Wind Energy Systems

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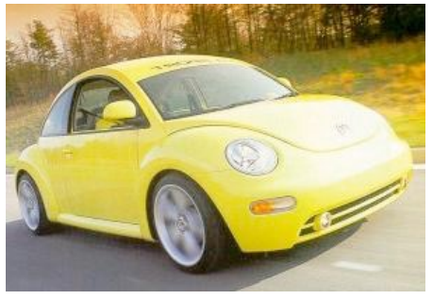
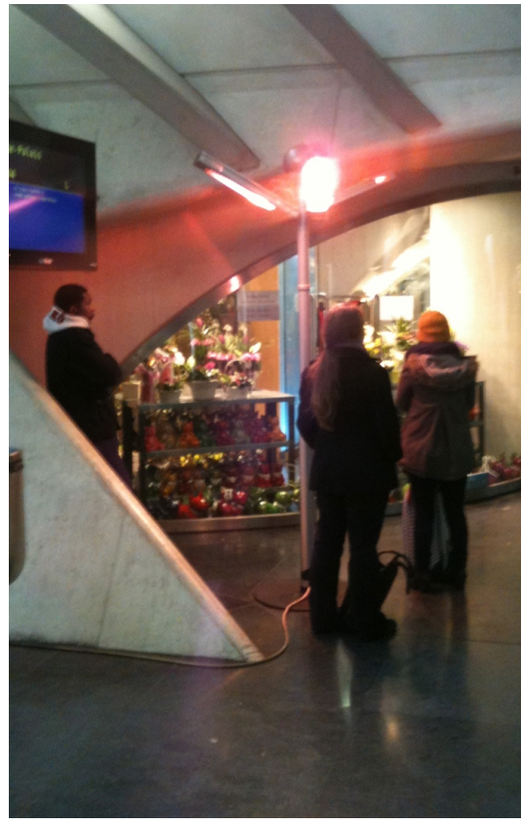
Freiburg, May 10, 2022

Our personal energy consumption: 5 kW





- a typical European needs 5 kW
(1 kW electricity + transport + heating …)

- this equals 120 kWh or 12 litres of petrol per day

- one return flight from Europe to China consumes about 1200 litres of kerosene per person (~100 days)

5 kW: one large electric heater, switched on from birth to death

[MacKay 2009. wikipedia]

Dependence on Oil and Gas Imports

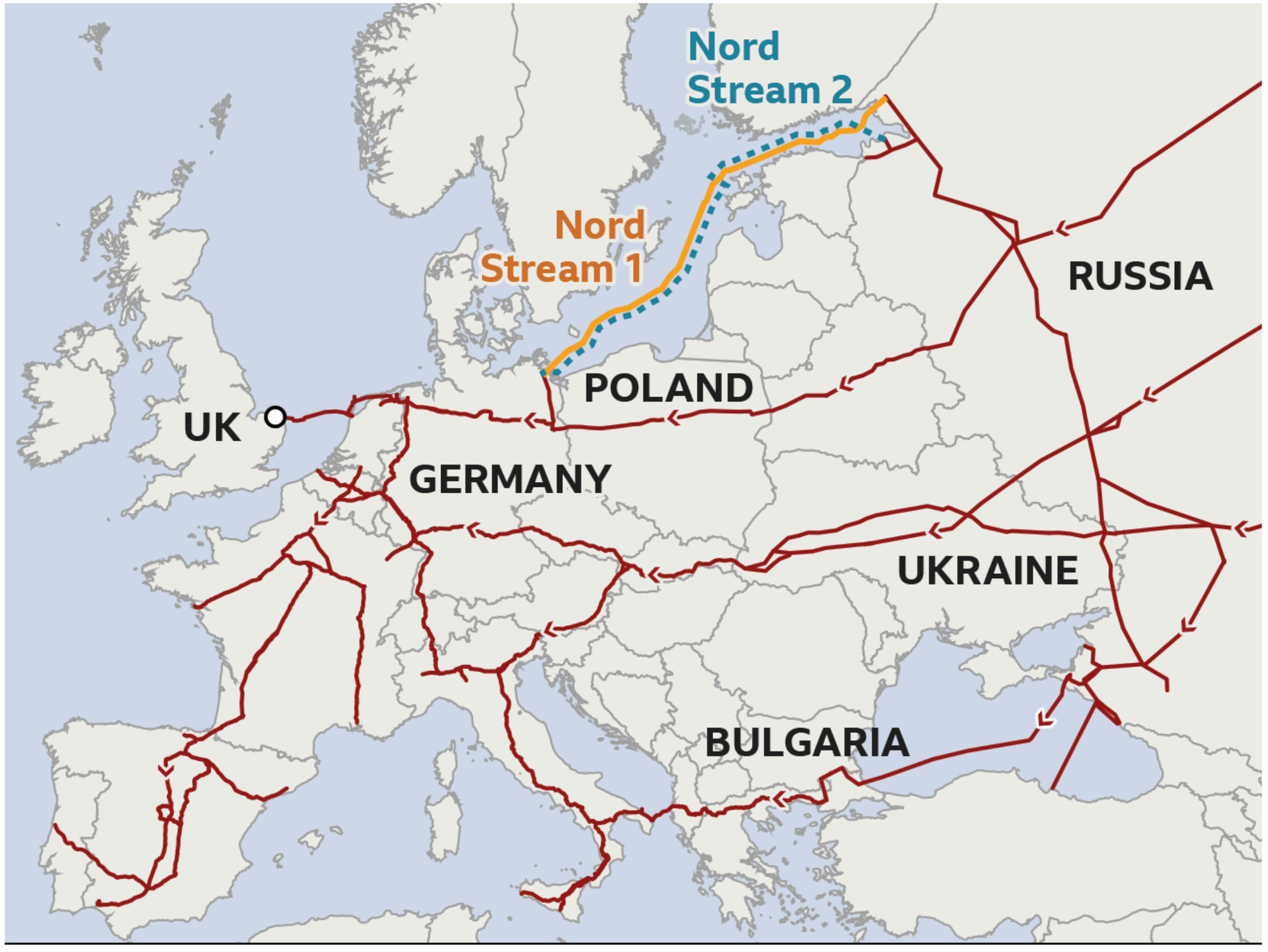
- each day, each person in Germany consumes
3 litres of petrol and 3 cubic metres of gas
(about half from Russia)

- Energy content equivalences (with a grain of salt):
  - **1 litre of petrol** contains as much energy as
  - **1 cubic metre of gas** or
  - **10 kWh electricity**

- our daily consumption of 120 kWh per person corresponds to either 12 litres of petrol or 12 cubic metres of gas

- thus, today, **oil and gas imports cover half of our energy needs,** in particular for transport and heating.

The Most Important Gas Pipelines in Europe



Source: European Network of Transmission System Operators for Gas

BBC

The Most Important Gas Pipelines in Europe

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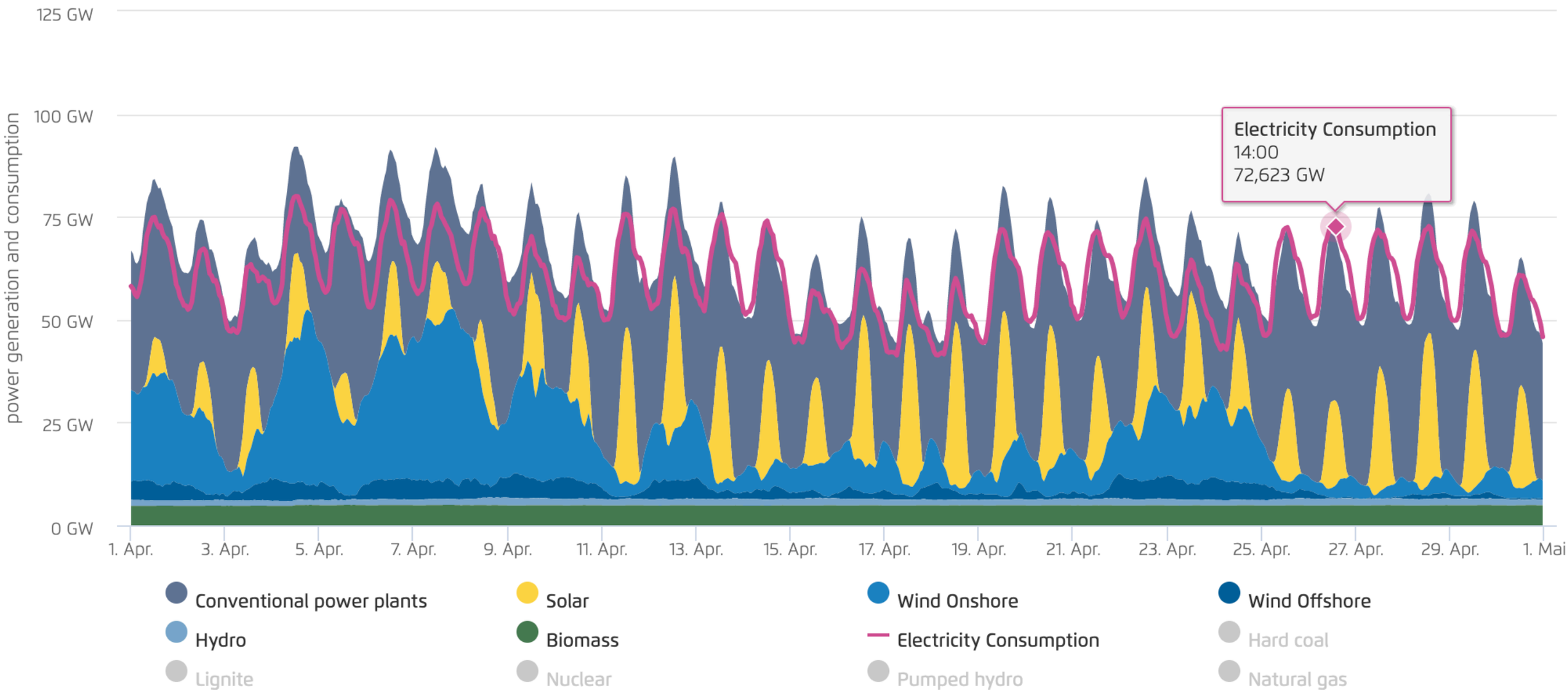
100% Renewable Energy = Electrification

In the carbon neutral future, we need to save energy, and all remaining energy needs, including transport and heating, need to be powered by renewable energy. Concretely, this means:

- significant carbon pricing: tax on coal, oil and gas
- battery electric vehicles for transport (or biogas)
- heat pumps for heating

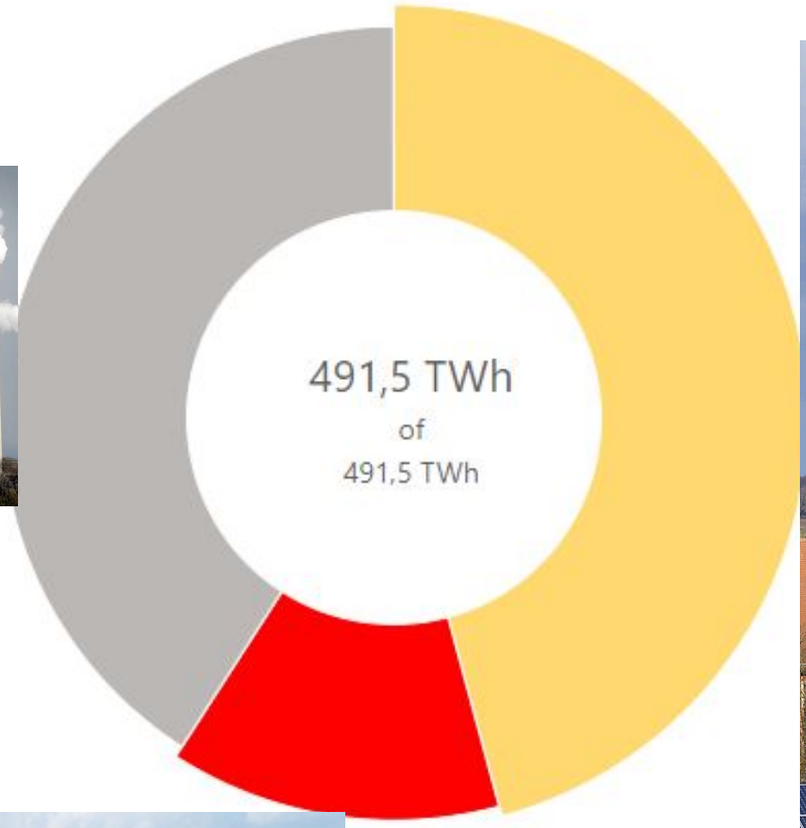
- ubiquitous use of (renewable) electricity
- fluctuating price of electricity (due to intermittency of wind and solar sources)

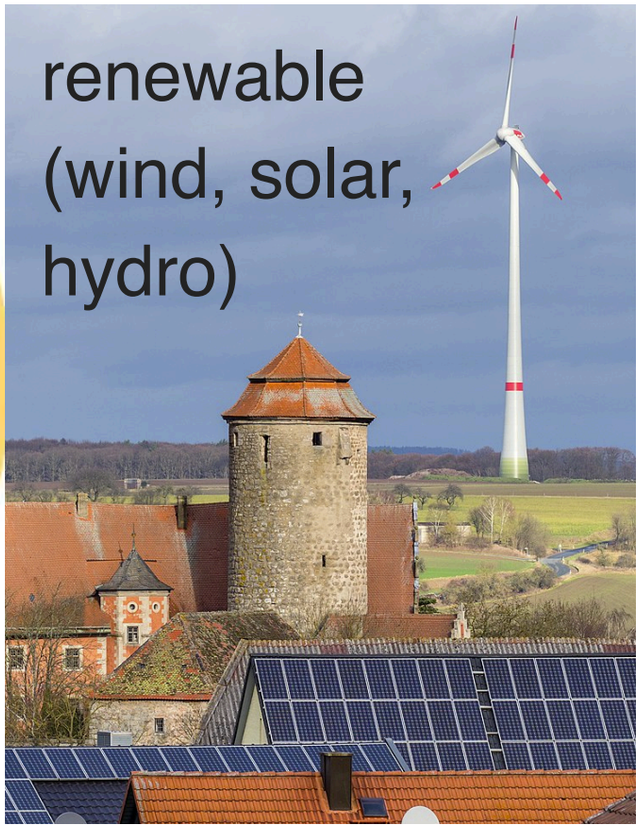
Electricity production in Germany in April 2022 [Agora]



Wind and solar contribute already now significantly to Germany's electricity production (33% in 2021), but have high variations.

Last year,
54% of Germany’s electricity was of nuclear or fossil origin





[Fraunhofer ISE, Energy Charts, electricity generation in Germany in 2021]

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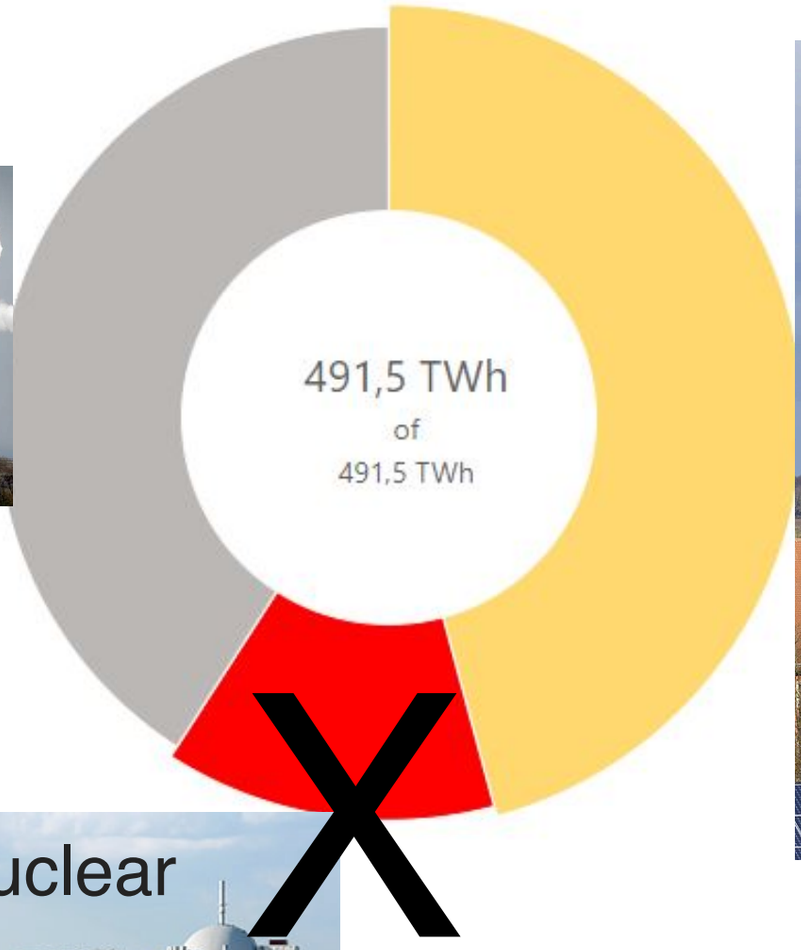

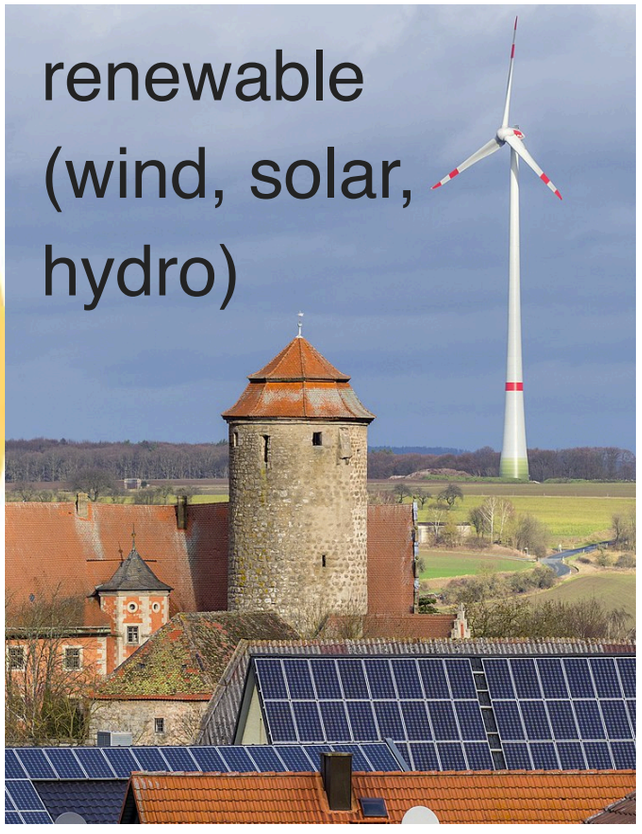

This December the last 3 nuclear power plants in Germany stop operation.

[Fraunhofer ISE, Energy Charts, electricity generation in Germany in 2021]

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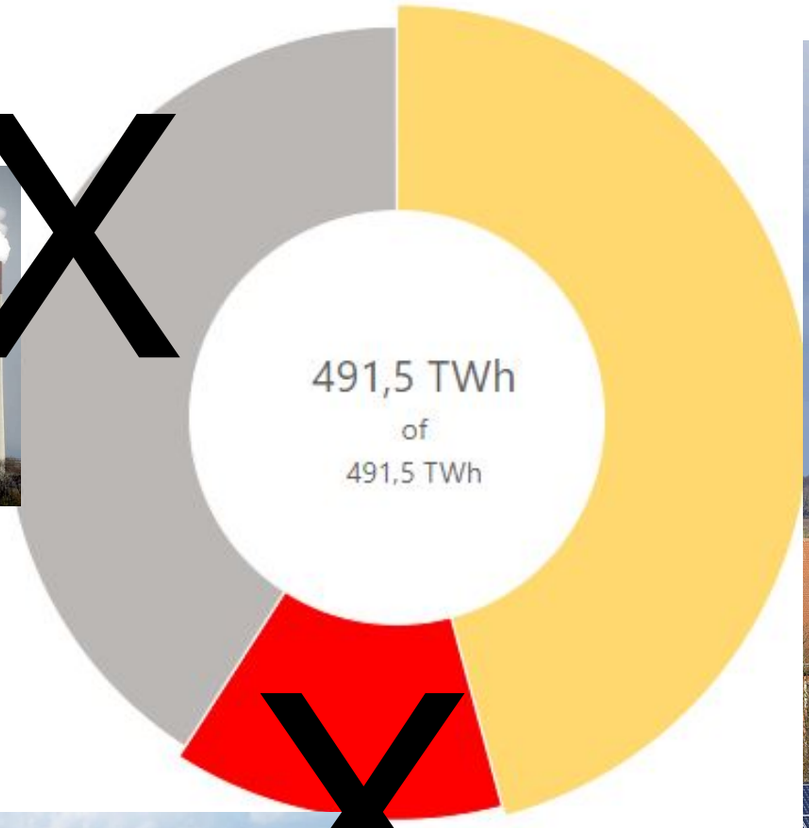

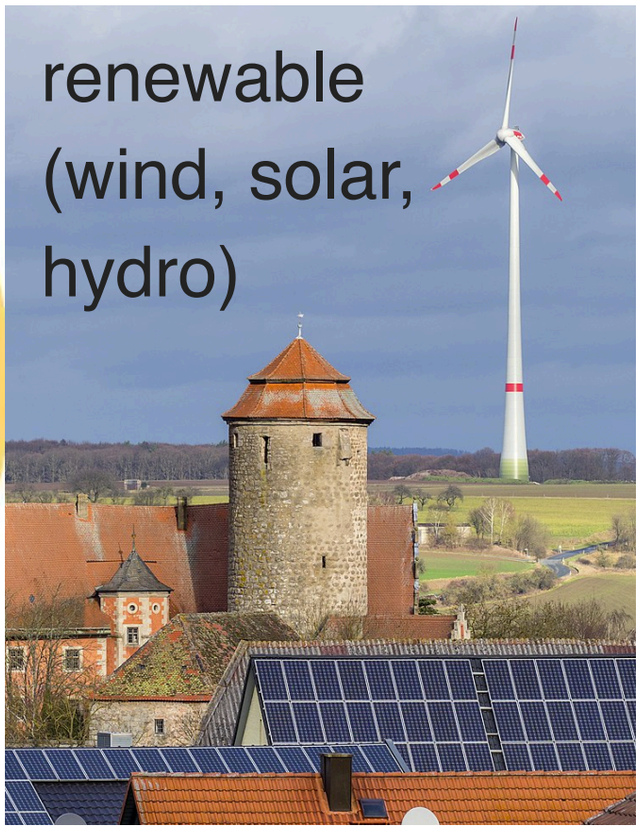

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Sustainable Energy Sources

Solar and wind energy are abundant and have the potential to cover all human energy needs

E.g. 125 m^2 solar cells per person, or 10% of the Sahara desert for humanity.
Or 10% of the Atlantic covered with offshore wind parks.

Two main problems of both:

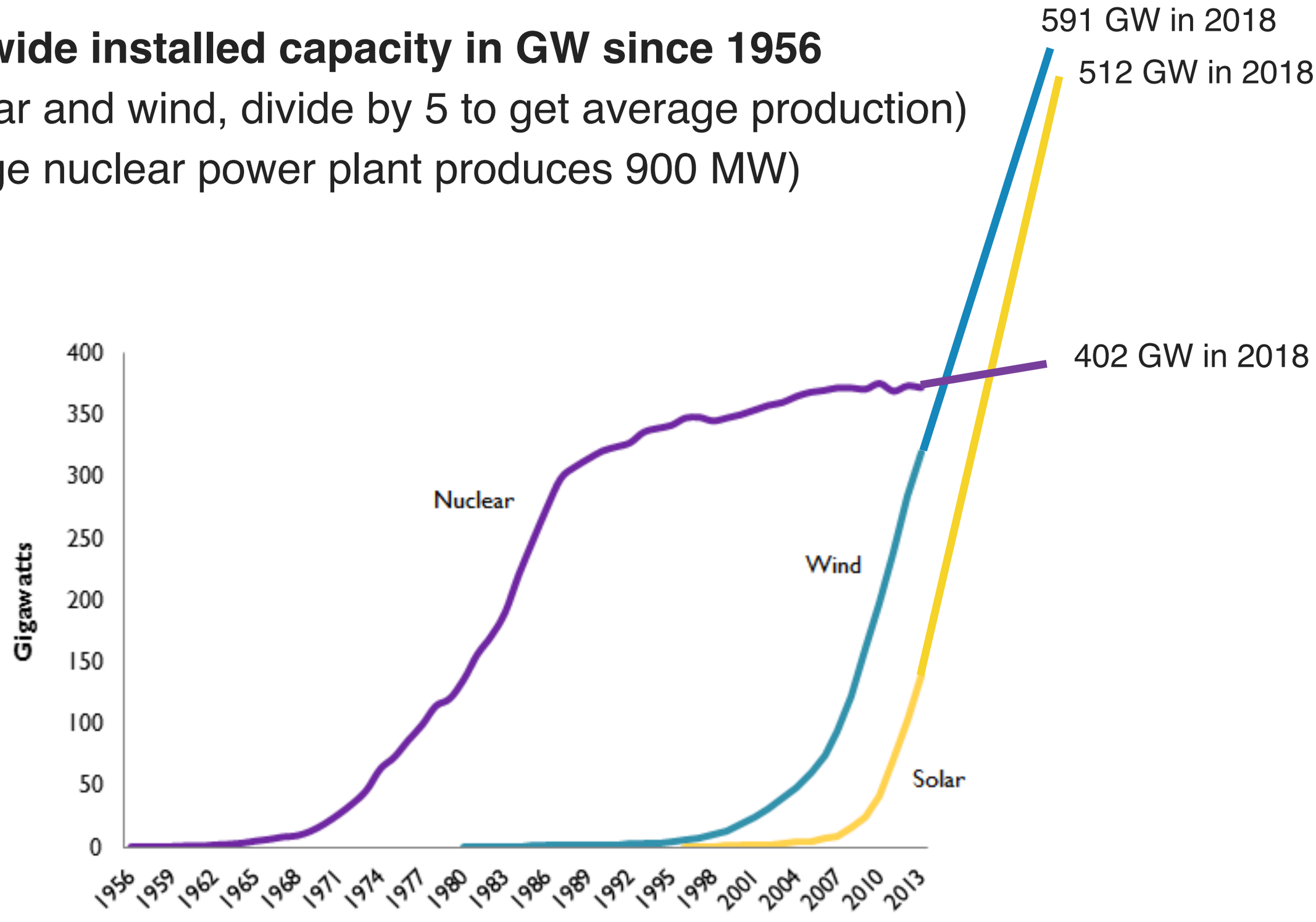
- not available at all times
- low power densities

Worldwide, wind and solar power grow strongly and provide already as much electricity as 250 nuclear power plants

Worldwide installed capacity in GW since 1956

(for solar and wind, divide by 5 to get average production)

(average nuclear power plant produces 900 MW)

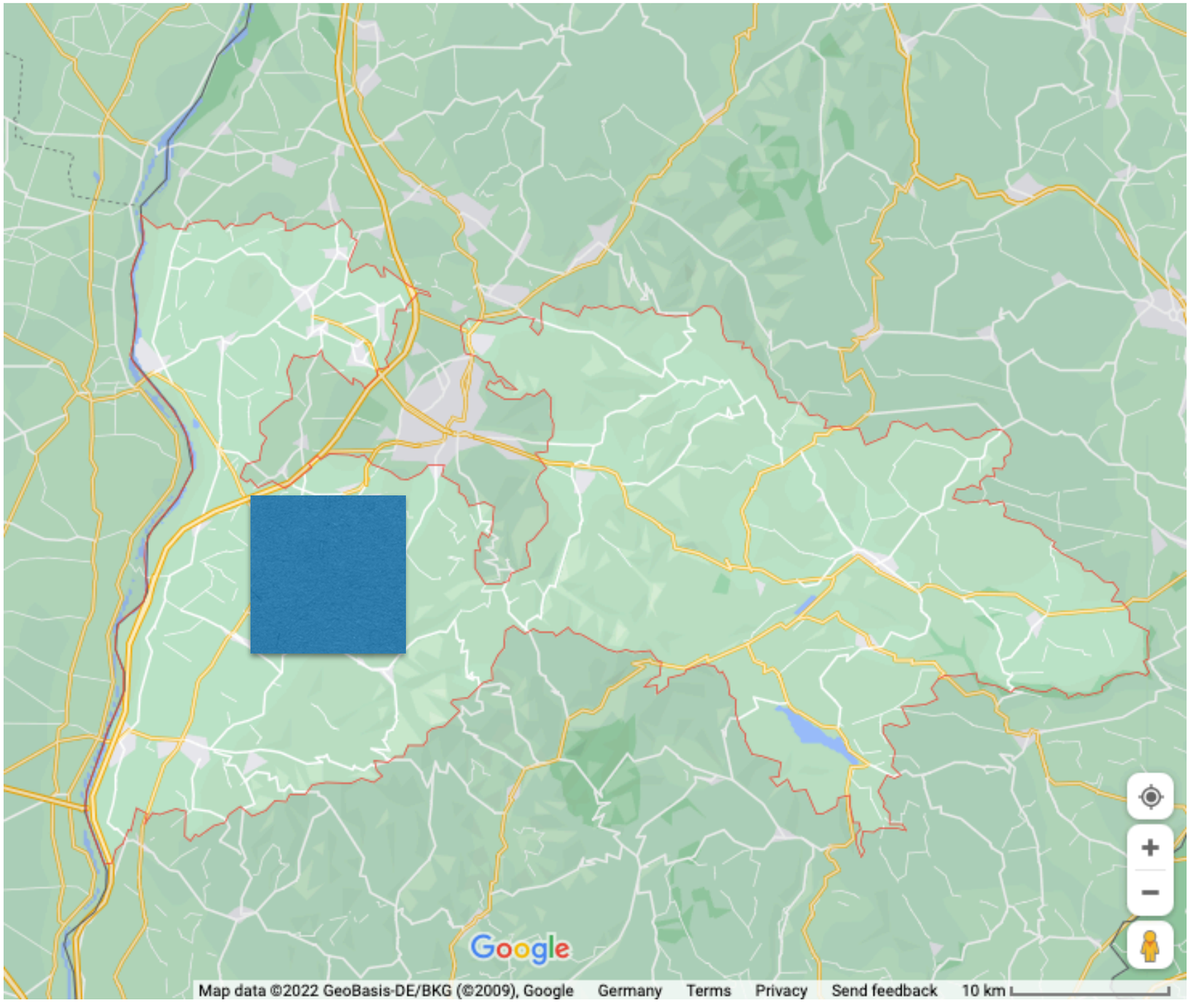


Sources: IAEA; Ochs and Ray; BP; Flavin

What is needed for 5 MW installed power ?

Solar in Southern Europe: area of 125 m x 200 m

Map of Freiburg and Breisgau, and Square of 10 km x 10 km



Average annual solar production per square metre of PV farm is about 10 W, i.e., each person in Germany would need 250 square meters, i.e., about 100 square kilometres for all direct and indirect Energy needs of 400 000 people in Freiburg and surroundings

Agri-Photovoltaik allows us to make dual use of land

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turbine and tower weigh 700 tons

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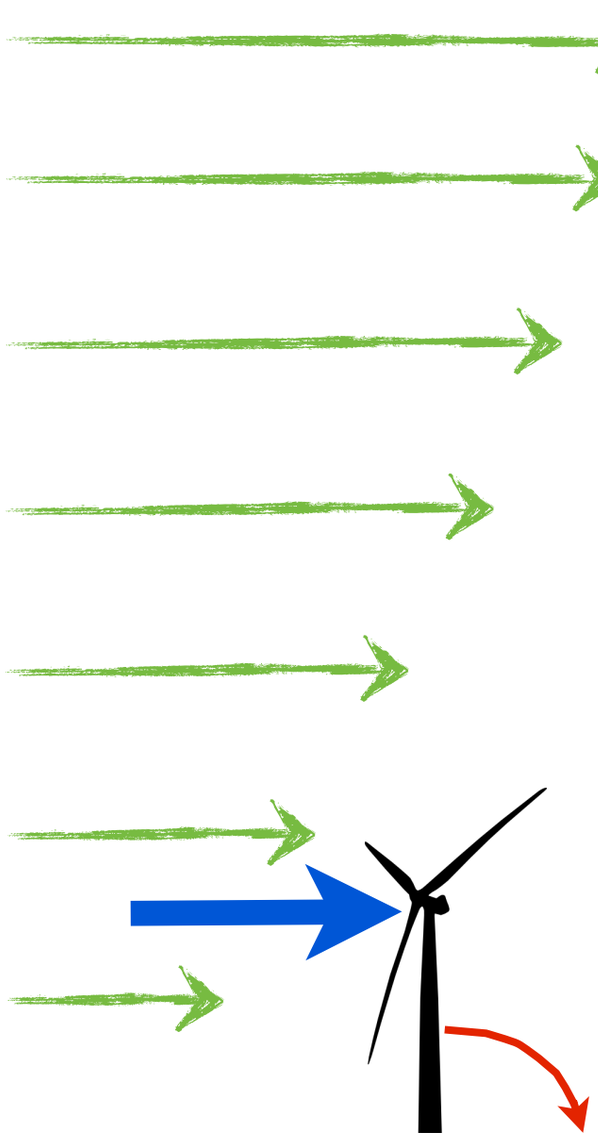
Could we harvest wind power in high altitudes with less material ?

A sunny morning in Freiburg …

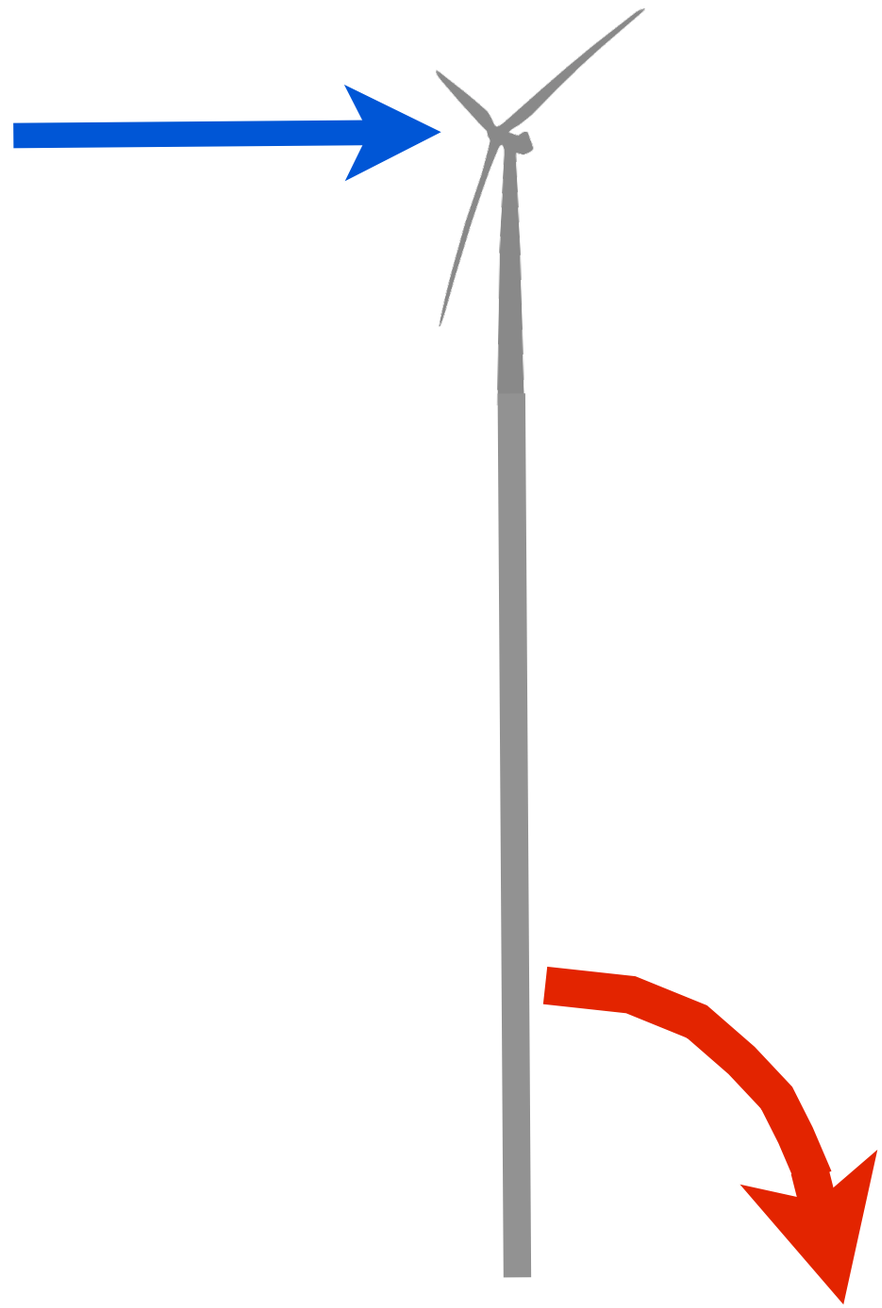
1) Even on a sunny day, there is some wind up in the hills.

2) There is still a lot of sky above the turbine.

A turbine of 500m height is difficult to build



Long lever arm leads to large torque



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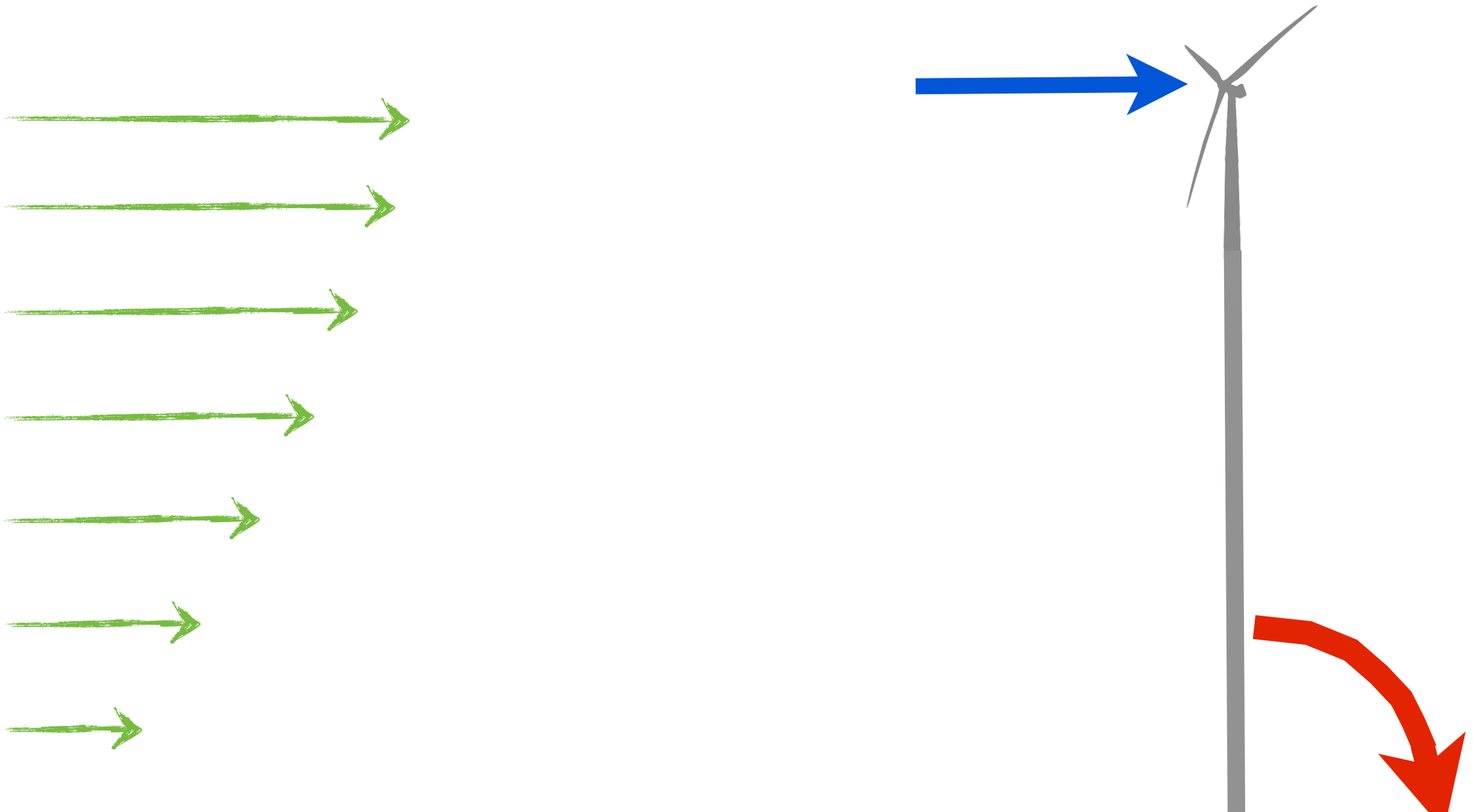

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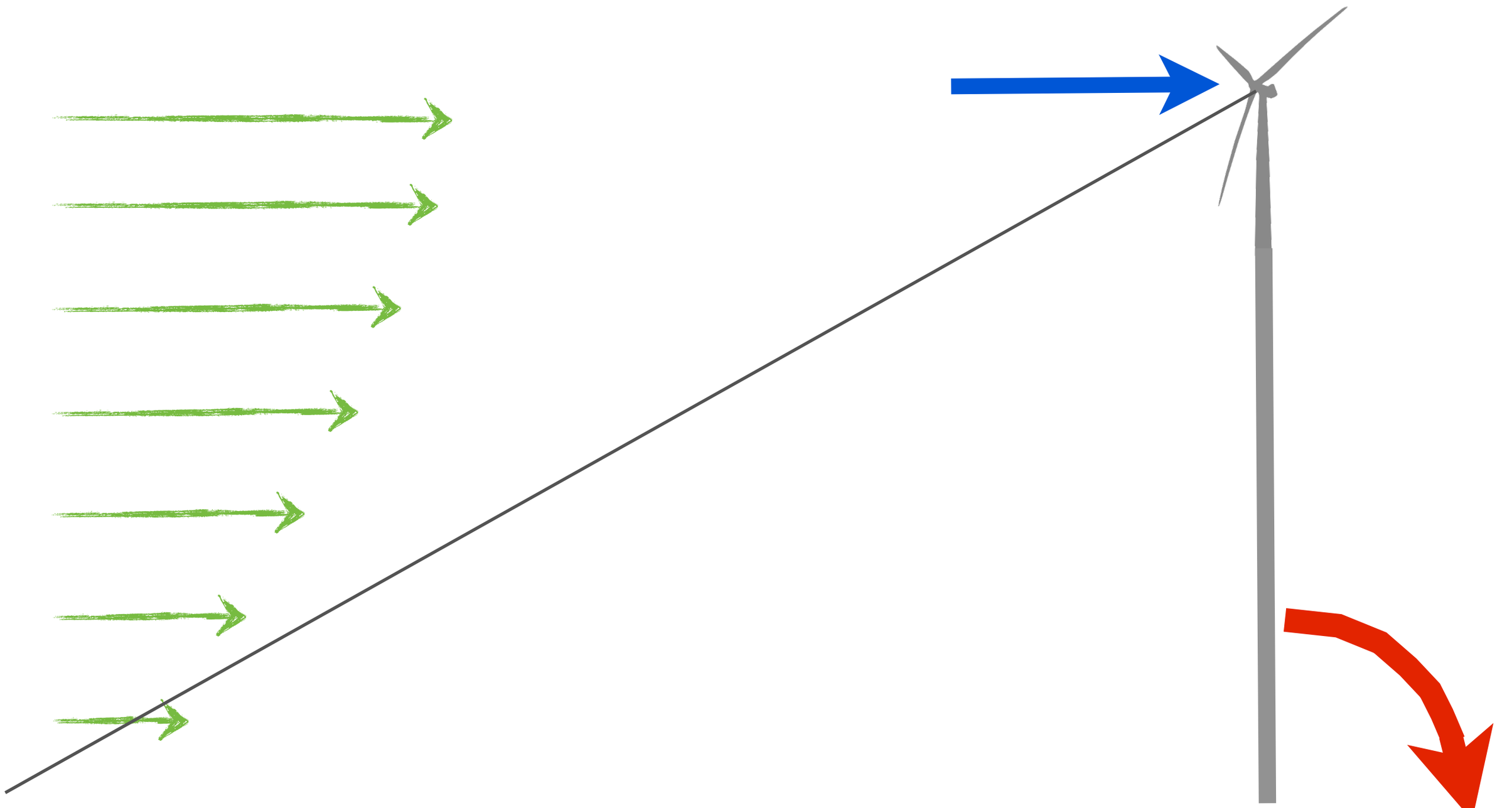

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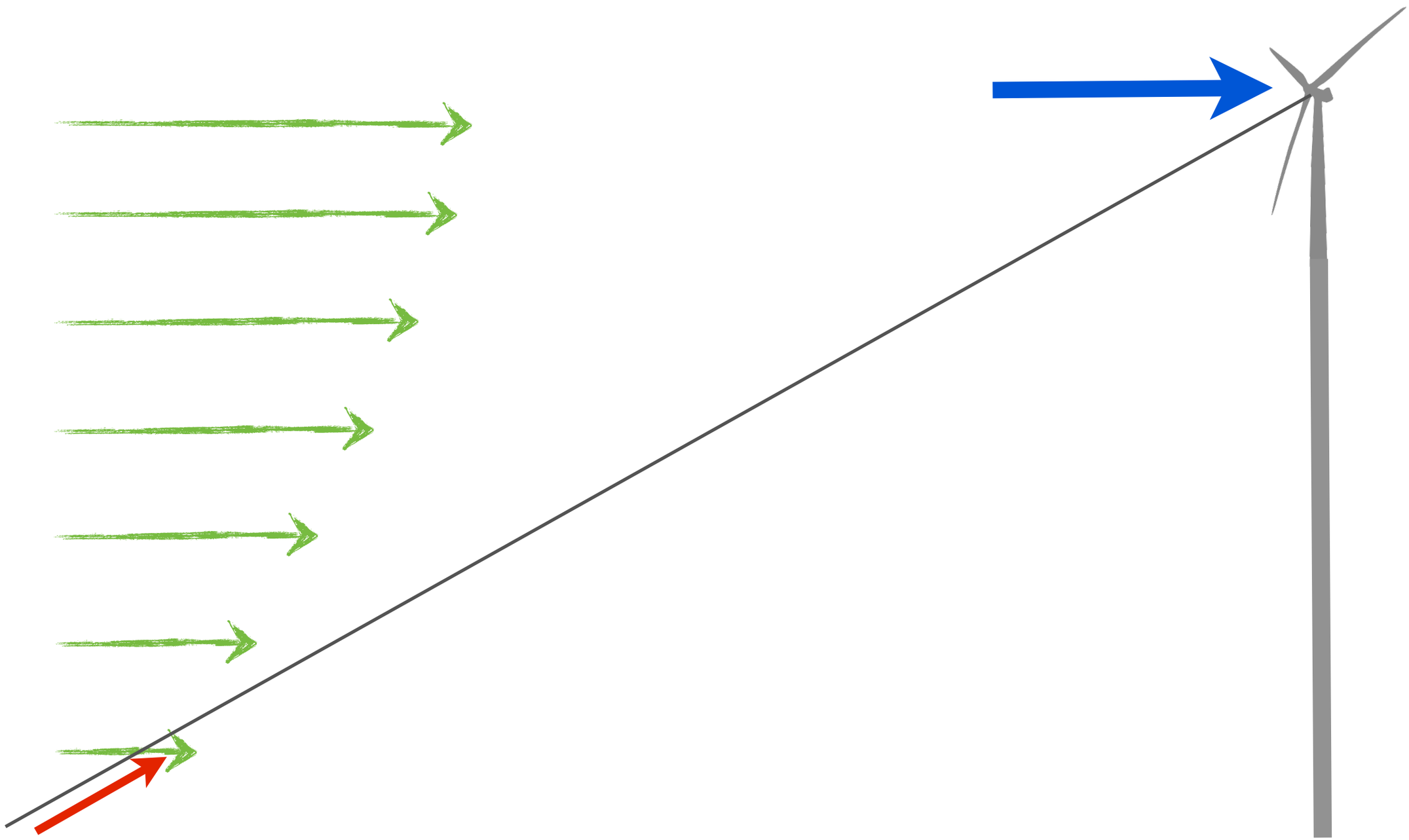

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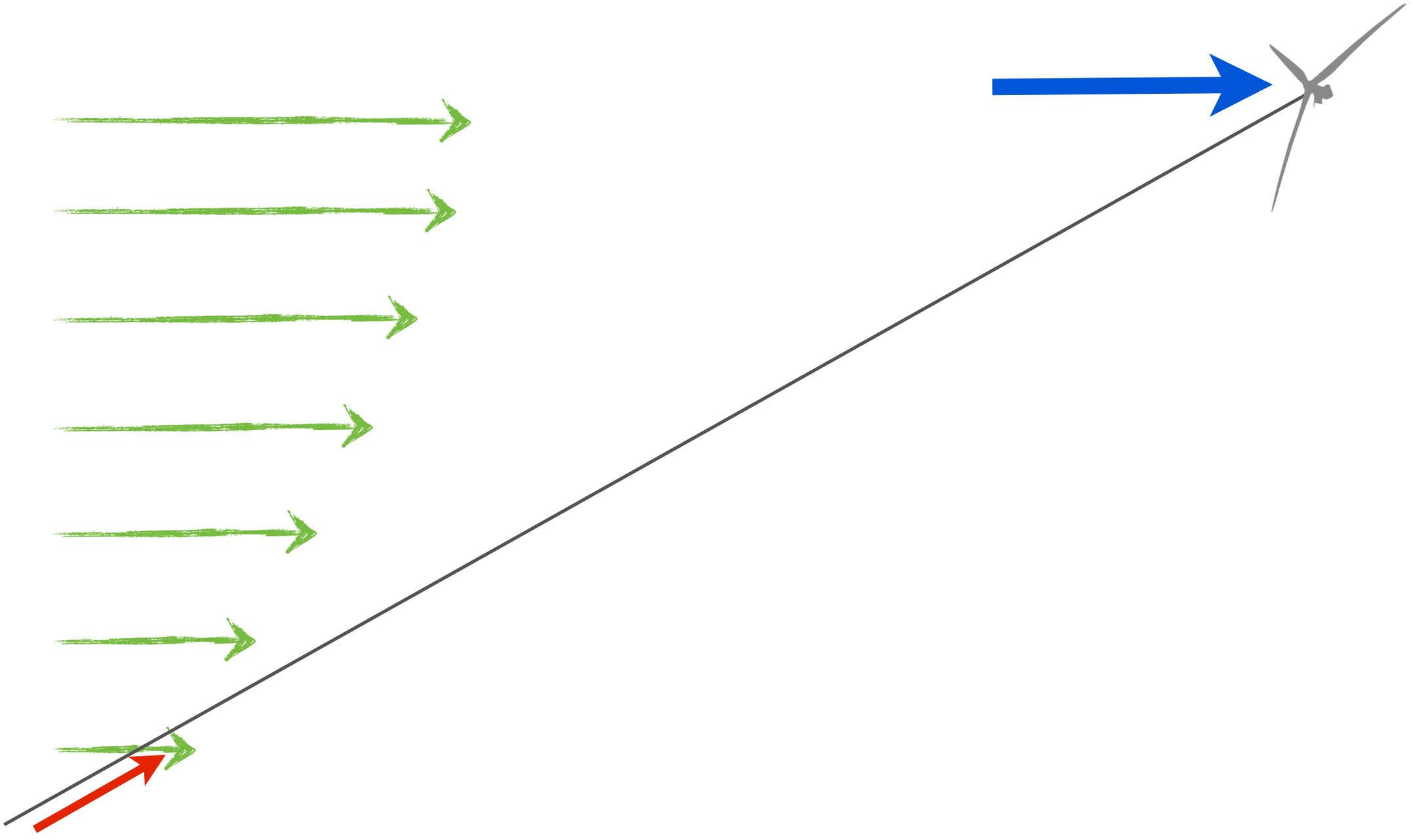

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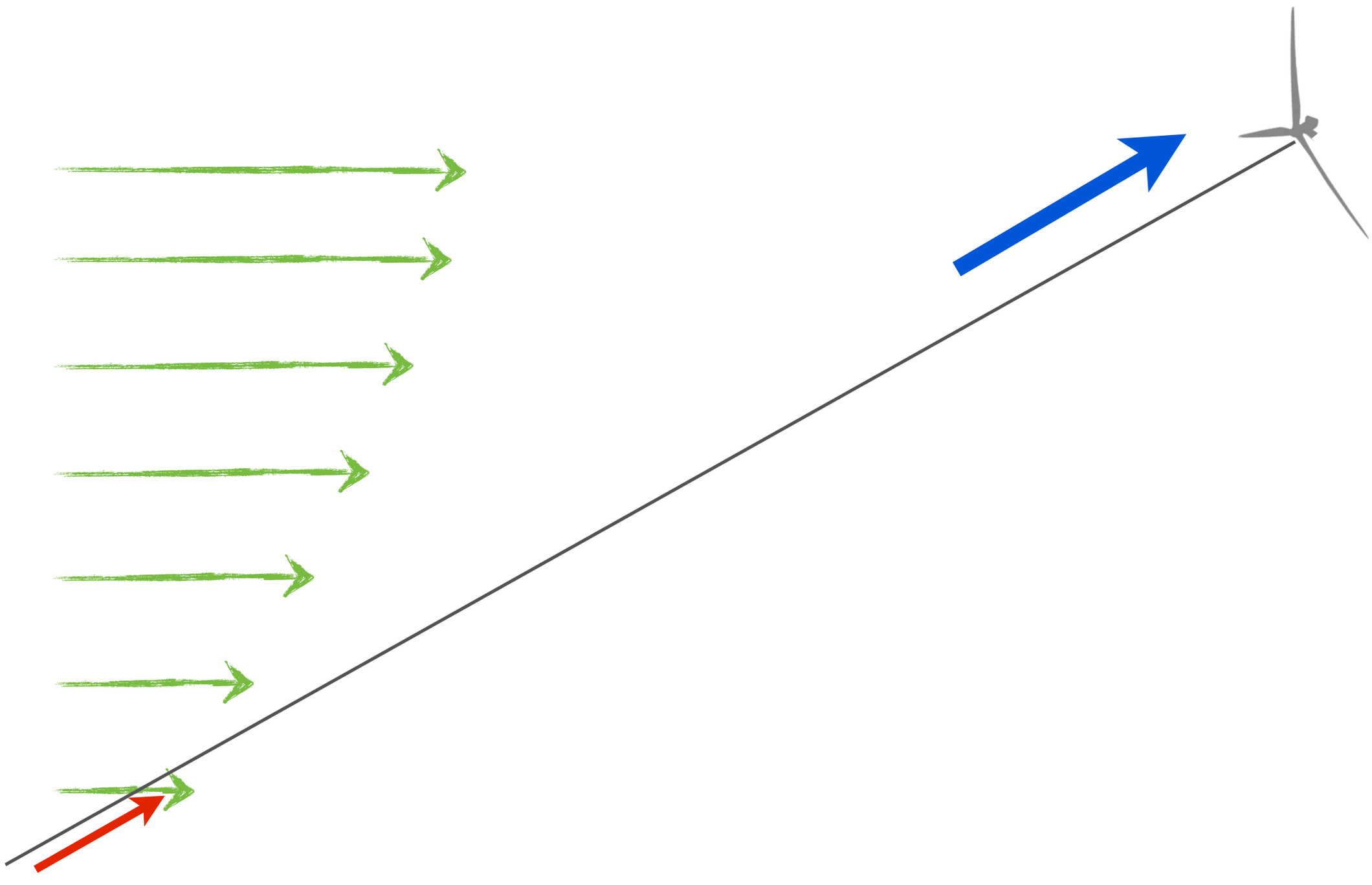
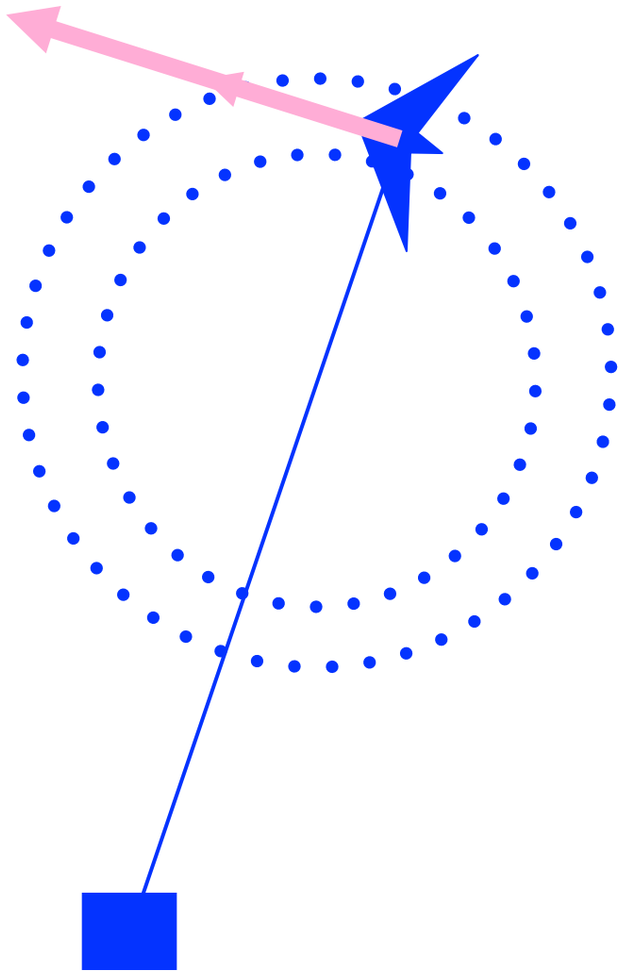


Metamorphosis of a Wind Turbine

ERC HIGHWIND

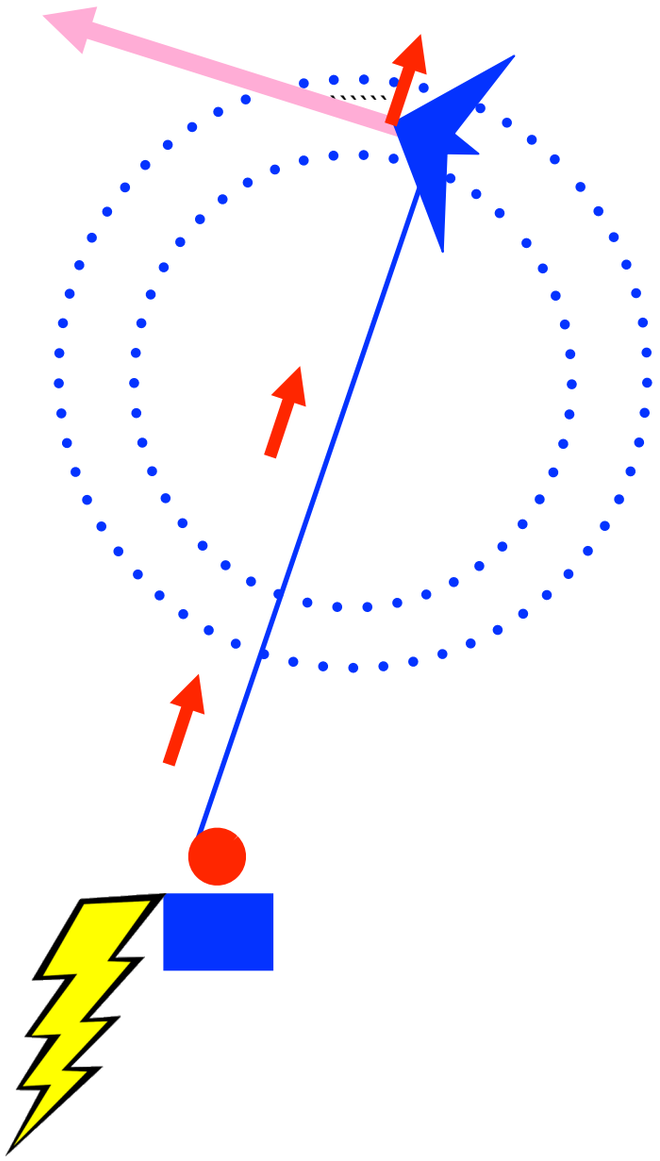
Crosswind Kite Power



- kite flies fast loops in **crosswind** direction
- very strong force on tether

But where could a **generator** be driven ?

Generator on Ground (Pumping Cycle)



Cycle consists of two phases:

- **Power generation phase:**
  - Fly kite fast, have high force
  - unwind cable
  - generate power

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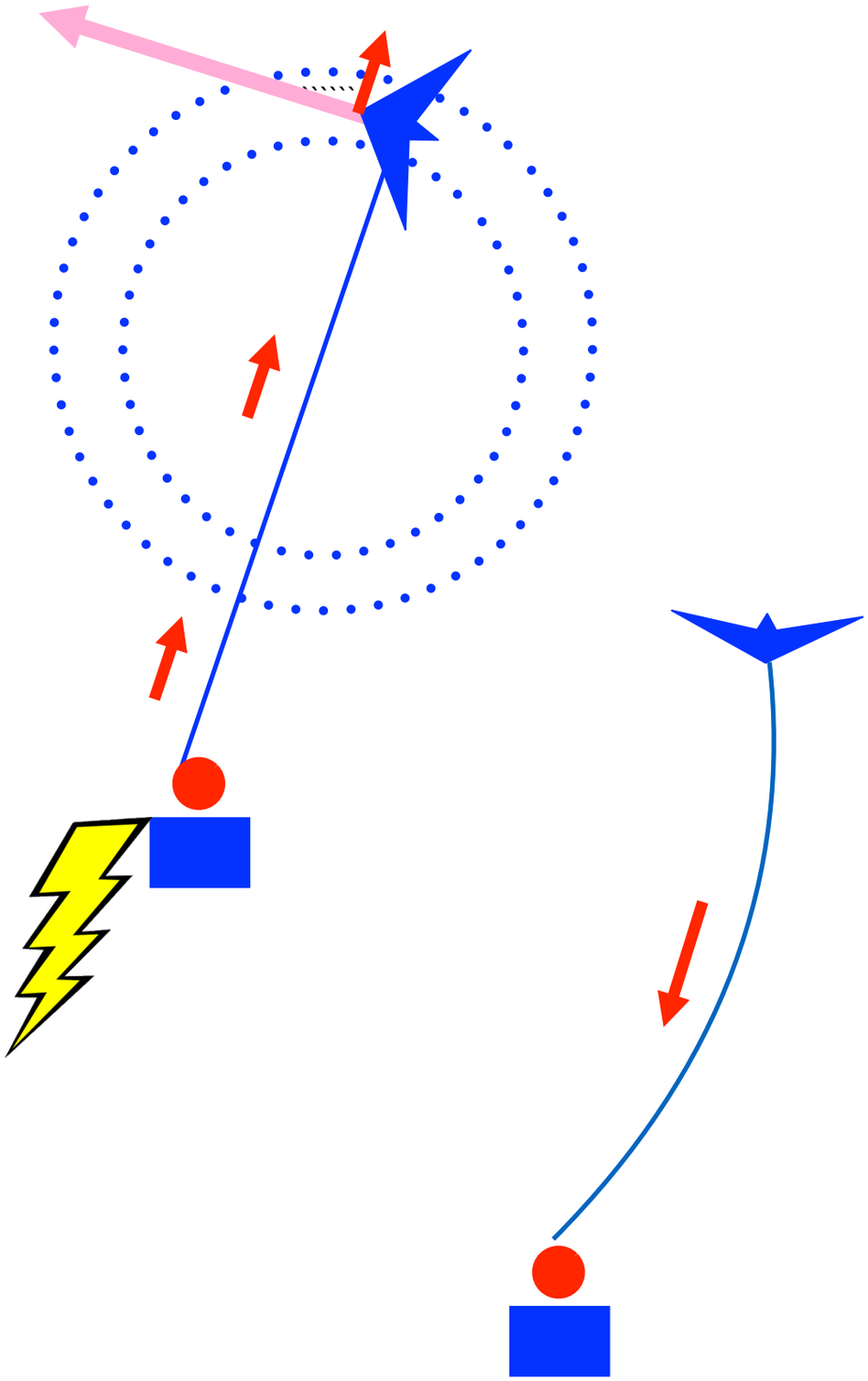


Cycle consists of two phases:

- **Power generation phase:**
  - Fly kite fast, have high force
  - unwind cable
  - generate power

- Retraction phase:
  - Slow down kite, reduce force
  - pull back line
  - consume power

Pro: all electric parts on ground

Can deliver about 40 kW
per m^2 wing area

How much is 40 kW per m² wing area ?

More realistic estimate: wing produces full power only 25% of a year, so we get about **10 kW per m² .**

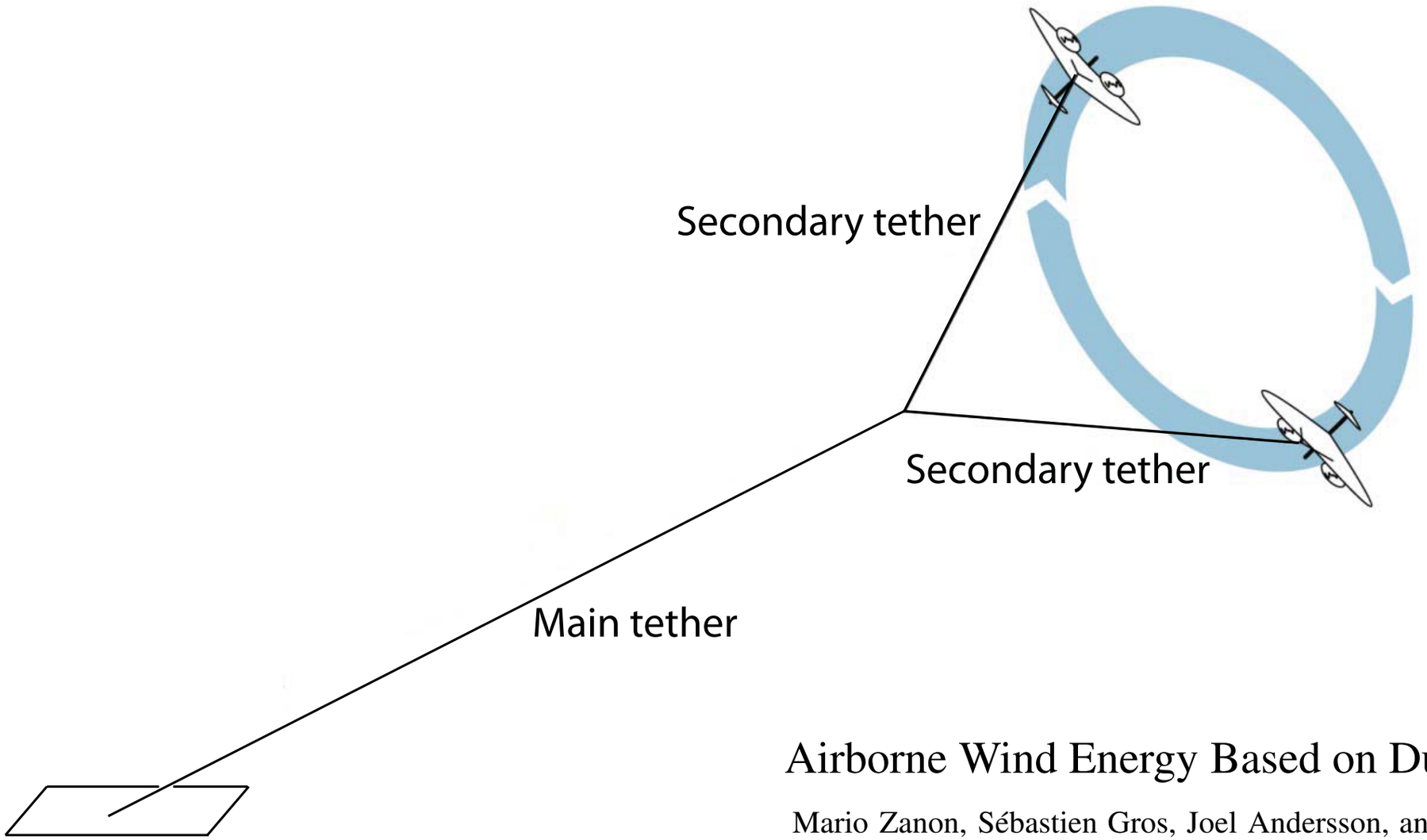
Two people need 1 m² wing surface to cover all their energy needs !

[master students Wouter Vandermeulen and Jeroen Stuyts]

1 m² wing surface corresponds to 250 m² of photovoltaic cells in Italy

Dual Kite Systems

- Two airfoils circling around each other have **less tether drag**
- can reach 40 kW/m² already with small devices
- centrifugal forces compensate each other



Airborne Wind Energy Based on Dual Airfoils

Mario Zanon, Sébastien Gros, Joel Andersson, and Moritz Diehl

IEEE TRANSACTIONS ON CONTROL SYSTEMS TECHNOLOGY, VOL. 21, NO. 4, JULY 2013

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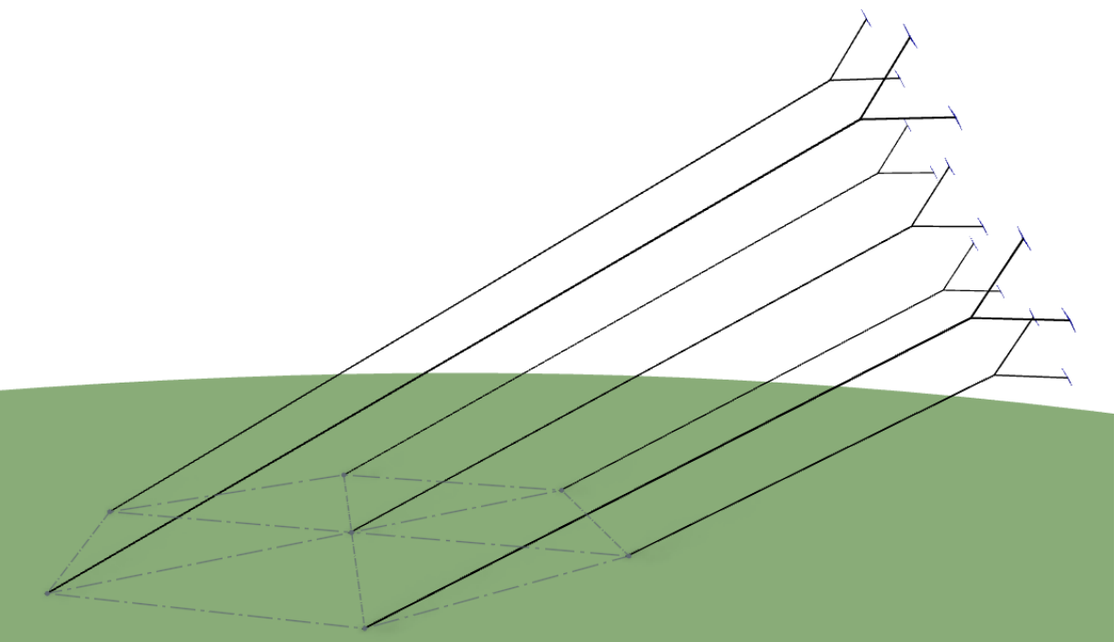
Power Density per Ground Area

2 MW/km² for Conventional Wind Farm

20 MW/km² for Solar Photovoltaic Farm



30 MW/km² for “Vertical Wind Farm” consisting of dual kite systems in varying altitudes (estimate by M.D.)

Summary and Personal Conclusions

We need:

- consistently high carbon prices that drive fossil fuels out of the market
- 100% renewable electricity (wind, solar, hydro, …) as soon as possible
- lots of solar and wind power installations (also above fields and forests)
- lots of battery electric vehicles
- heat pumps for heating (and cooling)
- adaptive electricity consumers, varying electricity prices
- incentives for research on novel renewable technologies such as airborne wind energy

Our Vision: replace tons of steel and concrete…

Our Vision: replace tons of steel and concrete…

…by a cable and intelligent control

Short Term Vision of Researchers in Freiburg

(Company Kiteswarms + University of Freiburg)