.3 MWh/2 = 16.5 MWh. It would take about 16.5/0.85 = 19.2 MWh of electricity to produce this amount of H_2 by electrolysis.
- Since removing 1 ton of CO_2 from the atmosphere requires (1.4+0.4)=1.8 MWh, we would need 4.95 MWh of energy for capturing these 2.75 tons of CO_2.
- At most 1 MWh of electricity to liquefy it.

Since there are 13.9 MWh of energy in 1 ton of gas, you would approximately need (19.2 + 4.95 + 1)/13.9 = 1.8 MWh of electricity to generate 1 MWh of LNG.

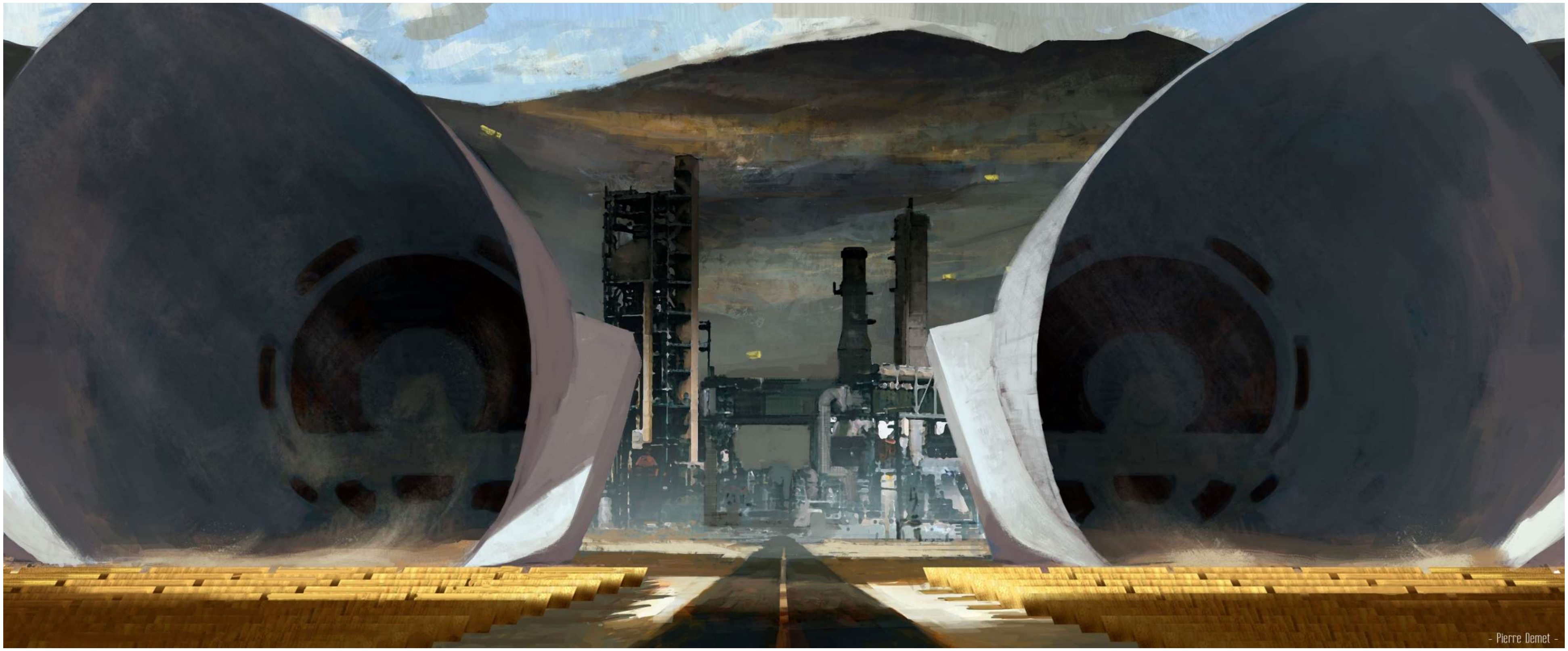
If PV energy is at 15 €/MWh: green LNG could cost around 27 €/MWh (if only energy costs are taken into account)

If PV energy is at 10 €/MWh (as it will be before 2025): the energy costs drop to **18€/MWh**

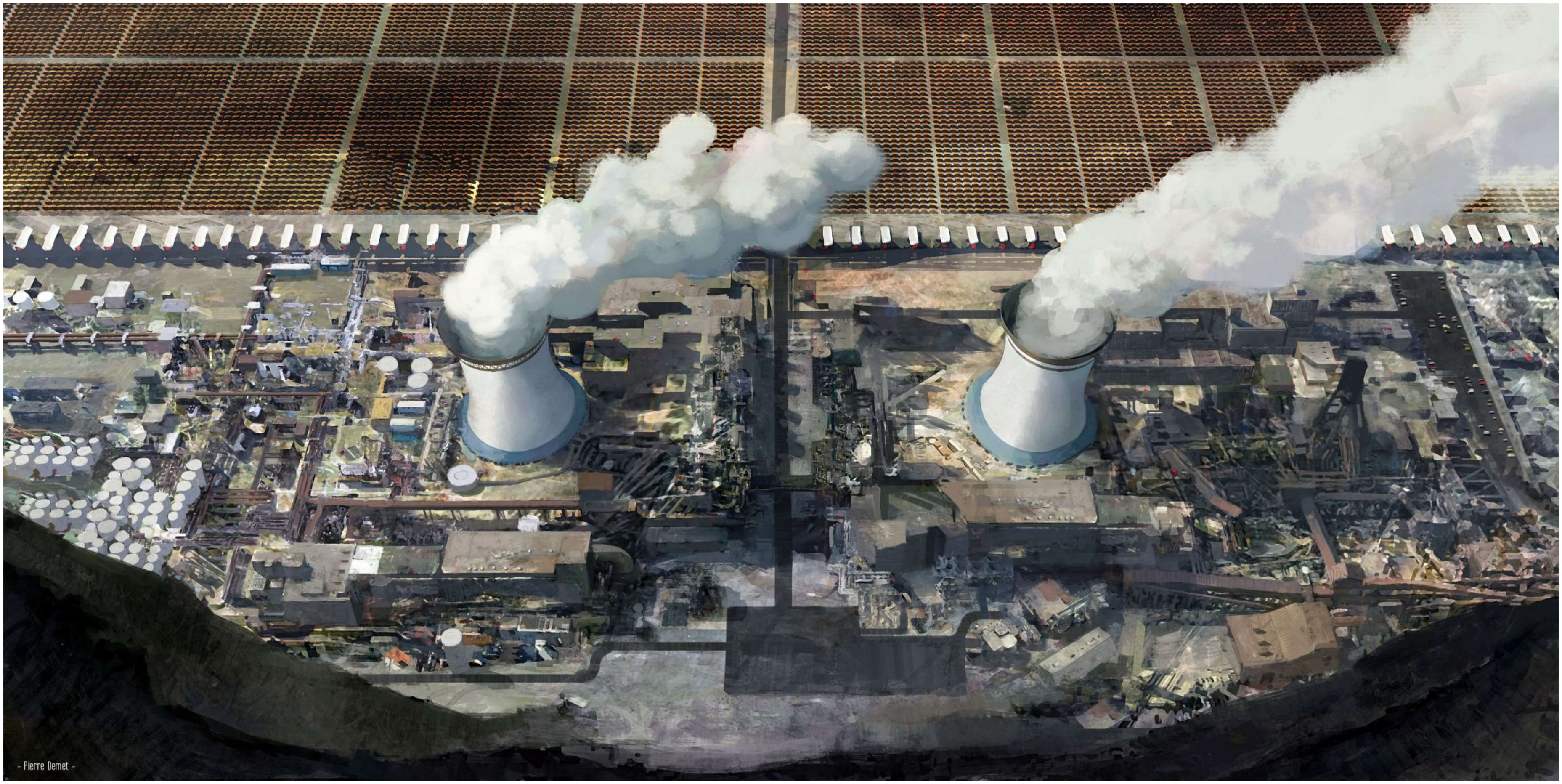
Observation : cheap renewable energies with carbon capture could lead to green fuels which are competitive with fossil fuels. This would considerably speed up the energy transition.

Artist representation of an infrastructure where solar energy and direct capture of CO_2 in the air are used to produce green CH_4. The green gas is then liquefied and shipped to consumption centers. Estimated price for the gas with PV energy less than 10 €/MWh: less than 20 €/MWh.

3. Transform CO2 into graphite using, for example, the Bosch reaction, and building a mountain of coal.



Artist representation of an infrastructure for capturing CO_2 in the air in a place where there is plenty of sun and transforming it into graphite (pure coal).


- Pierre Demet -

Energy needed to return to 280 ppm of CO_2

There are around 3.25×10^{12} tons of CO_2 in the atmosphere. To return to preindustrial levels (280 ppm), $(412-280)/412 * 3.25 \times 10^{12} = 1.04 \times 10^{12}$ tons of CO_2 have to be removed from the atmosphere.

Removing 1 ton of CO_2 from the atmosphere requires (1.4+0.4)=1.8 MWh.

One ton of graphite generates 8.9 MWh when combusted. Due to the energy conservation principle, transforming one ton of CO_2 into graphite and O_2 would at least require $12/((2*16+12)) * 8.9 = 2.42$ MWh of energy.

Transforming 1.05×10^{12} tons of CO_2 into graphite would require a minimum of 4,431,000 TWh of energy. This is 40 times our annual final energy consumption.

References

Study Committee: C1 WG: C1.35 (2020). *Global electricity network – Feasibility.* CIGRE Technical Report 775. Available at http://hdl.handle.net/2268/239969

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

Radu, D., Berger, M., Fonteneau, R., Hardy, S., Fettweis, X., Le Du, M., Panciatici, P. Balea, L. & Ernst, D. (2019). *Complementarity Assessment of South Greenland Katabatic Flows and West Europe Wind Regimes.* Energy. Available at http://hdl.handle.net/2268/230016

Berger, M., Radu, D., Fonteneau, R., Deschuyteneer, T. & Ernst, D. (2020). *The Role of Power-to-Gas and Carbon Capture Technologies in Cross-Sector Decarbonisation Strategies.* Electric Power Systems Research, March 2010. Available at http://hdl.handle.net/2268/235110