Zero energy emissions:
The missing pieces of the puzzle

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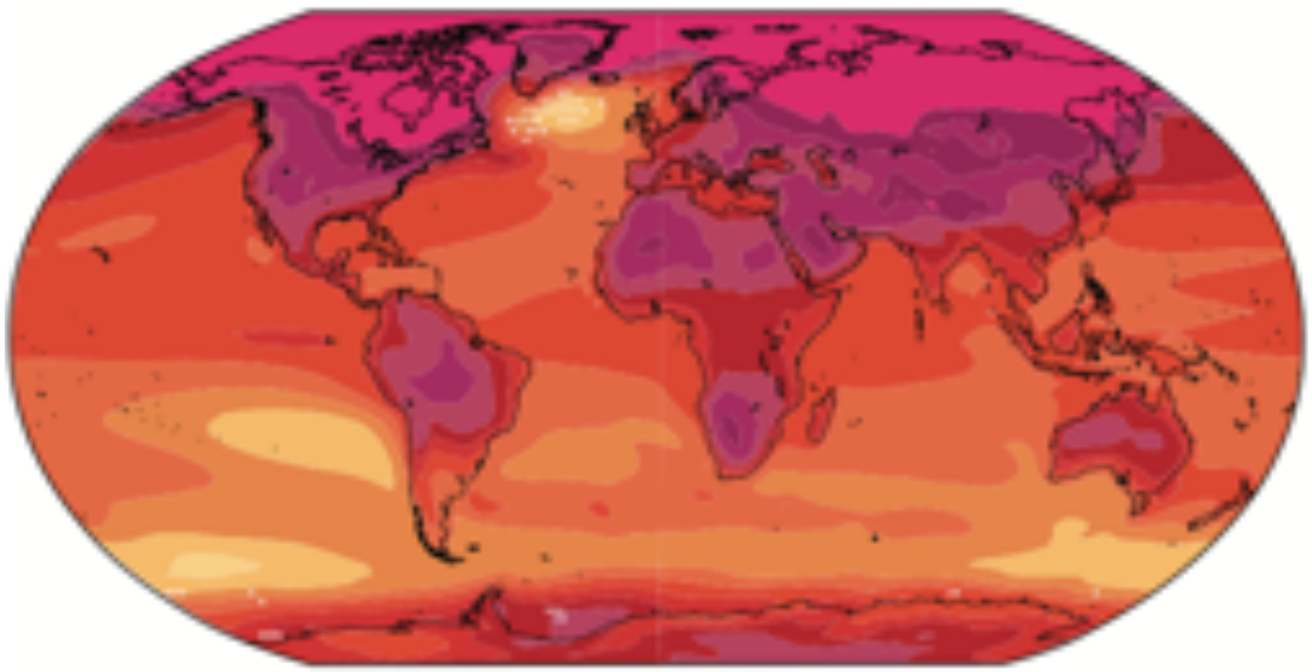
Sustainability Talks
Uni Freiburg
14. November 2019

Outline

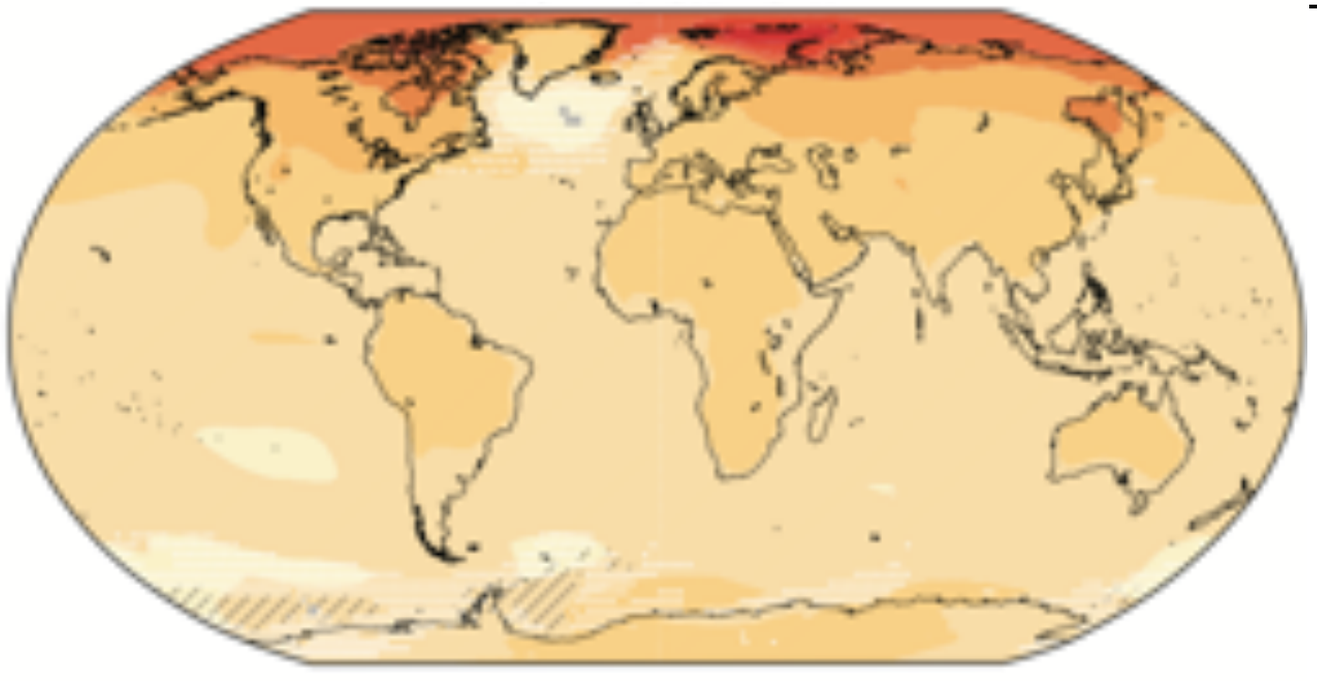
A. Negative emissions ASAP

Zero (then negative) emissions as soon as possible



← Crocodiles in the Arctic

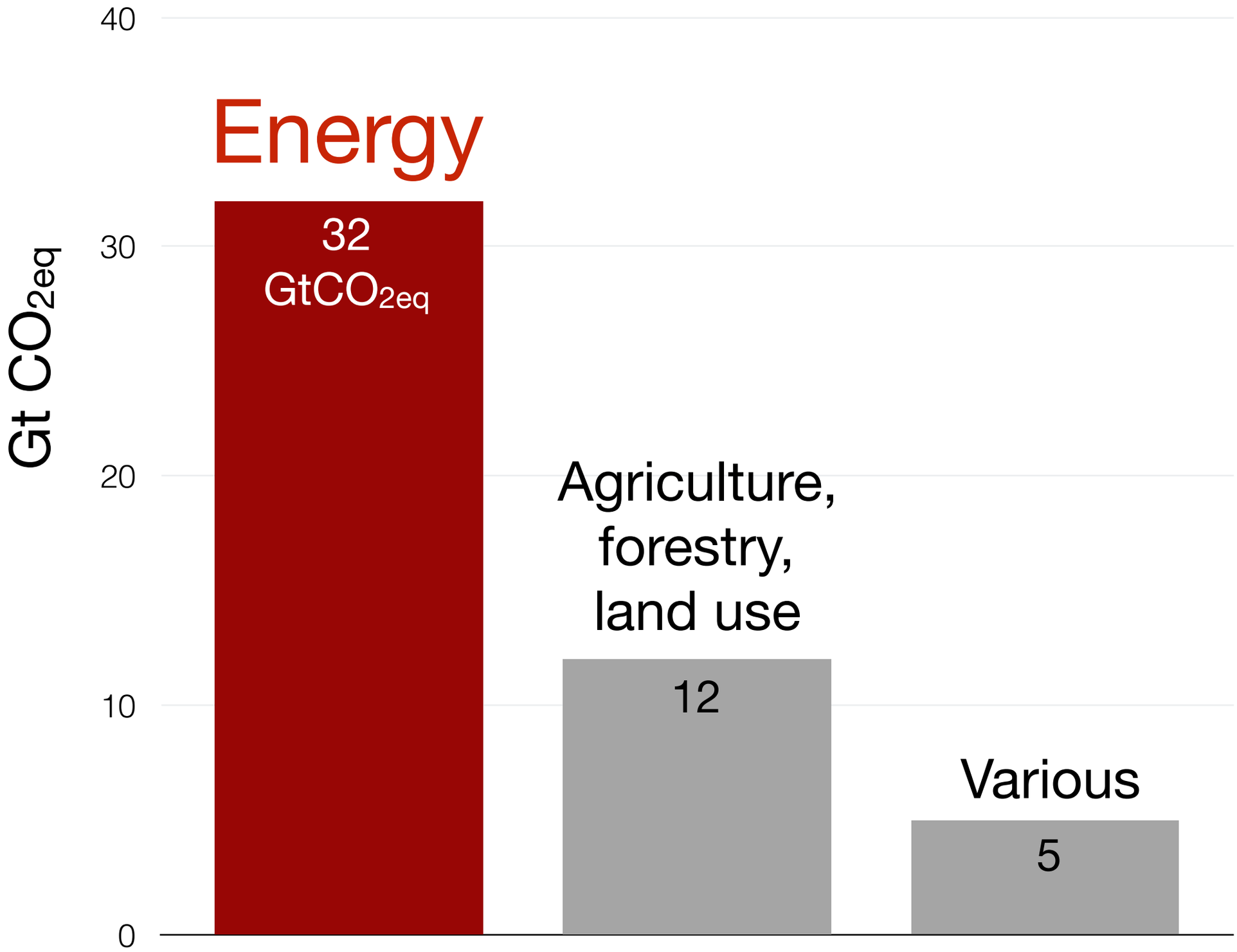
Projected temperature change by 2081–2100 compared with 1986–2005



← The planet we know

Source: IPCC (2014), AR5 WG2

Share of the energy sector



Data source: IPCC (2014), AR5 WG3 Chapter 5, pp.354-355

Two camps

We can eliminate energy emissions with technology, over the next decades. It will not be easy, but it is doable.

(Of course, this doesn't fix the many other problems.)

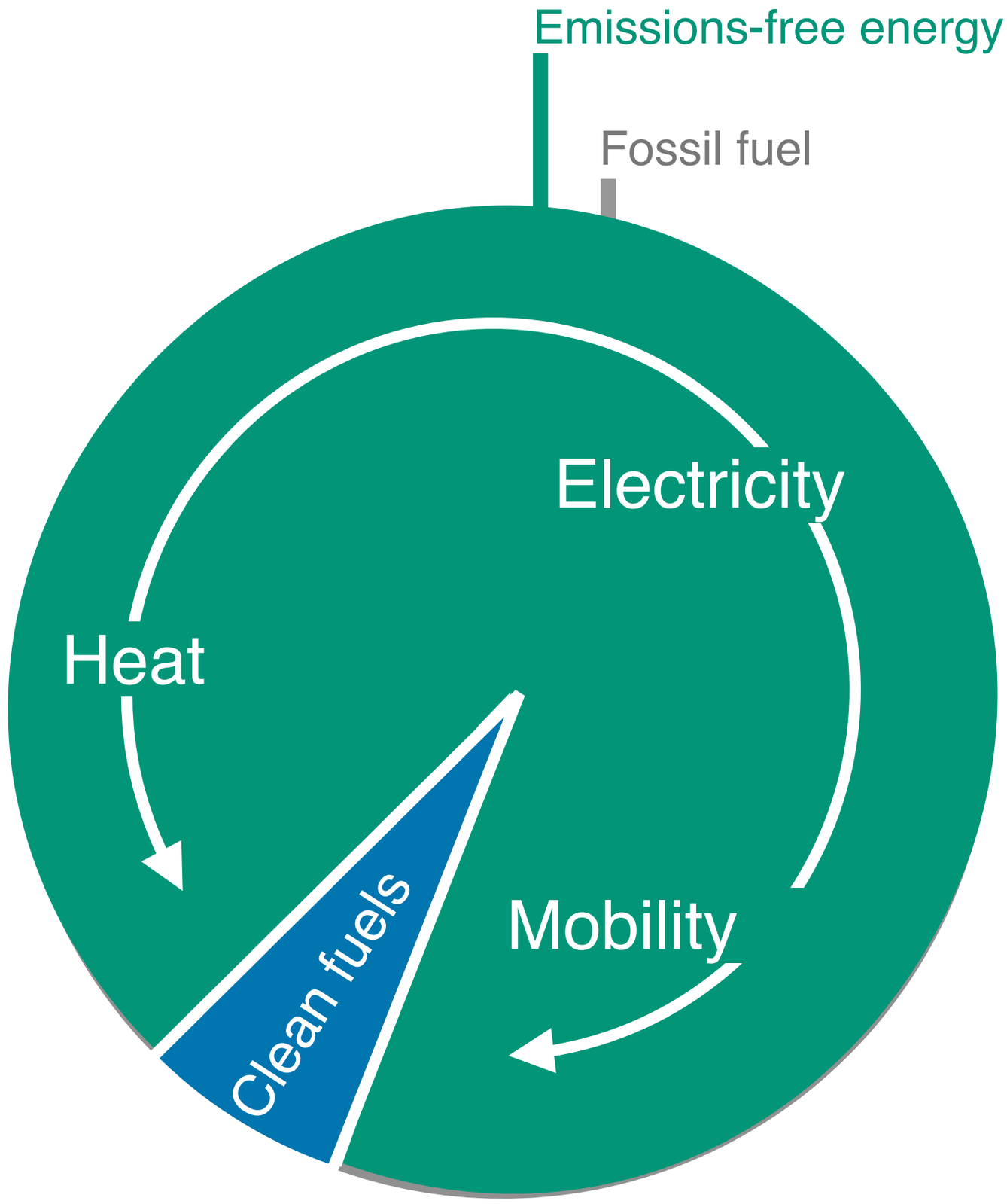
We need to change society copmletely to solve the many interconnected environmental and social problems.

Outline

A. Negative emissions ASAP

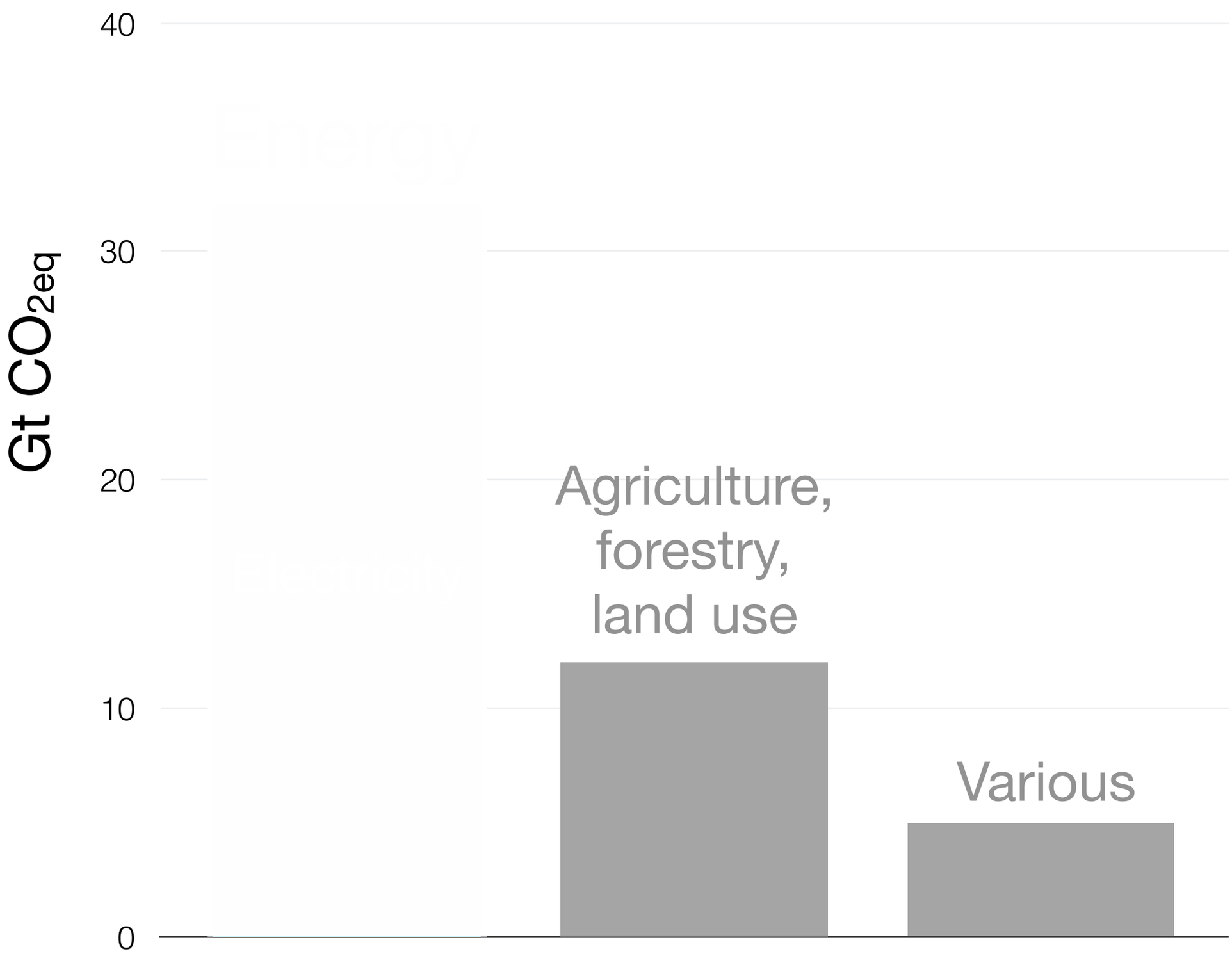
B. The puzzle and the pieces

The puzzle: Zero-emissions energy



Data source: U.S. EIA, Figure: Anthony Patt

The puzzle: 0-emissions energy = 0-emissions electricity



Data source: IPCC (2014), AR5 WG3 Chapter 5, pp.354-355

What puzzle pieces are available?

Power-to-x

Electric cars

Wind power

Batteries

Heat pumps

Combined heat and power

Hydrogen

Carbon capture and storage

District heating

Fusion power

Supergrids

Nuclear

Bioenergy

Hydropower

Photovoltaics

Fuel cells

Concentrating solar power

Smart grids

https://colossalshop.com/products/1000-colors-puzzle

Which pieces to start the puzzle with?

- **Fast**: it must be on the market, ready to build, with as little bureaucracy as possible

- **Affordable**: energy should have roughly the same cost in the future as it does now

- **Acceptable**: people must be willing to live close to it, or at least accept that it exists somewhere in their country

- **Credible**: it must actually work, and must actually lead to zero or very low CO_2 emissions

Acceptable pieces: let's look at some candidates

	Fast?	Affordable?	Acceptable?	Credible?
Solar and wind power	✅	✅	?	✅
CCS	?	?	?	?
Nuclear power	❌	❌	❌	✅
Bioenergy	✅	✅	?	❌
Others (e.g. cold fusion)	❌/ ?	❌/ ?	❌/ ?	❌/ ?

Increasing agreement that solar and wind electricity can form the centrepiece of a fully renewable energy system

What puzzle pieces are available?

Power-to-x

Electric cars

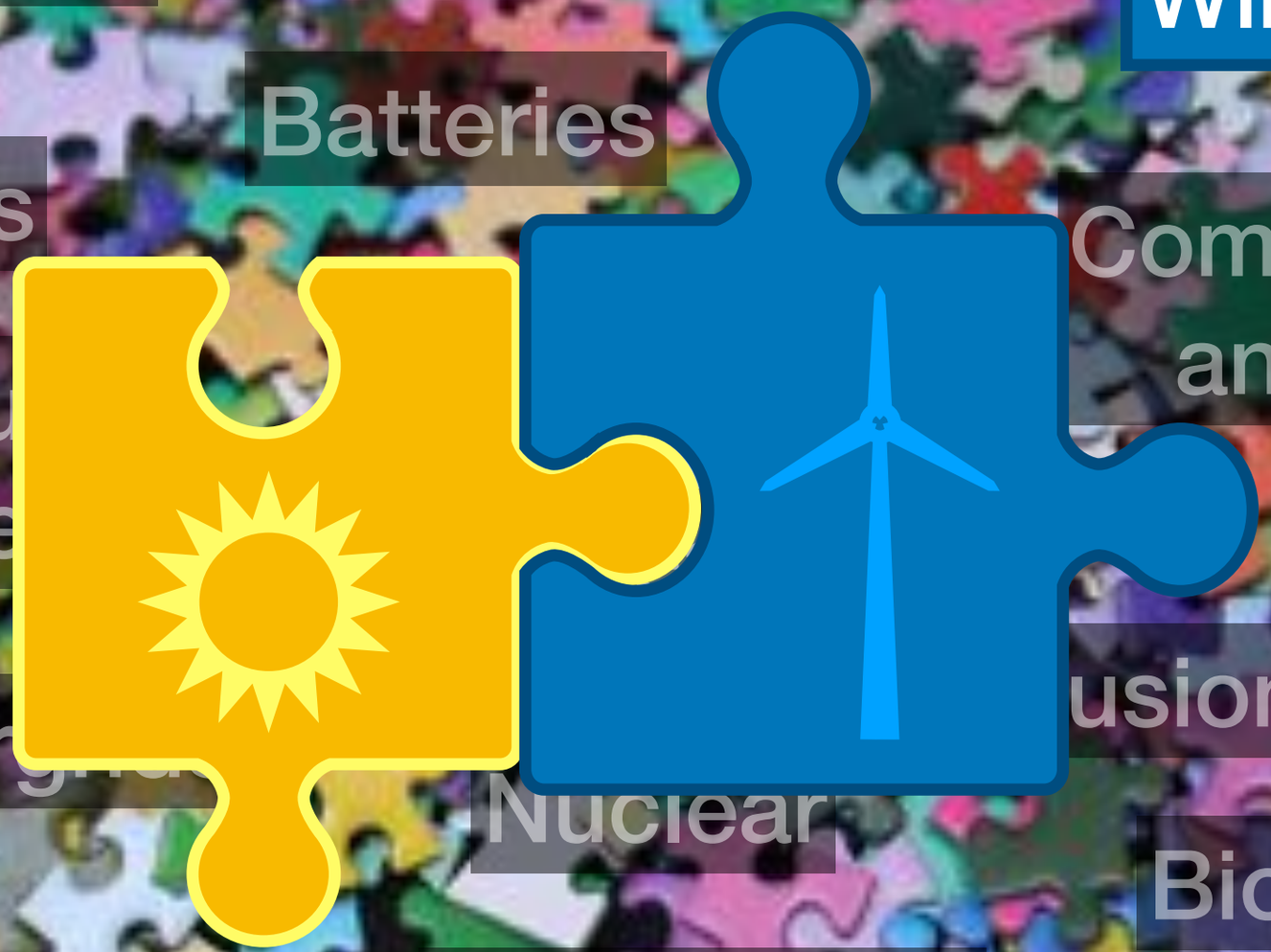
Wind power

Batteries

Heat pumps

Combined heat and power

Carbon captu and storage



Supergrid

usion power

Nuclear

Bioenergy

Hydropower

Photovoltaics

Fuel cells

Concentrating solar power

Smart grids

https://colossalshop.com/products/1000-colors-puzzle

Outline

A. Negative emissions ASAP

B. The puzzle and the pieces

C. How do these pieces hold up in practice?

A first big problem: resource availability and scale

- Local: individual buildings
- Communal to regional
- Subnational to continental
- Global

Communes and regions

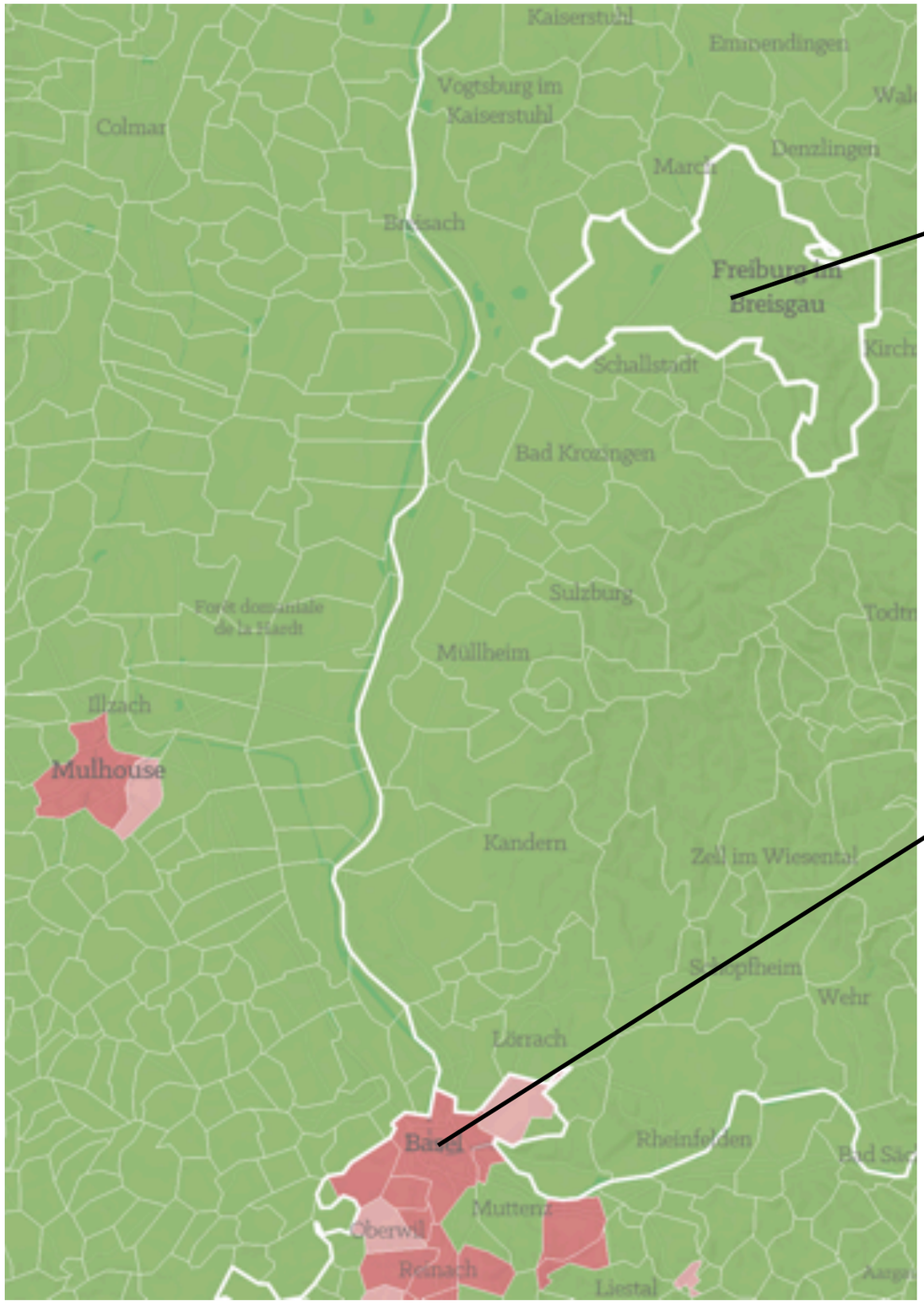
Renewable autarky possible?

Definitely no

Likely no

Maybe yes

Likely yes



Renewable electricity autarky

in **Freiburg im Breisgau** is likely possible.

219,030 people
1.2 TWh electricity demand
1.4 TWh generation potential

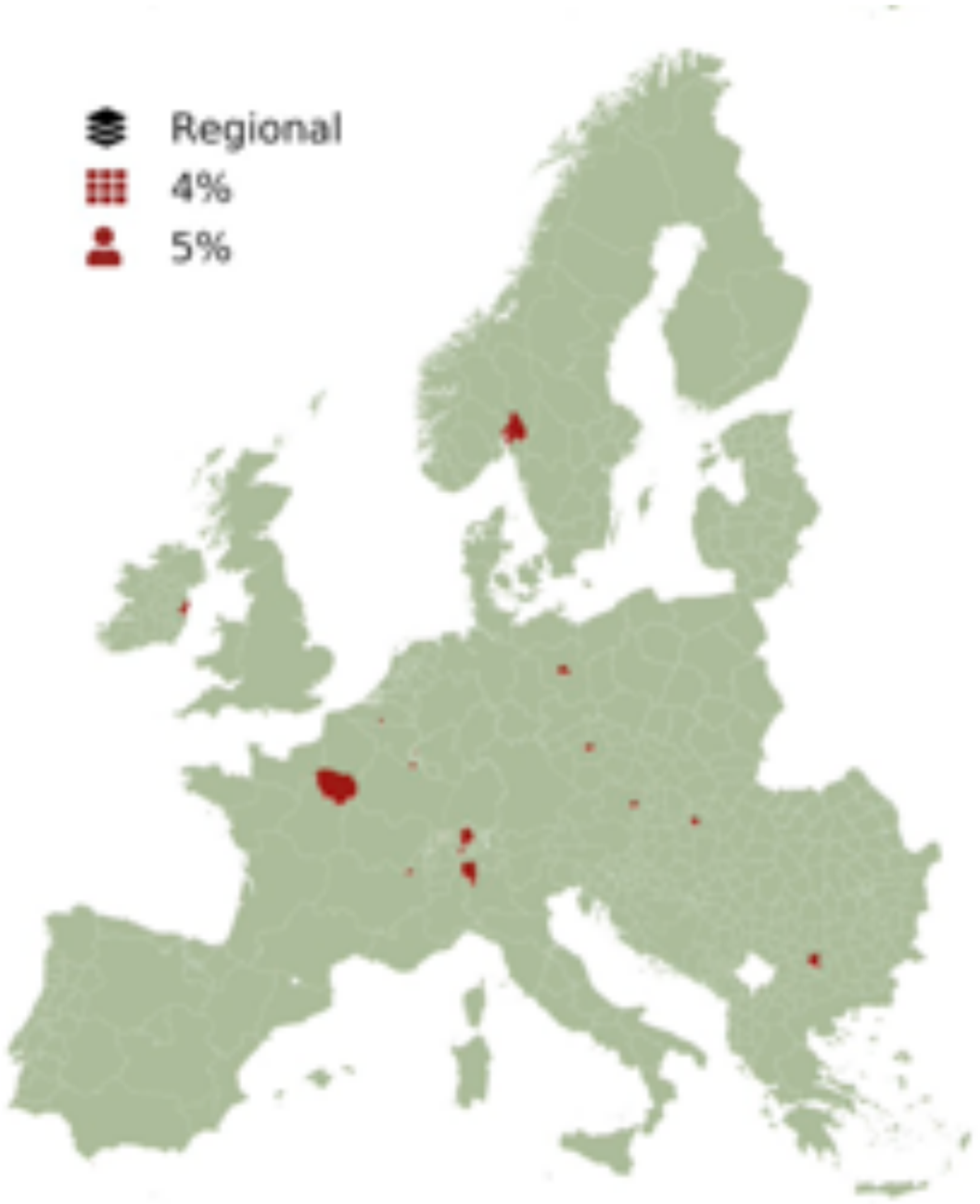
Renewable electricity autarky

in **Basel** is impossible.

161,193 people
1.2 TWh electricity demand
0.6 TWh generation potential

Communes and regions

Communes and regions



A first big problem: resource availability and scale

- Local: individual buildings

✓ Communal to regional

- Subnational to continental

- Global

Local scale: fully electric self-sufficient buildings

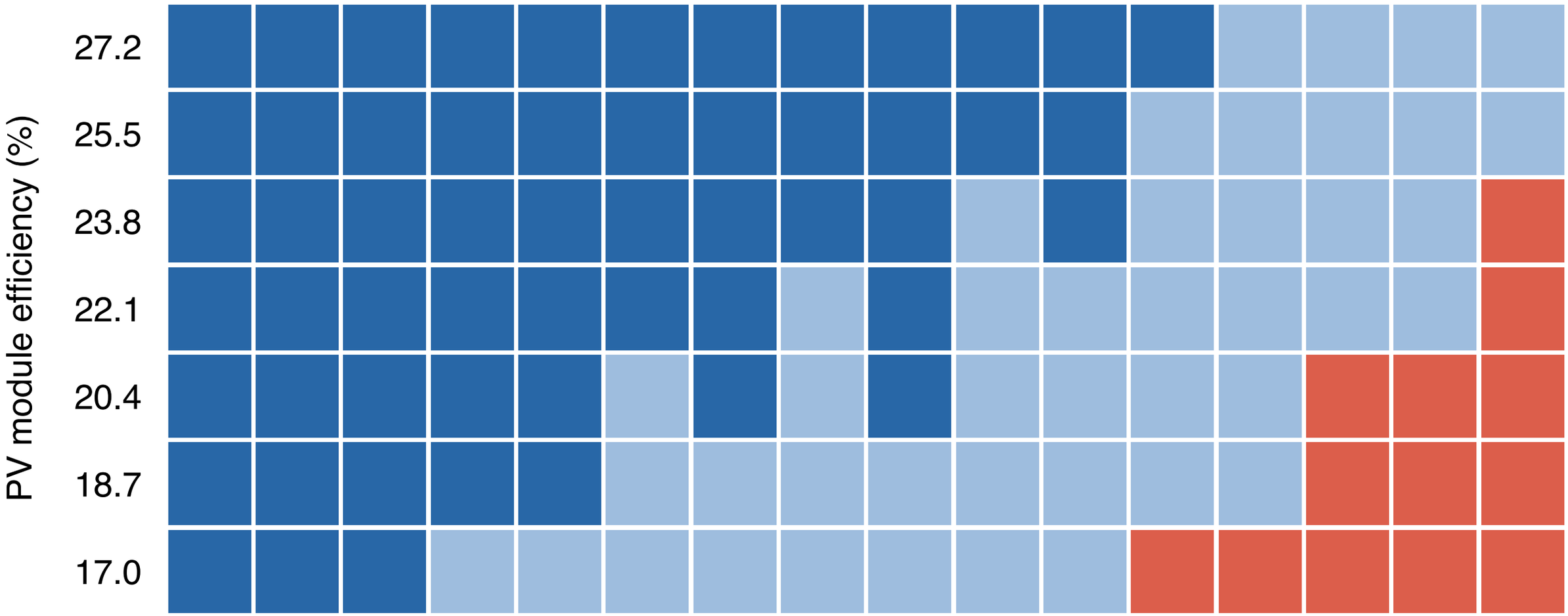
- Solar panels on roof
- EV charging
- Heat pump for heating
- Battery and hydrogen storage
- Self-sufficient (off-grid)

Local scale: fully electric buildings (incl. EV charging)

Can supply annual demand
and storage (true zero energy building)

Can supply annual demand,
but not storage (net zero energy building)

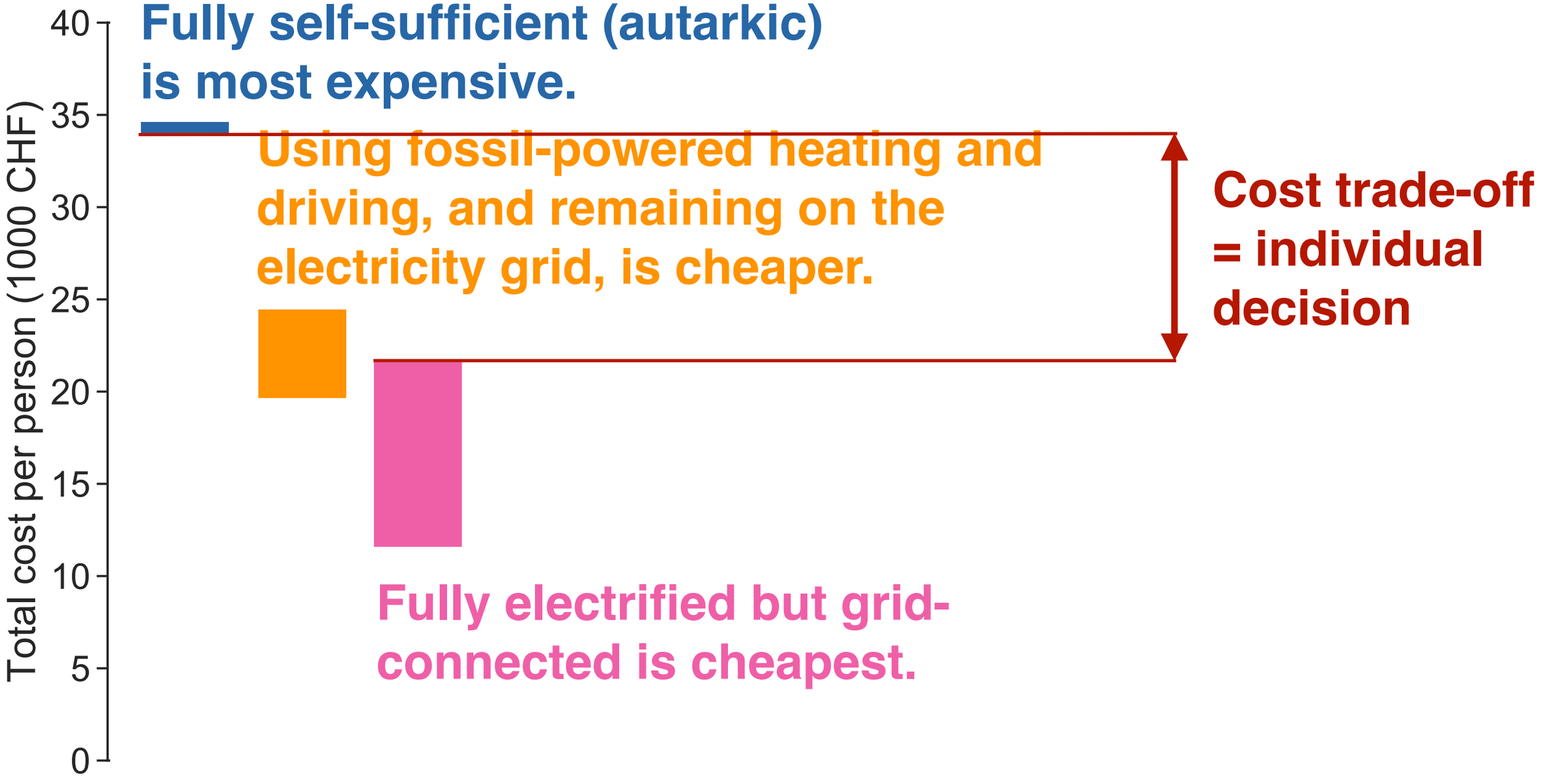
Unable to supply
annual demand



(20 vs 4 people, 2.75x more roof area.)

Gstöhl and Pfenninger, PLOS ONE (in review)

Local scale: fully electric buildings (incl. EV charging)



For one example case of a single-family building.

A first big problem: resource availability and scale

✓ Local: individual buildings

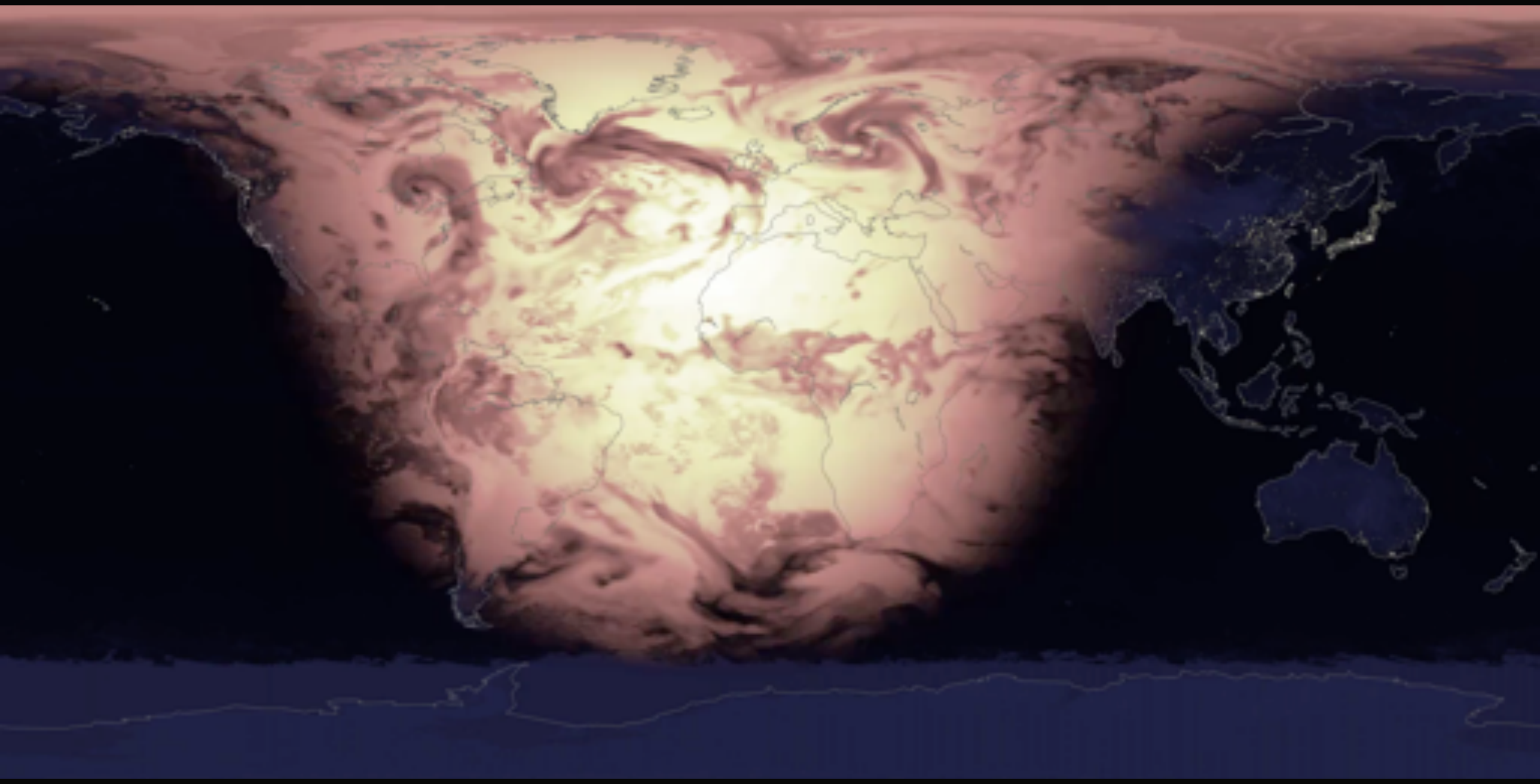
But variability!

✓ Communal to regional

But variability!

- Subnational to continental
- Global

Not just resource availability, but its variability!



Animation based on Renewables.ninja with NASA MERRA-2 data

Another set of problems: variability

- Hourly to daily variability
- Multi-day to weekly variability
- Seasonal variability
- Long-term variability (climate change)

Hourly to daily variability: ✓

https://media.treehugger.com/assets/images/2015/05/solarcity-tesla-powerwall-house-001.jpg.650x0_q70_crop-smart.jpg

https://www.growingproduce.com/citrus/are-there-bright-futures-in-solar-farming/

https://www.tesla.com/blog/introducing-megapack-utility-scale-energy-storage

Hourly to daily variability: ✓

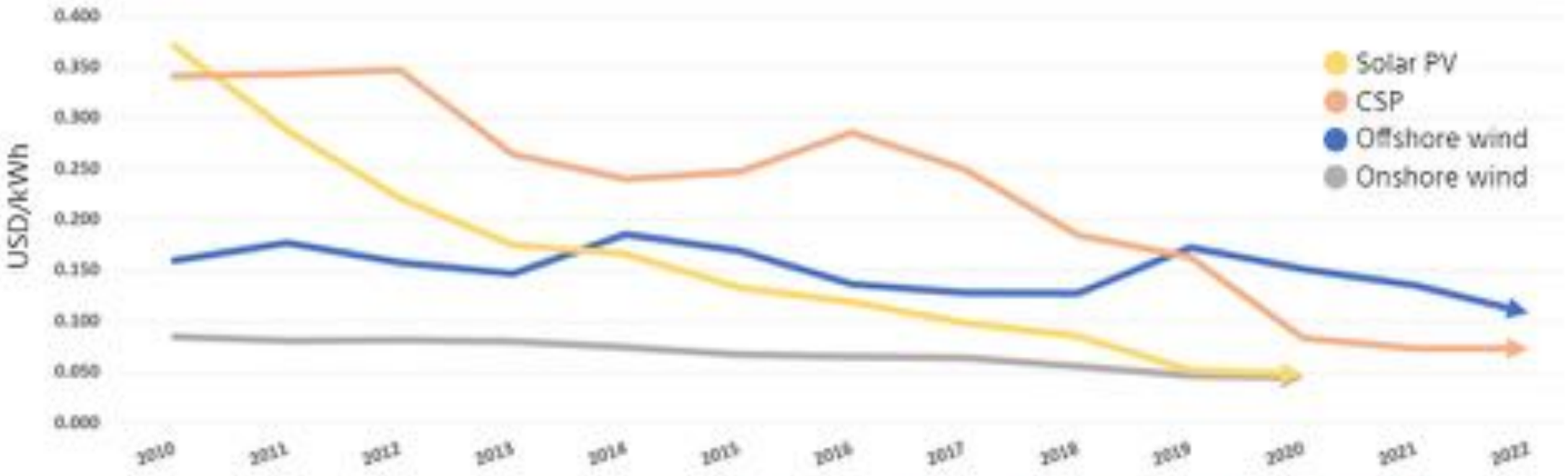
Tesla's new Solar Roof costs less than a new roof plus solar panels, aims for install rate of 1K per week

Darrell Etherington @etherington / 12:16 am CEST • October 26, 2019 Comment

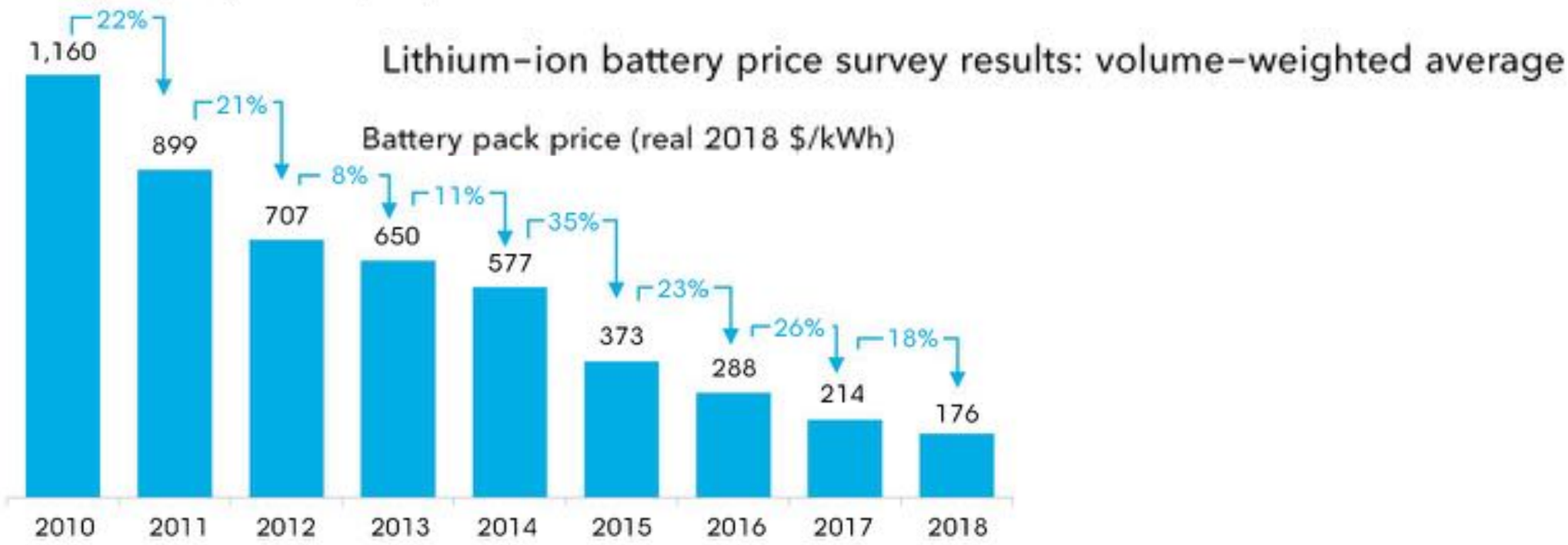
https://techcrunch.com/2019/10/25/teslas-new-solar-roof-costs-less-than-a-new-roof-plus-solar-panels-aims-for-install-rate-of-1k-per-week/

Hourly to daily variability: ✓

Electricity generation costs falling

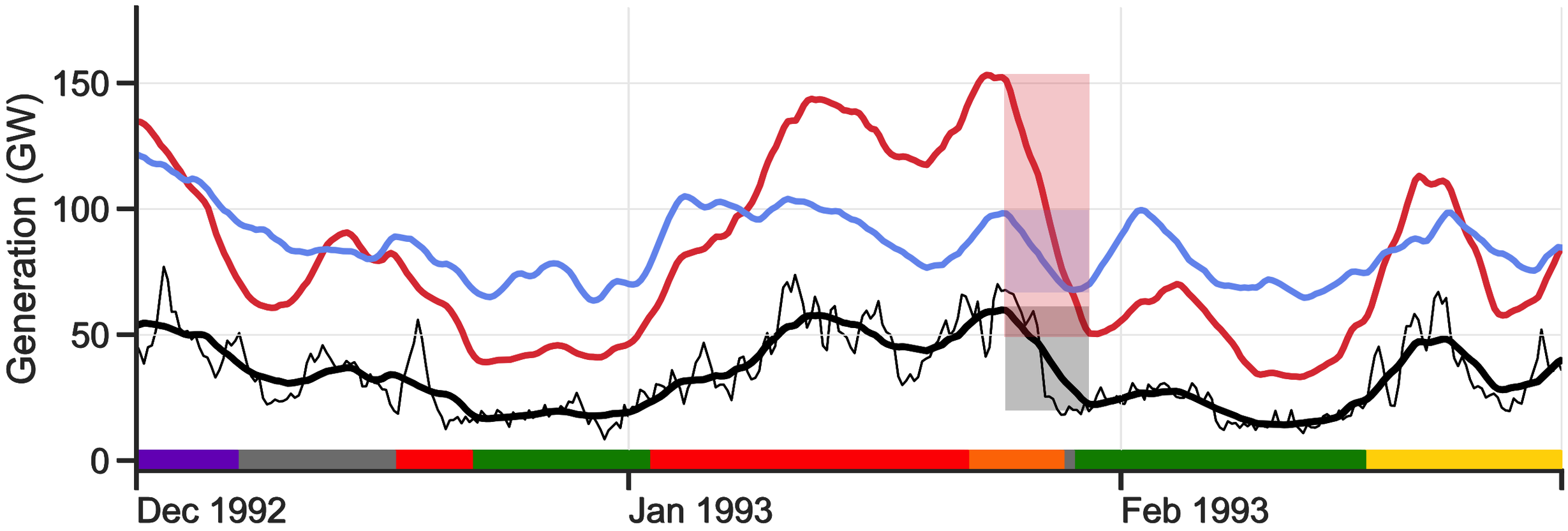


Electricity storage costs falling

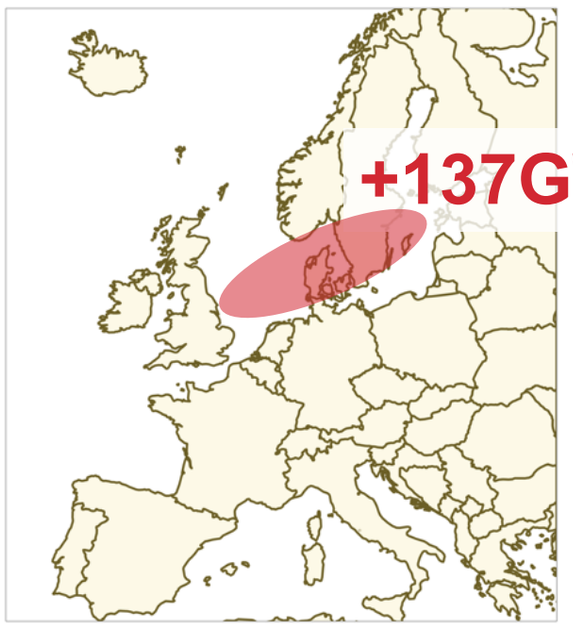


IRENA: https://www.irena.org/newsroom/pressreleases/2019/May/Falling-Renewable-Power-Costs-Open-Door-to-Greater-Climate-Ambition
BNEF: https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/

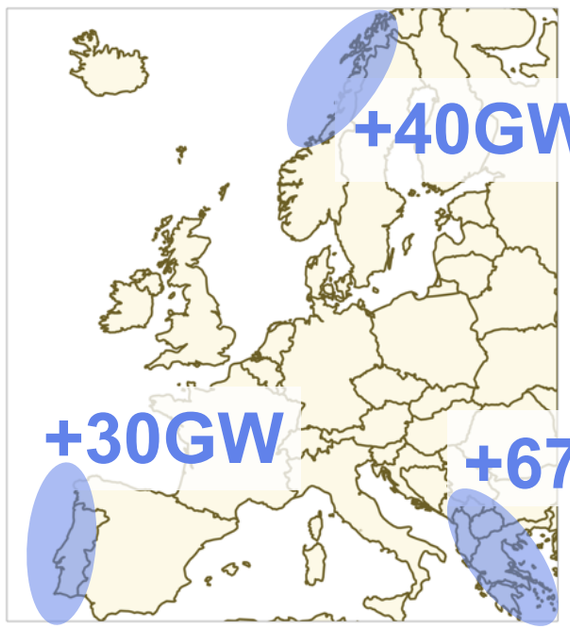
Multi-day to weekly variability: ✓



Planned



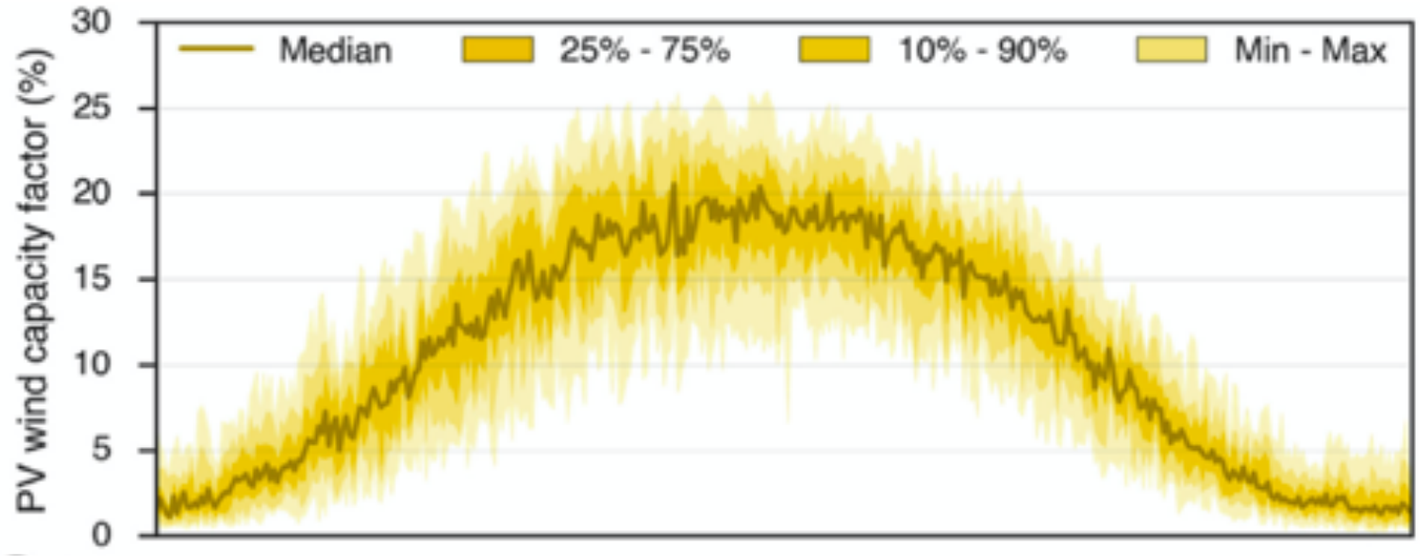
Balanced



Grams et al. (2017). https://doi.org/10.1038/nclimate3338

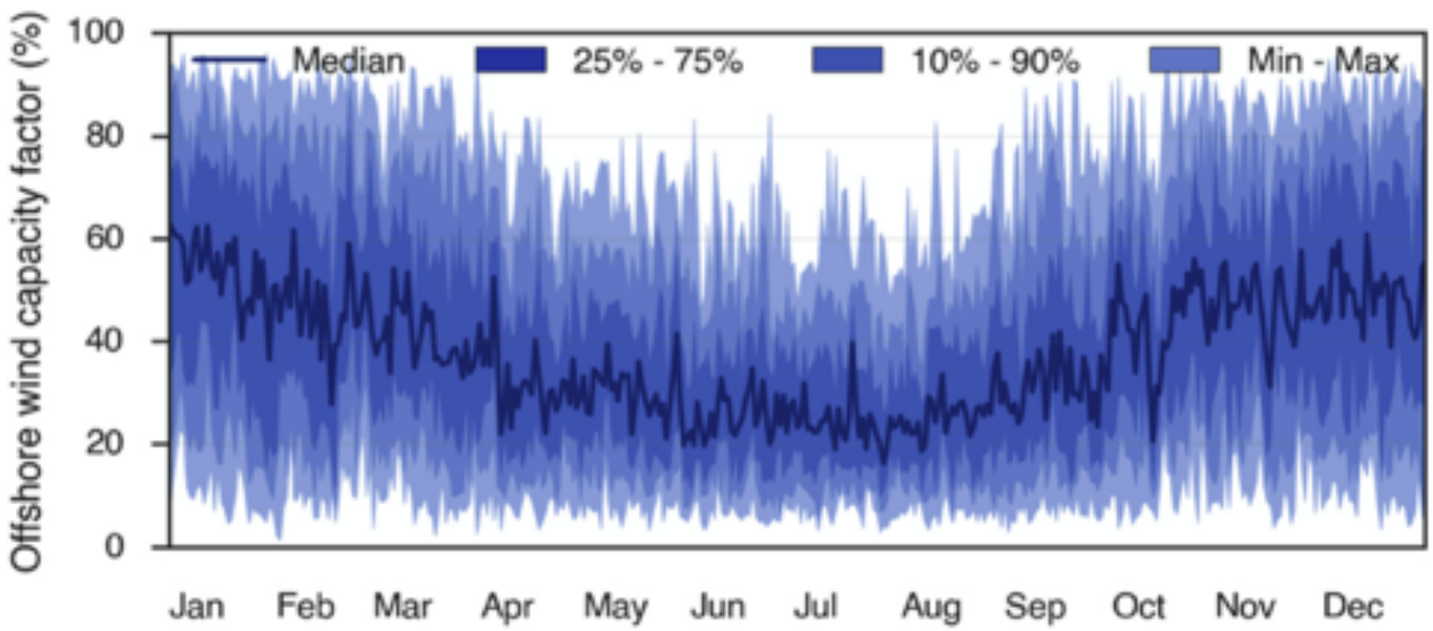
Seasonal variability: ✓

Photovoltaics



Anticorrelation

Offshore wind



Pfenninger and Staffell (2018). https://doi.org/10.1016/j.energy.2017.12.051

Seasonal variability: ✓

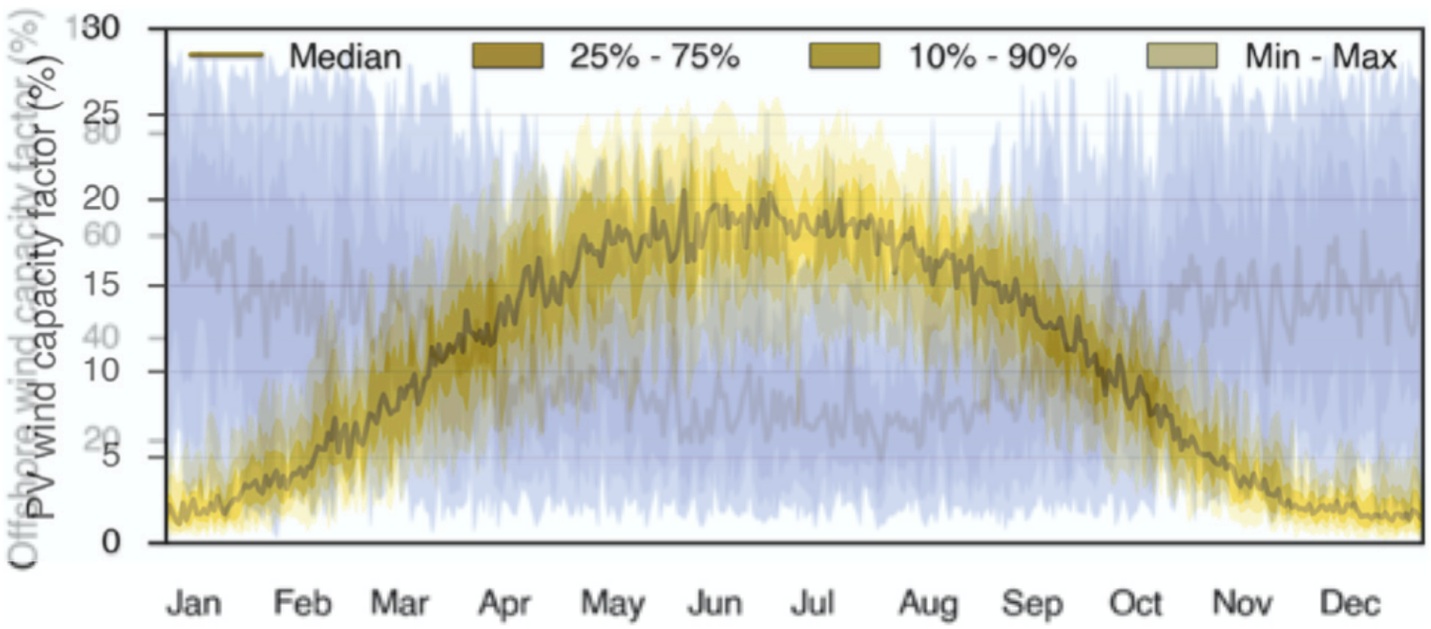
E.g. hydrogen, pumped hydropower

With very cheap wind and PV, this is not a problem

Anticorrelation + **Seasonal storage** + **Overcapacity**

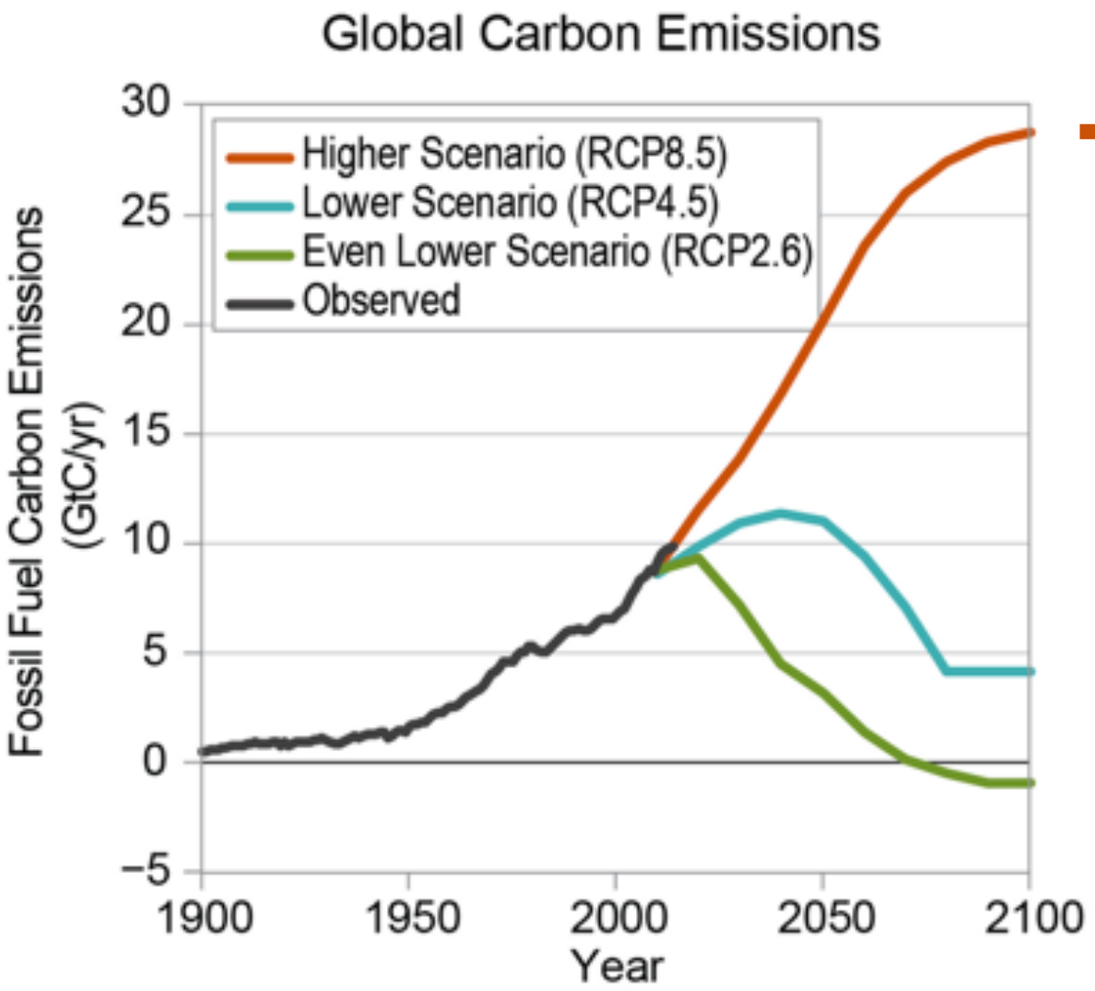
Offshore wind

Photovoltaics

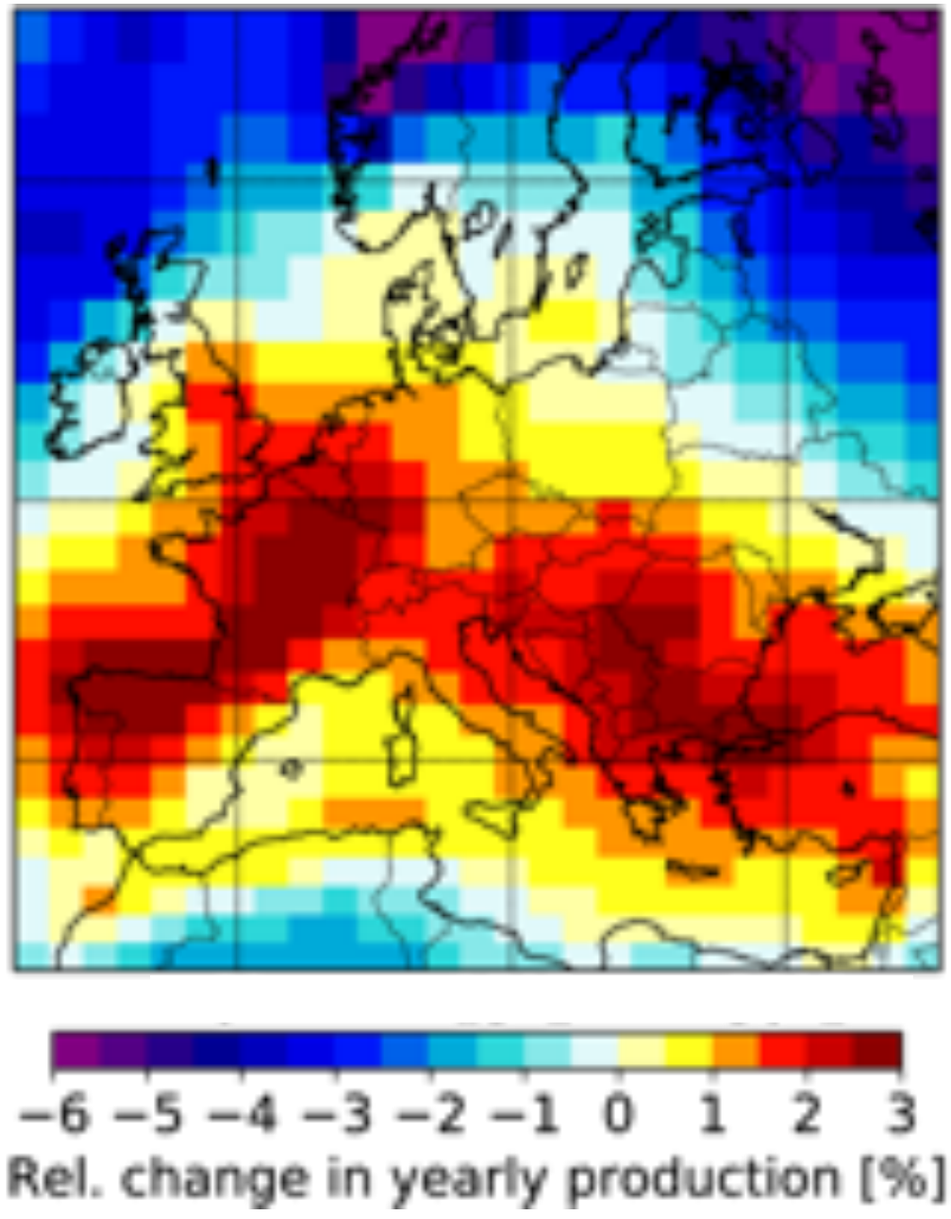


Pfenninger and Staffell (2018). https://doi.org/10.1016/j.energy.2017.12.051

Long-term variability (climate change): ✓



https://nca2018.globalchange.gov/chapter/2/



2060-2080

Photovoltaics: a no-regrets investment in Europe irrespective of climate change

Müller, Folini, Wild and Pfenninger (2019). https://doi.org/10.1016/j.energy.2018.12.139

Another set of problems: variability

✓ Hourly to daily variability

✓ Multi-day to weekly variability

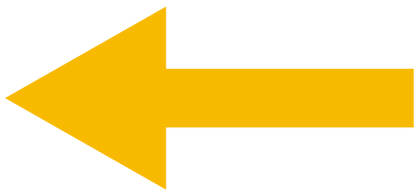
✓ Seasonal variability

✓ Long-term variability (climate change)

Back to the question of resource availability and scale

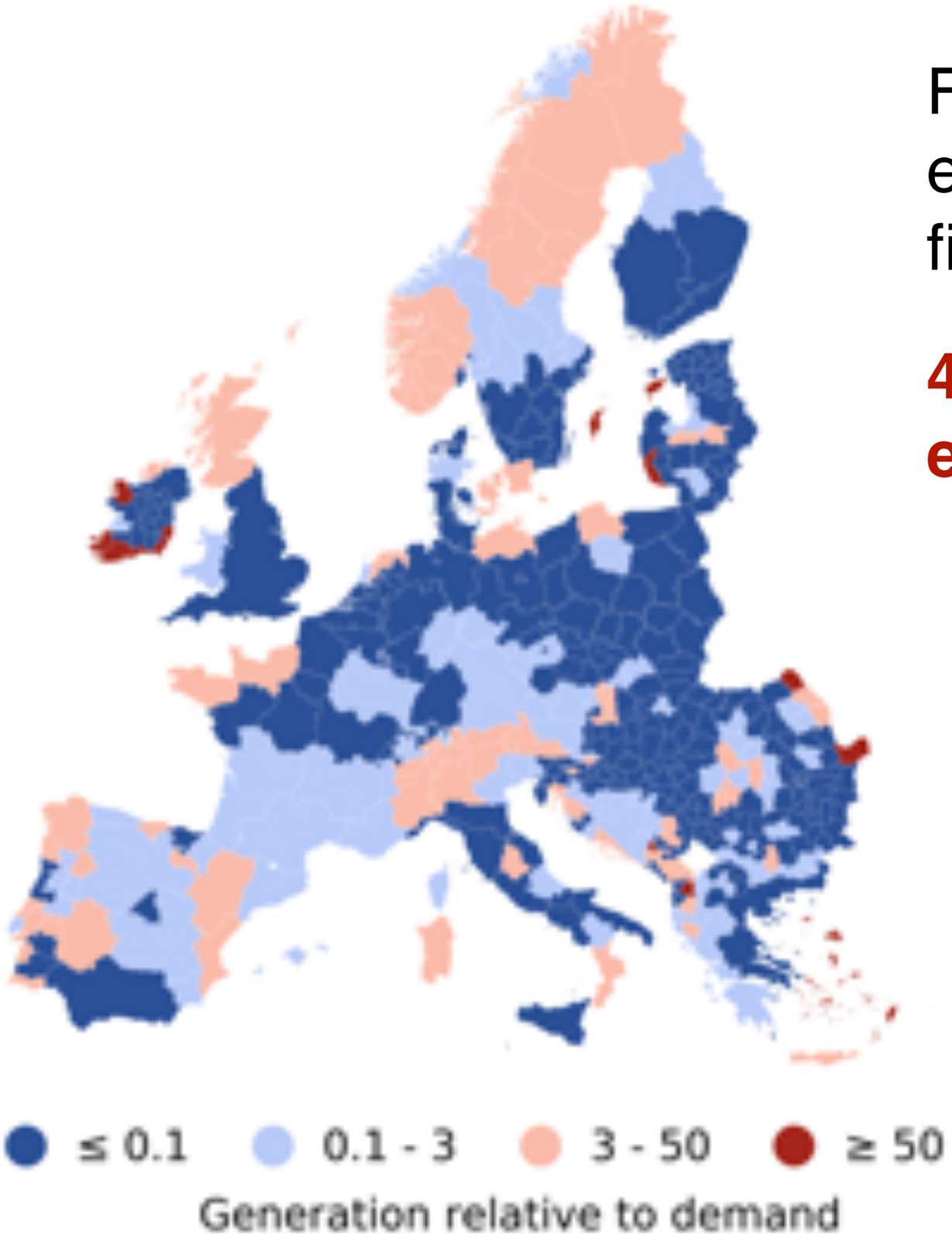
✓ Local: individual buildings

✓ Communal to regional

- Subnational to continental 

- Global

Subnational to continental



Fully optimised continent-scale electricity system across all 497 first-level subnational divisions

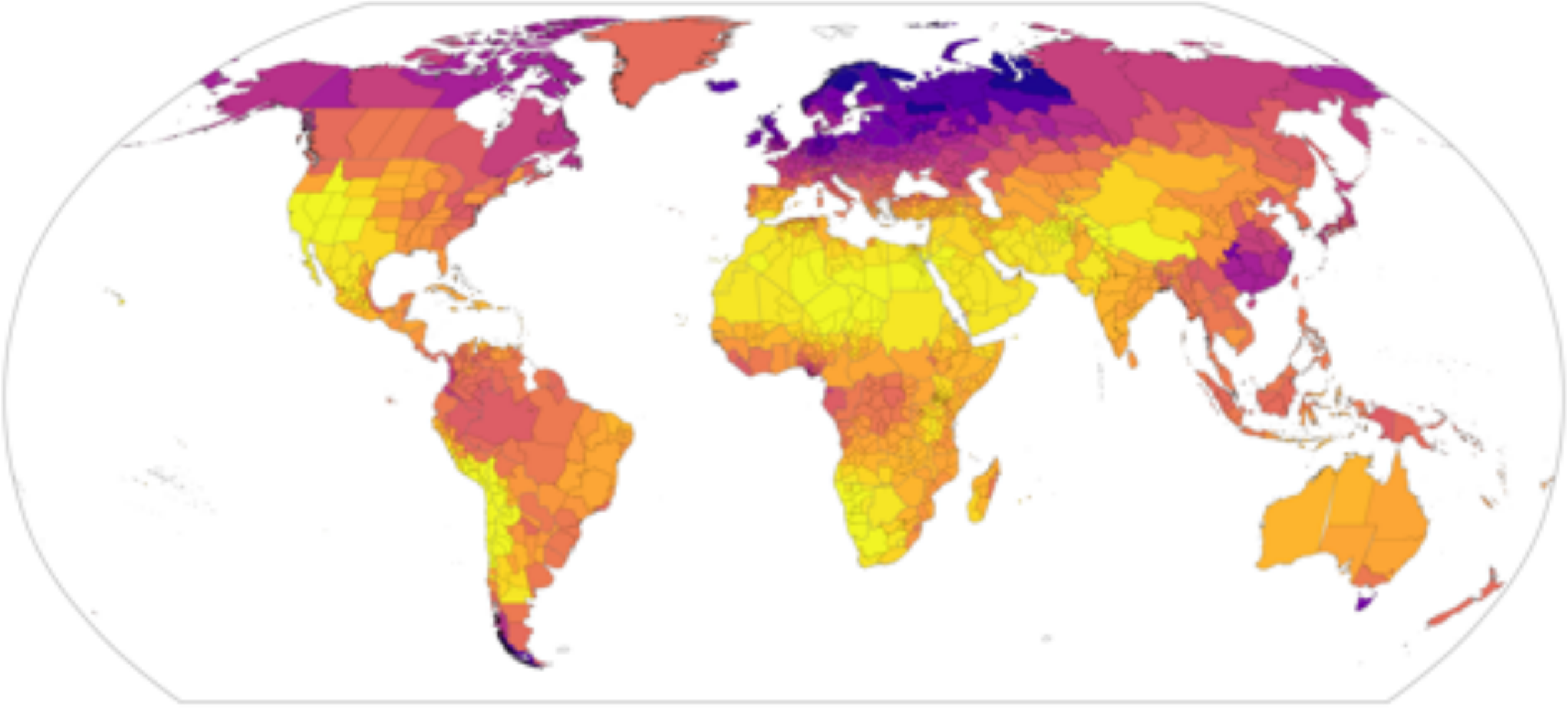
4x the capacity of today's electricity transmission system

What if I don't want to build so many new transmission lines?

Tröndle et al. *Nature Energy* (in review)

Global: ✓

Most parts of the world have better renewable resources than Europe does — especially when it comes to solar power.



Renewables.ninja

Long-term average photovoltaic capacity factor

0.10 0.11 0.12 0.13 0.14 0.15 0.16 0.17 0.18 0.19 0.20 0.21 0.22 0.23

Pfenninger and Staffell (in preparation)

A system with solar and wind power at its core

Resource availability and scale

- ✓ Local
- ✓ Communal to regional
- ✓ Subnational to continental
- ✓ Global

Variability in time

- ✓ Hourly to daily
- ✓ Multi-day to weekly
- ✓ Seasonal
- ✓ Long-term / climate change

Outline

A. Negative emissions ASAP

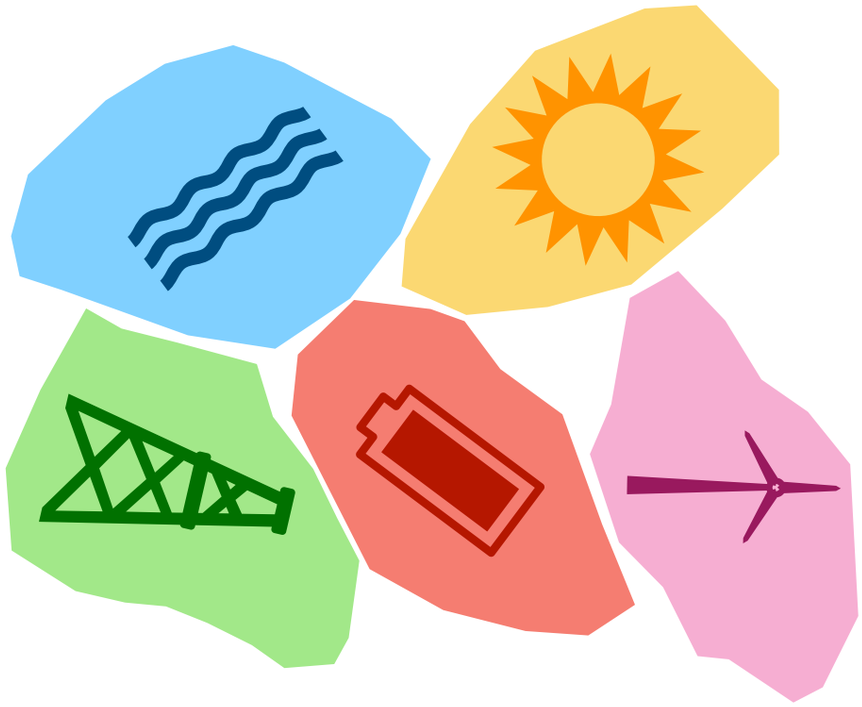
B. The puzzle and the pieces

C. How do these pieces hold up in practice?

D. So, what's missing?

Building with irregular building blocks

Building with irregular building blocks



The missing piece is mortar to fill in the gaps

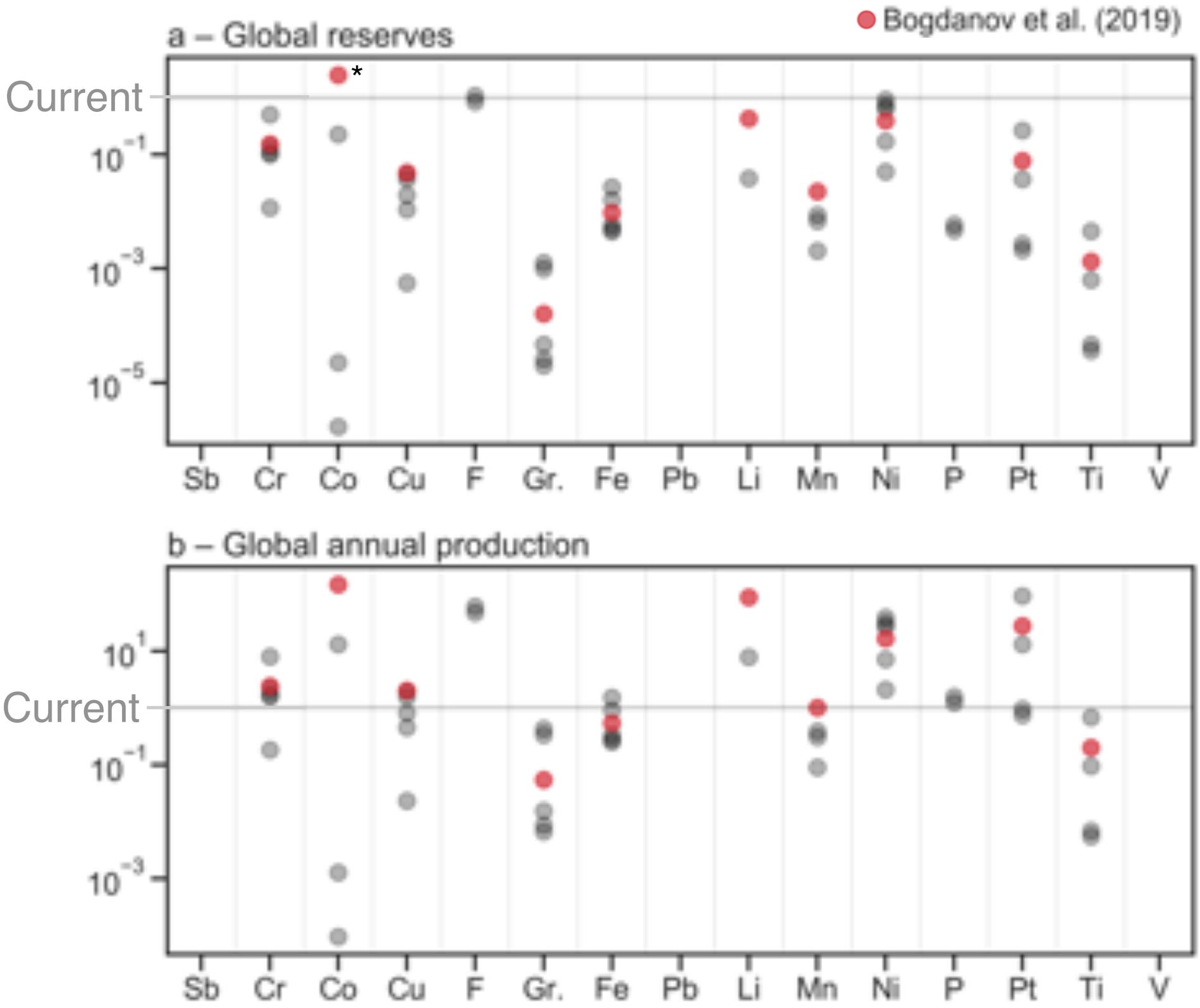
Photo by Andrew Buchanan on Unsplash

Mortar

Part of the mix:
to be provided
by science

Part of the mix:
to be provided
by policy

An example: material requirements

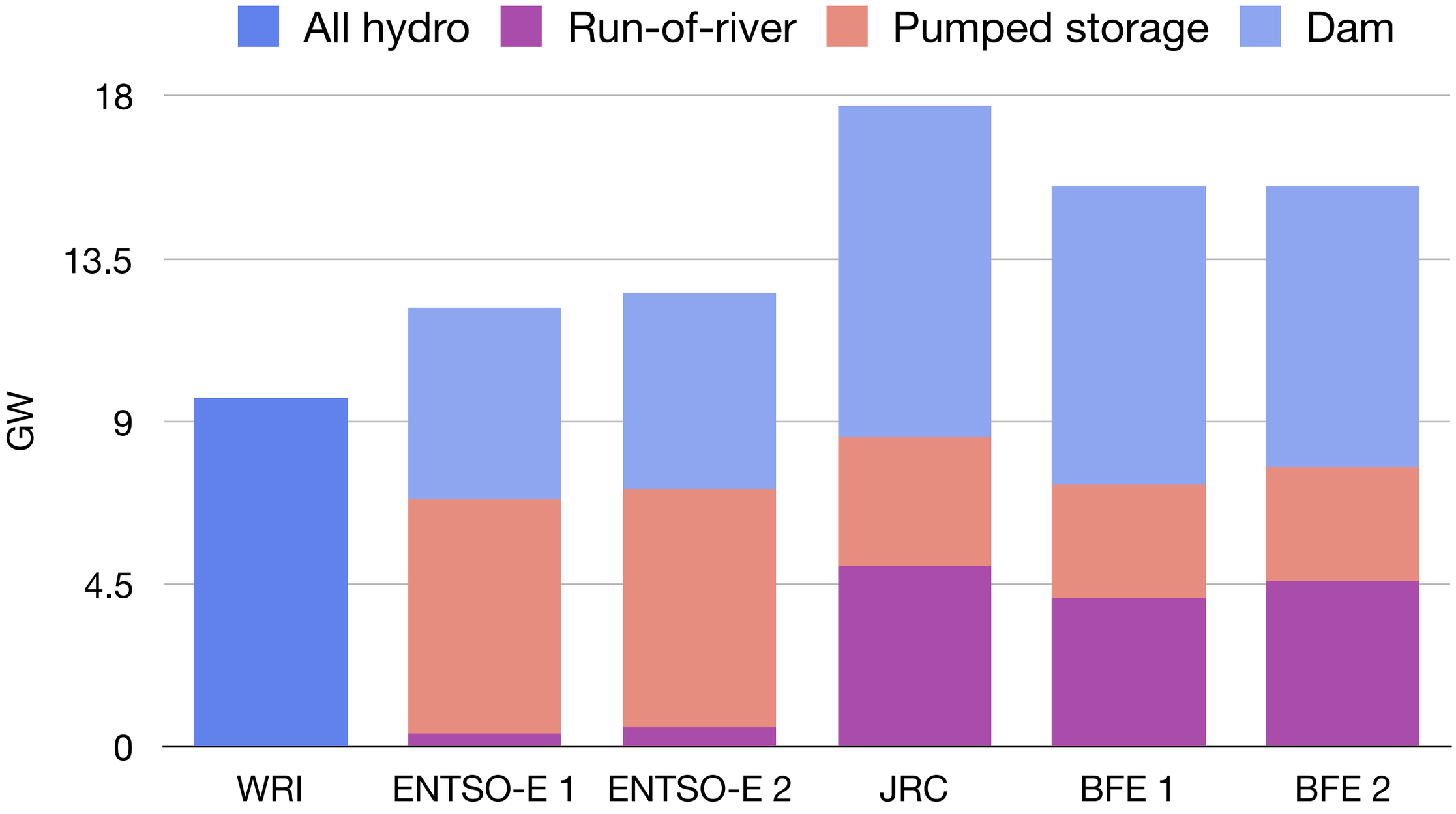


* Li-Ion Batteries

Huber et al. (in preparation)

Another example: better data

Different sources completely disagree on how much hydropower capacity exists in Switzerland!



Data: Bryn Pickering

The most important piece is still missing

✓ Engineering details to figure out, for example:

Material requirements and better data

Role of district heating

Electric vehicle charging schemes

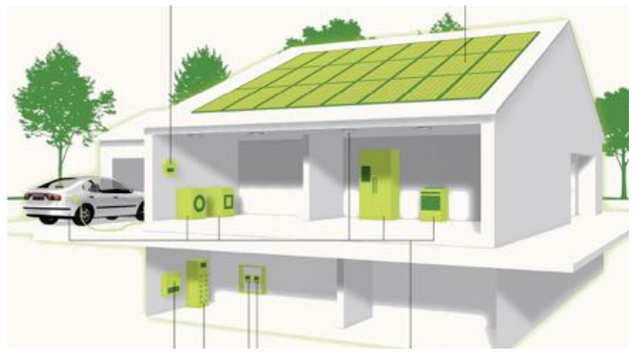
…

These details can only be filled in once clear decisions on what path to follow have been made.

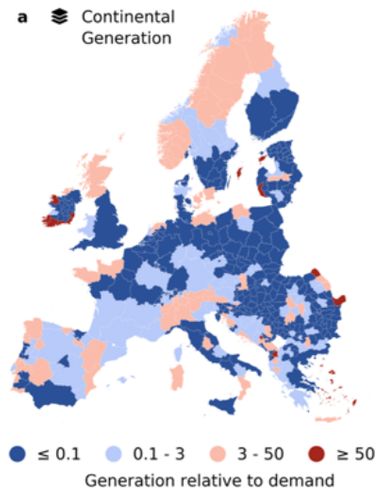
Clear decisions: the missing ingredient

- Very different systems are possible
- There are trade-offs with cost and required infrastructure
- Different system designs are mutually exclusive
- Before stacking up pieces, better decide ***what*** to build

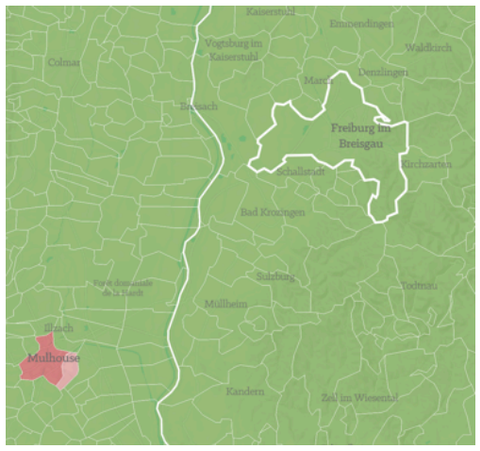
✓ Self-sufficient houses



✓ Continent-wide optimised system



✓ Self-sufficient communes or regions



Tröndle et al. *Nature Energy* (in review)

How can research help? Decision support to identify tradeoffs

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

+

www.callio.pe

"Engage": makes energy planning models accessible to stakeholders through a cloud-based scenario and visualisation tool

Tom Harris + Rob Spencer @ NREL

Are there really no missing pieces?

Photo by It's Nathan on Unsplash

Missing pieces are on their way: clean aviation fuels

World first demonstration of complete thermo-chemical process for CO2-to-fuel with concentrating solar system (Aldo Steinfeld's group, June 2019, roof of ETH Zürich)

Cost of this could credibly be <1 EUR/liter fuel

Missing pieces are on their way: negative emissions

ClimeWorks: ETH Zürich spinoff working on **direct air capture**.

This might be quite easy with lots of cheap renewable electricity!

https://www.nytimes.com/2019/02/12/magazine/climeworks-business-climate-change.html

Two camps

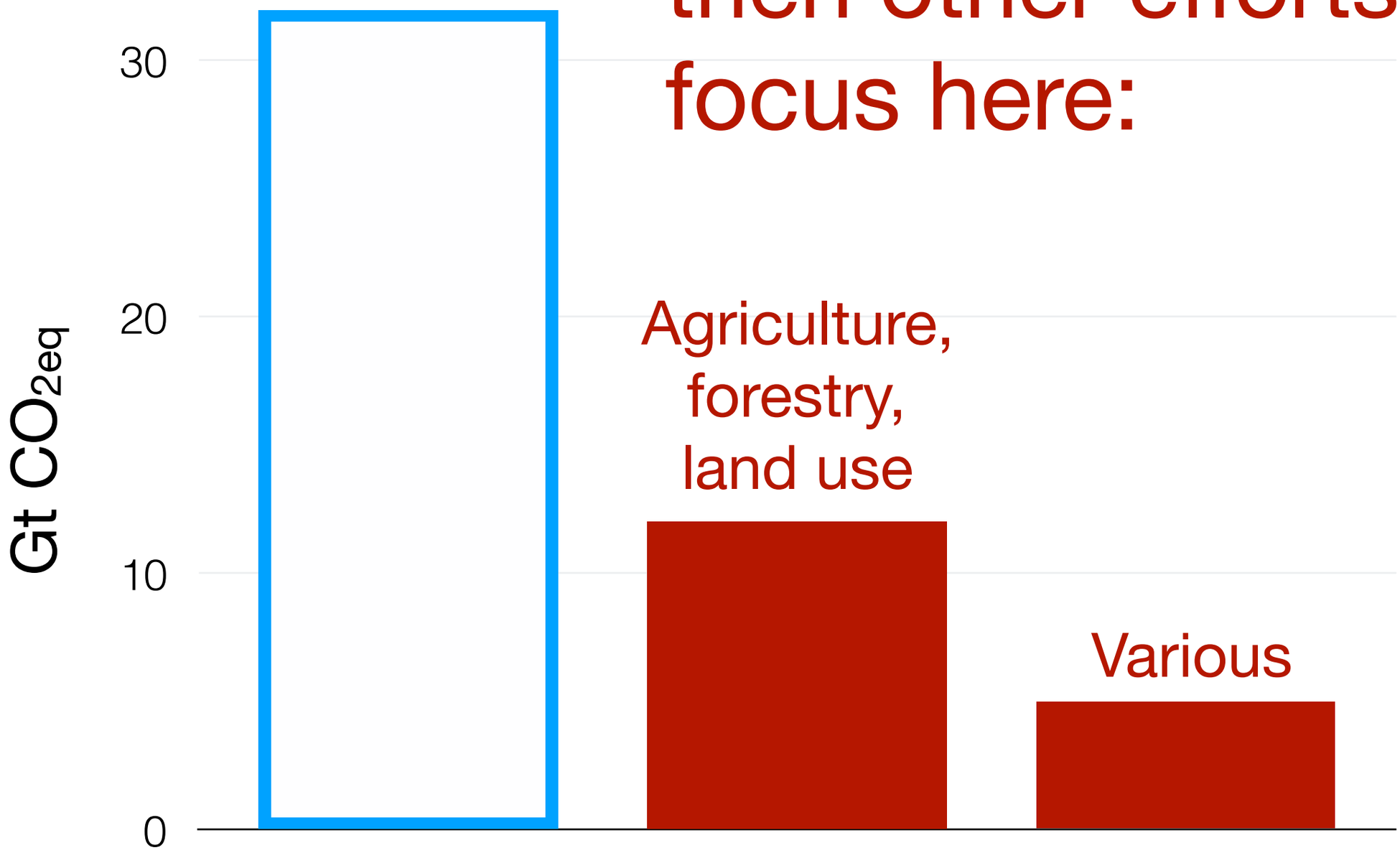
But if it seems possible to get to zero energy emissions it with “just” technology, isn’t that good to know?

Ok, but we can’t address climate change without also changing peoples’ behaviour and lifestyles.

What about behaviour and societal change?

If techno-fixes can deliver clean energy,

then other efforts can focus here:



Data source: IPCC (2014), AR5 WG3 Chapter 5, pp.354-355

Summary

1.
This is a solvable problem

2.
The pieces are here

3.
The mortar is missing

Engineering details

Decisions

4. What are we waiting for?

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