Decision support with energy system modelling

(with examples using Calliope)

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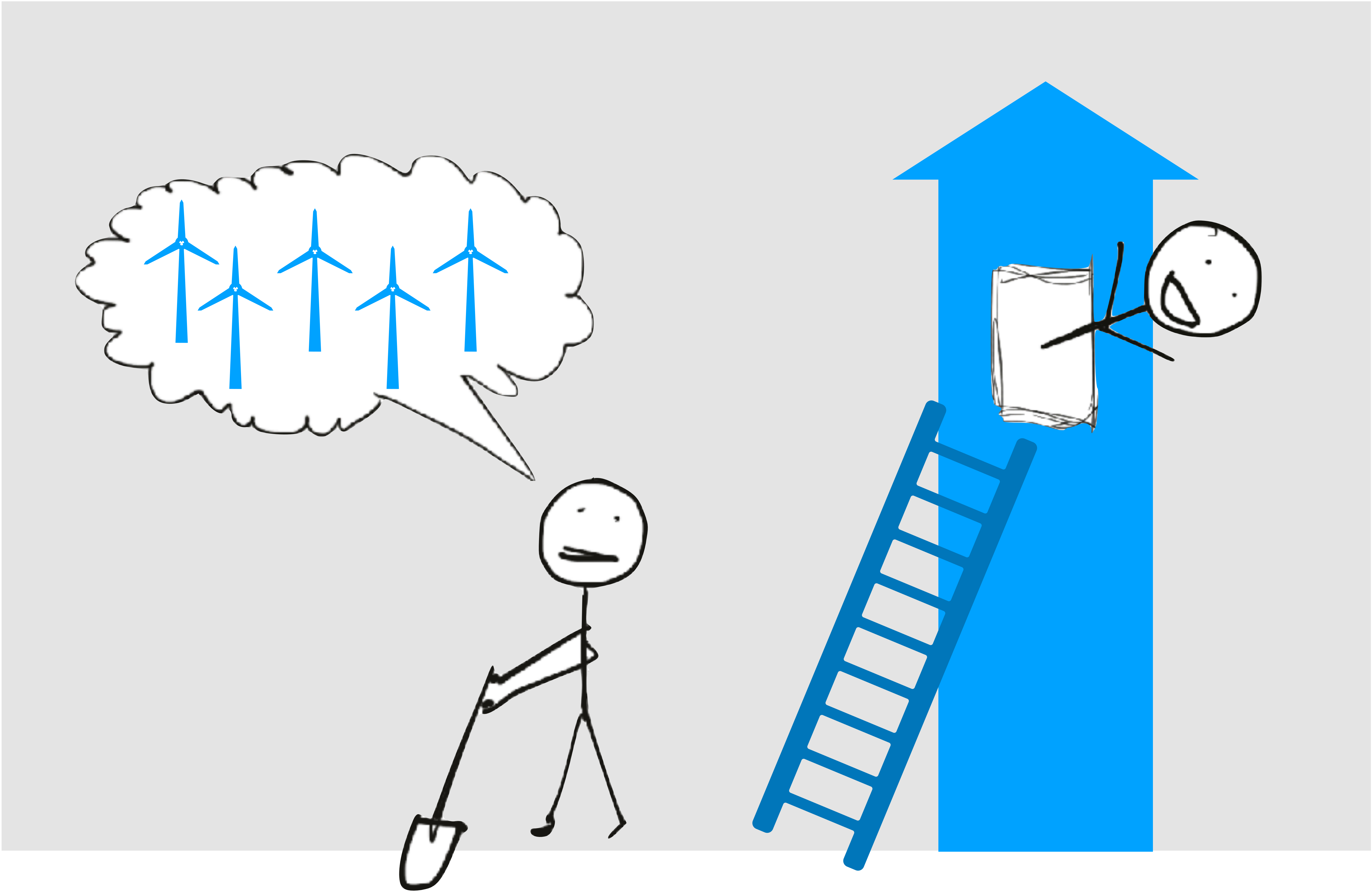
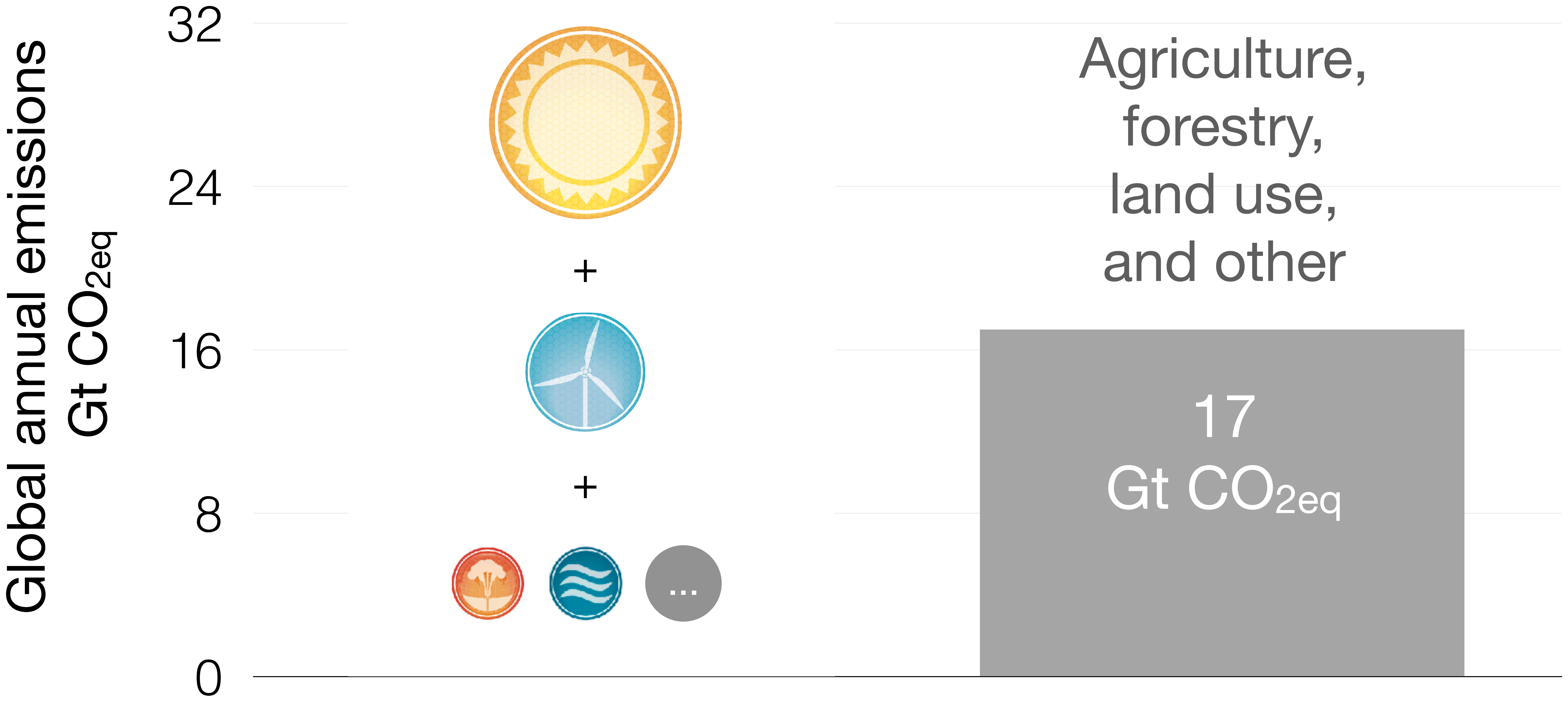


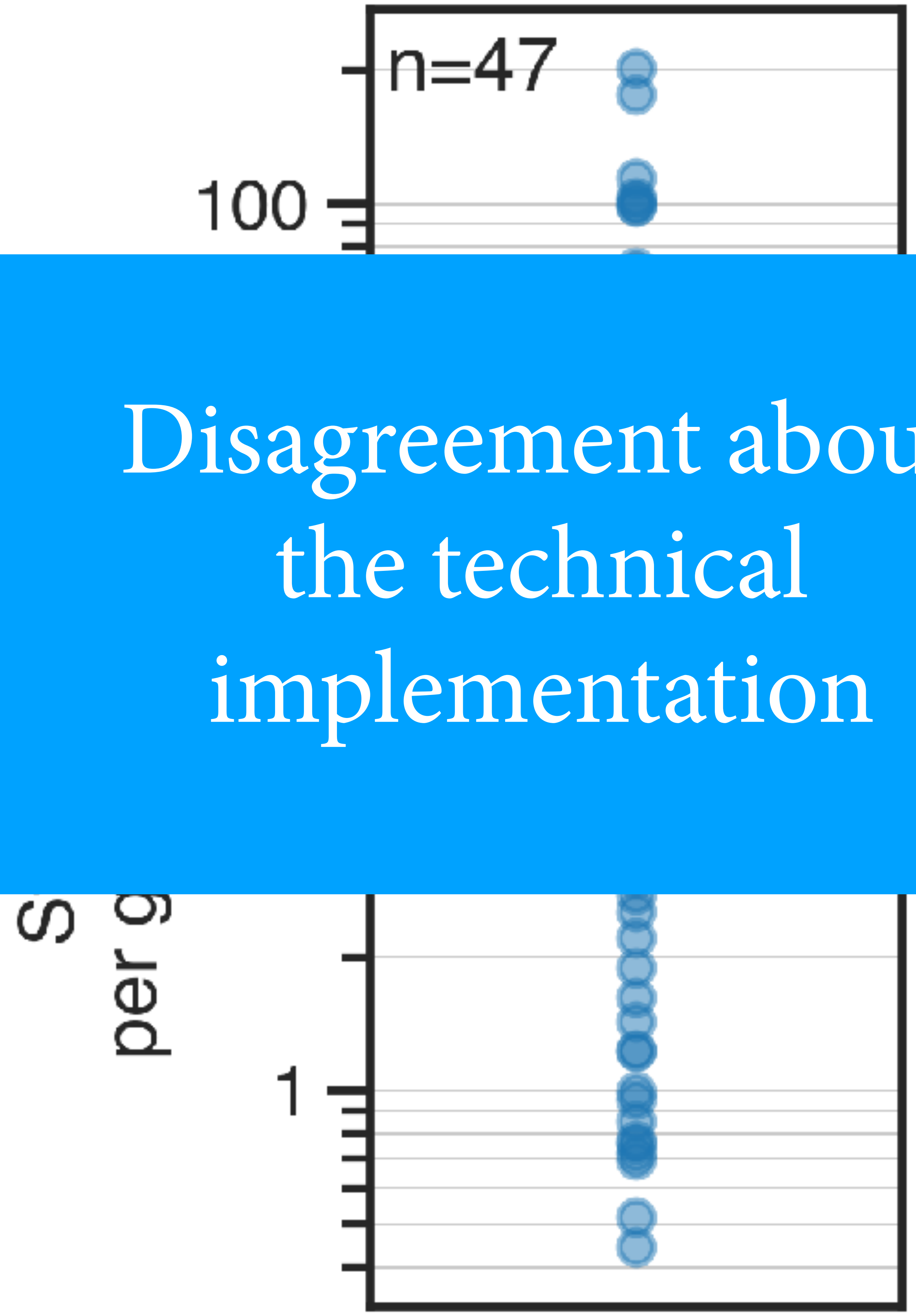
EPSRC Supergen Energy Networks Hub
22 April 2021

Eliminating energy emissions is urgent



IPCC (2014), AR5 WG3 Chapter 5, pp.354-355
Cho (2010). *Science*

No agreement on how to proceed

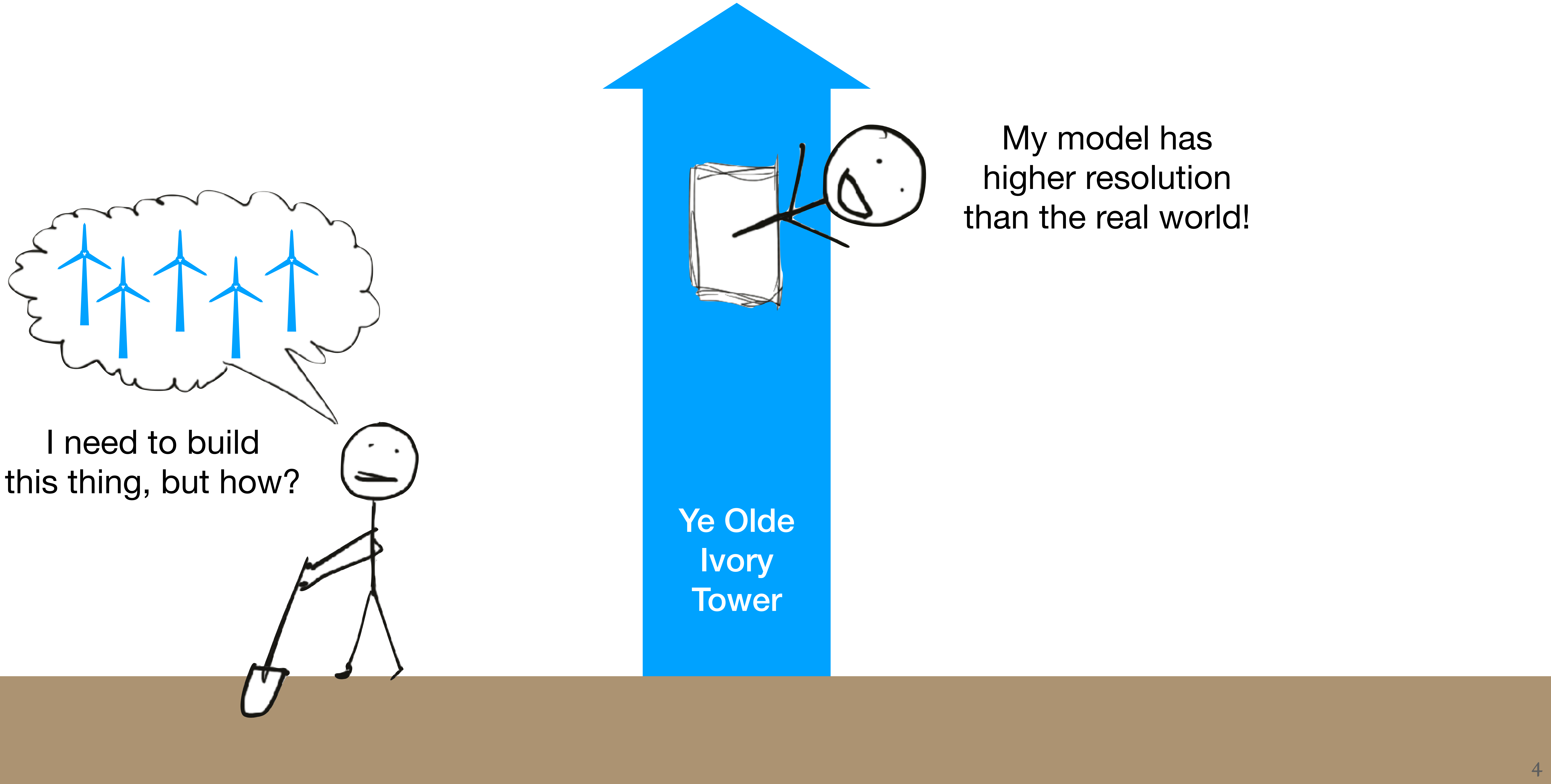


Disagreement about the technical implementation

Disagreement about what is socially and politically acceptable

Huber, Heeren and Pfenninger (in review). *Environmental Science and Technology*   www.svp-dottikon.ch/media/Kant-_Nationale_SVP_ab_2016/Abstimmung_2017_05_21_Energie-Ztg.pdf

Energy system modelling



Ladders of practicality

Answering scientific questions
that are also policy relevant

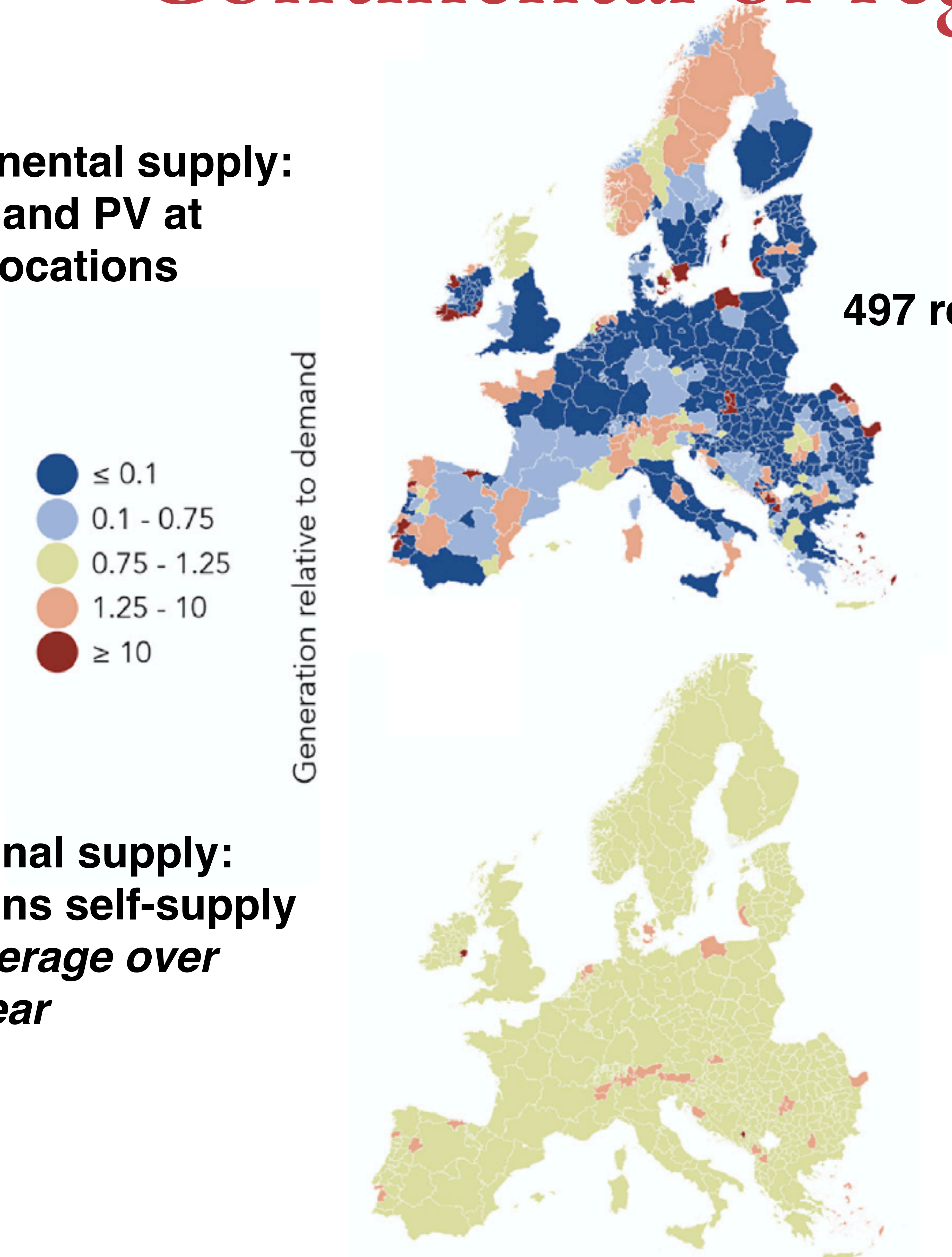
Self-sufficiency in policy discussions

"Davos is aiming to become energy self-sufficient by 2036."
– https://www.davos.ch/en/information/meeting-place/industry-focal-points/energy/environment

"We [the UK] can make ourselves energy self-sufficient in renewable energy."
– https://www.bbc.com/news/election-2017-40120184

Continental or regional scale supply?

Continental supply: Wind and PV at best locations



497 regions

Regional supply: Regions self-supply *on average over the year*

Continental supply requires 2.5x the capacity of today's electricity transmission system

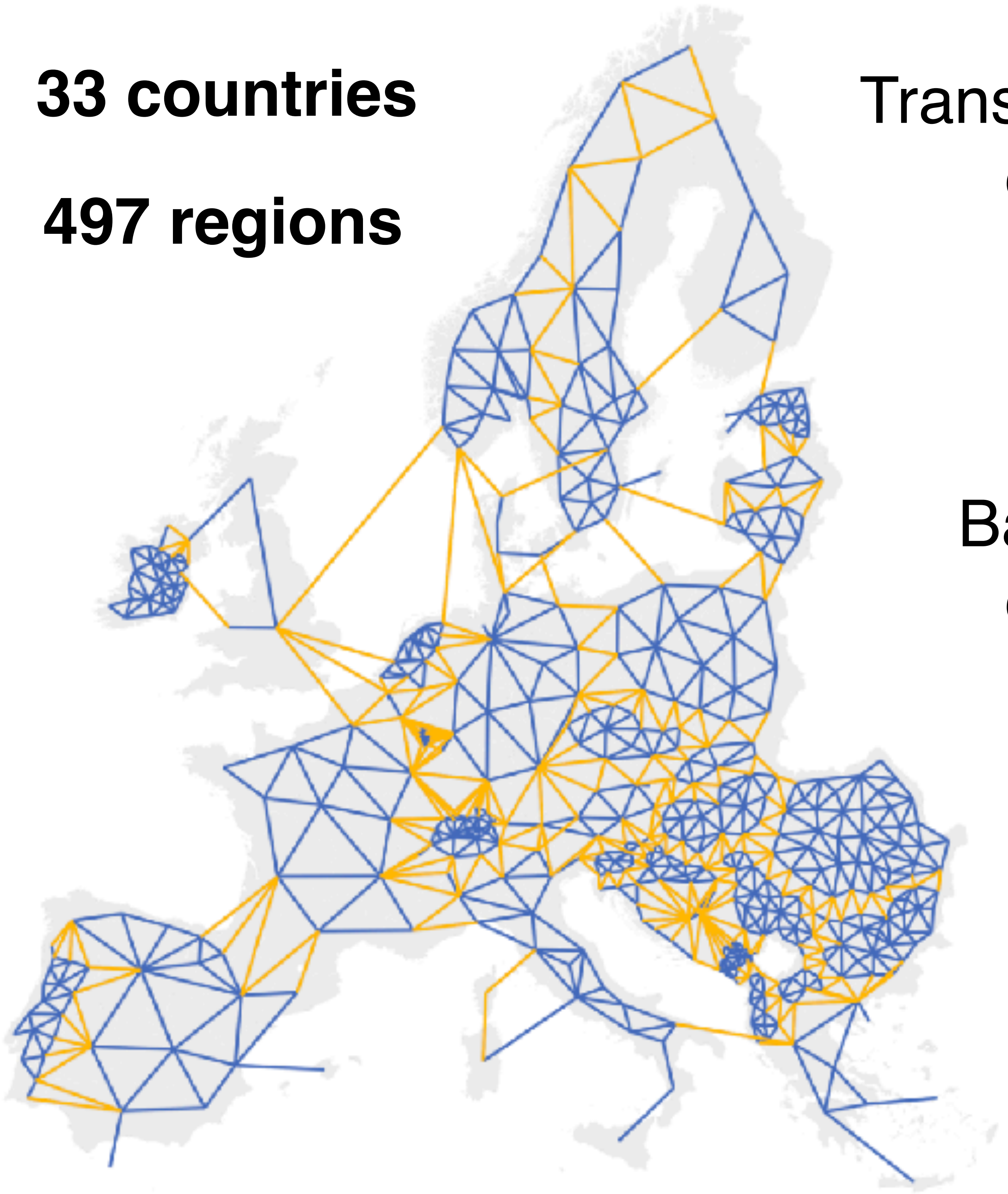
What if I don't want to build so many new transmission lines?

Tröndle et al. (2020). *Joule*. https://doi.org/gg8zk2

Less integrated systems are possible, but cost more

33 countries

497 regions



	Continental	**Countries self-sufficient on average**	**Regions self-sufficient on average**	**Countries cut off**	**Regions cut off**
Transmission capacity	100%	120%	80%	50%	0%
Balancing capacity	100%	116%	121%	138%	151%
Cost	100%	107%	122%	140%	170%

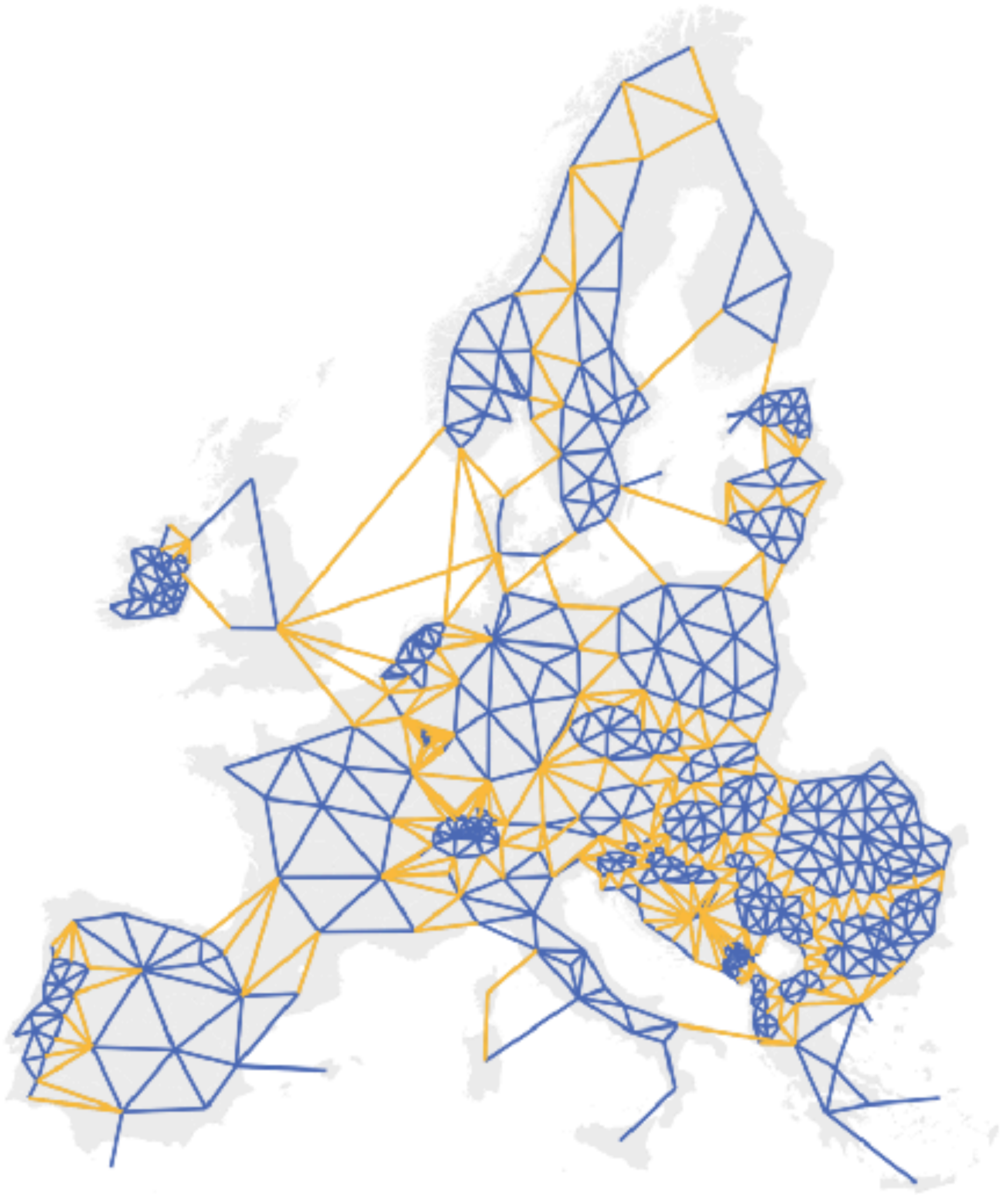
Tröndle et al. (2020). *Joule*. https://doi.org/gg8zk2

Tim Tröndle

How did we model it?

Euro-Calliope v1.0

Spatial resolution



497 first-level administrative units

Technologies

- PV
- Wind
- Biofuel
- Hydro
- Short and long-term storage

Temporal resolution

4 hours, single year, 2007–2016

Sensitivity analysis

- 10 weather years
- Uncertainty in technology costs, capital cost, bioenergy availability (by sampling a surrogate model)

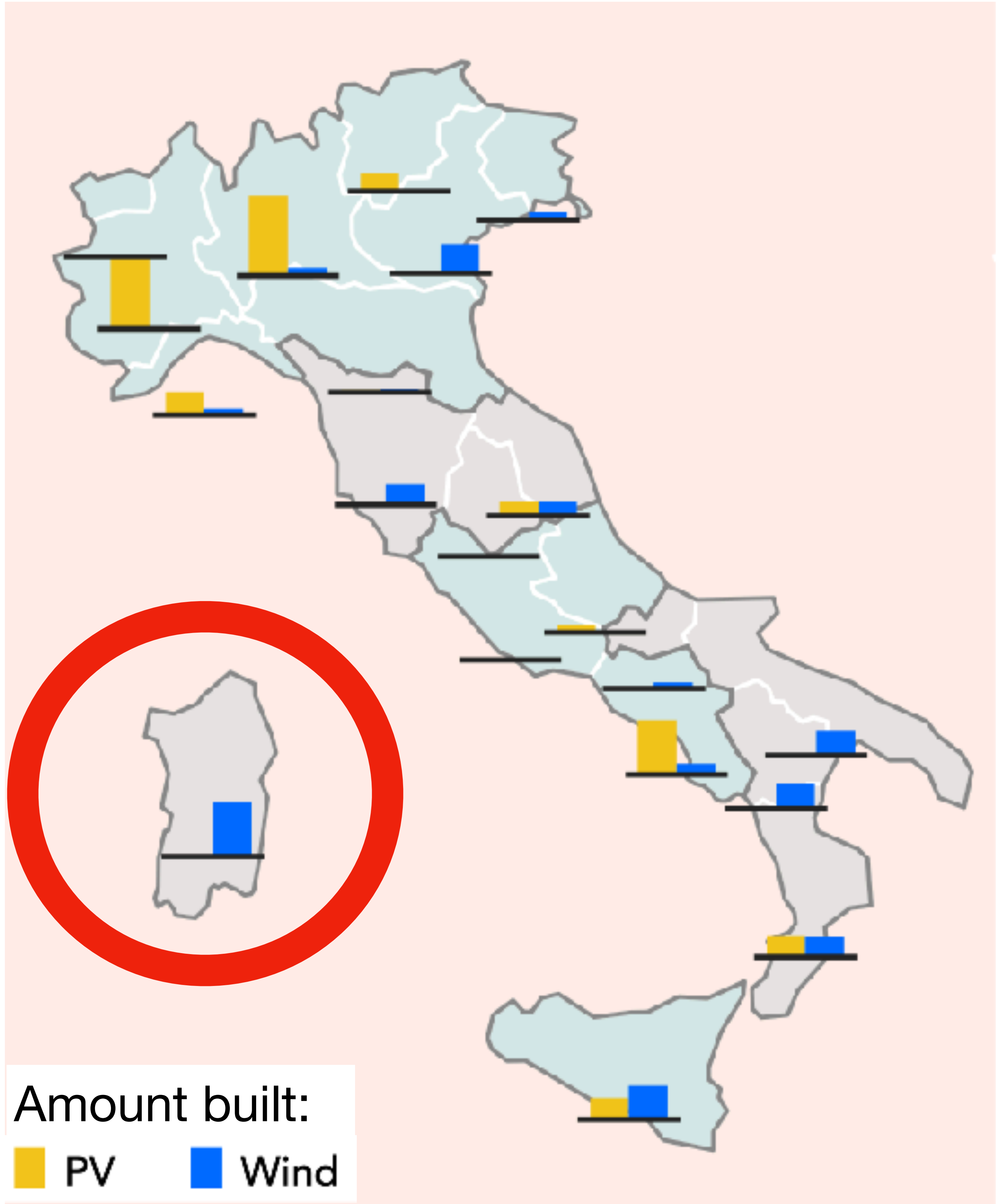
Reproducible workflow

github.com/calliope-project/euro-calliope

Tröndle et al. (2020). *Joule*. https://doi.org/gg8zk2

Going beyond cost minimisation

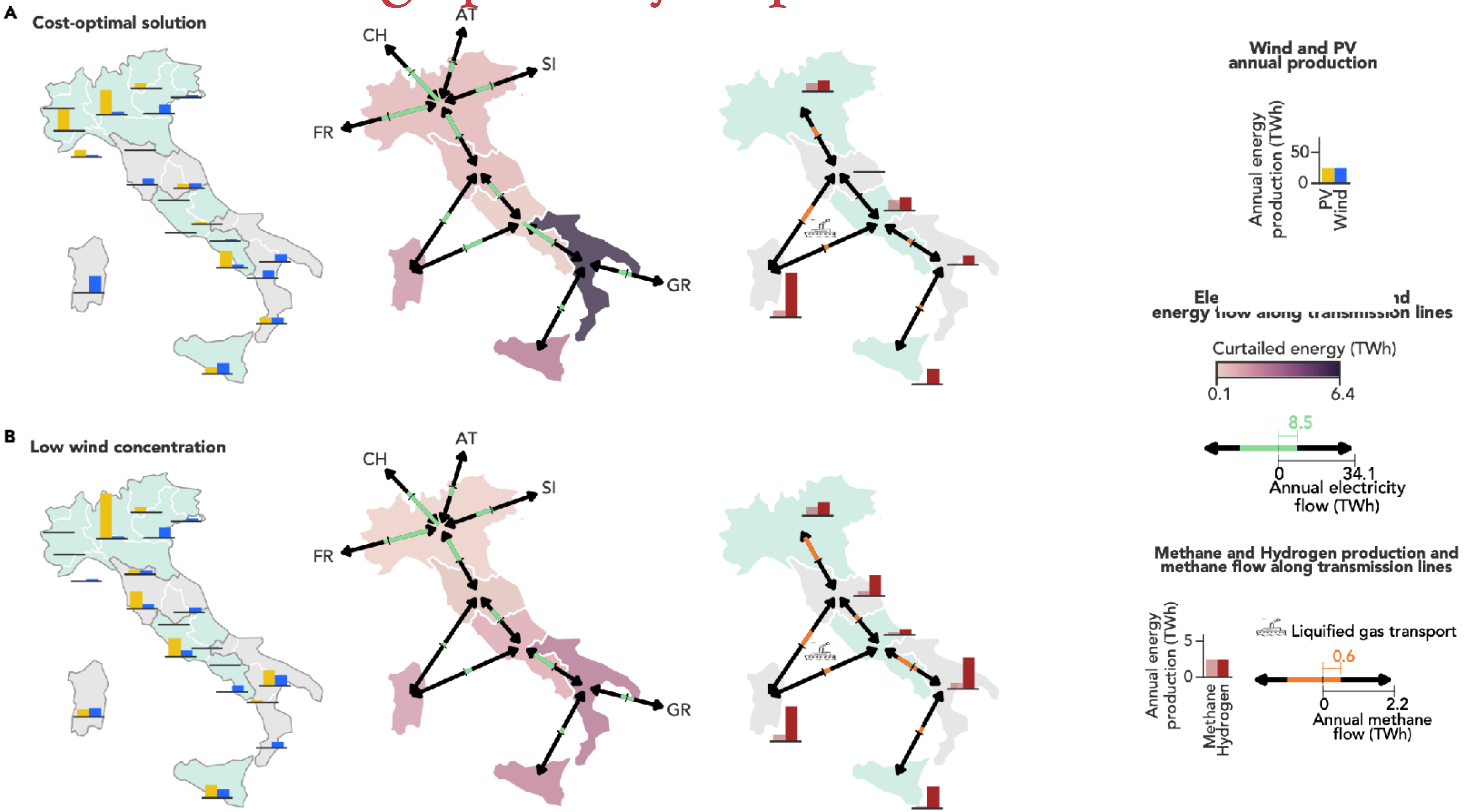
Cost-optimal deployment
of wind and PV across Italy



"Don't worry, the Sardinian people are
used to all the oil refineries, they will be fine"

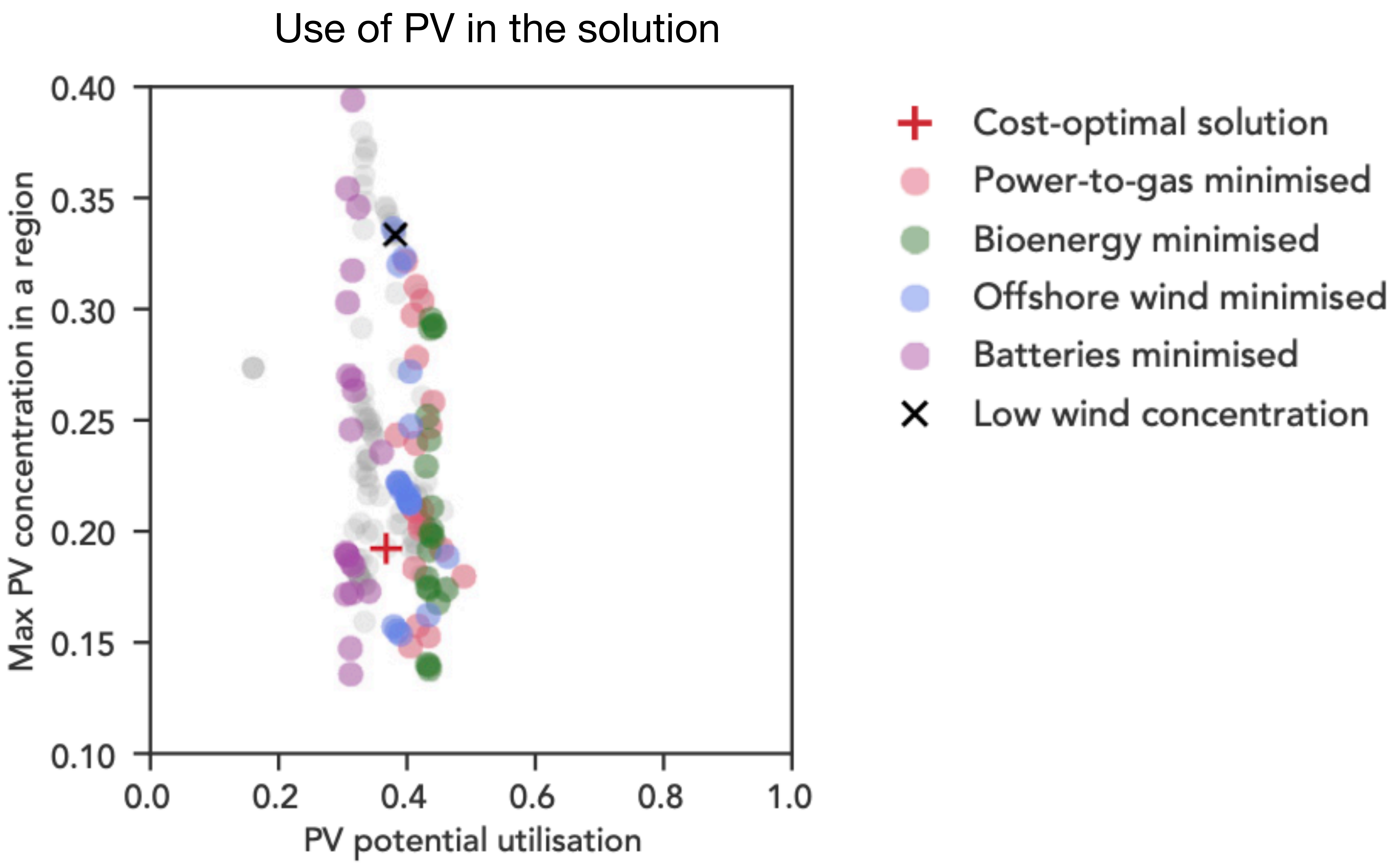
Lombardi et al. (2020). *Joule*. https://doi.org/gg8z6v

Finding spatially explicit alternatives



Lombardi et al. (2020). *Joule*. https://doi.org/gg8z6v

Potentially problematic technologies



Lombardi et al. (2020). *Joule*. https://doi.org/gg8z6v

Francesco Lombardi

How did we model it?

Calliope-Italy and the SPORES method (https://github.com/FLomb/Calliope-Italy)

Repeat

Repeat

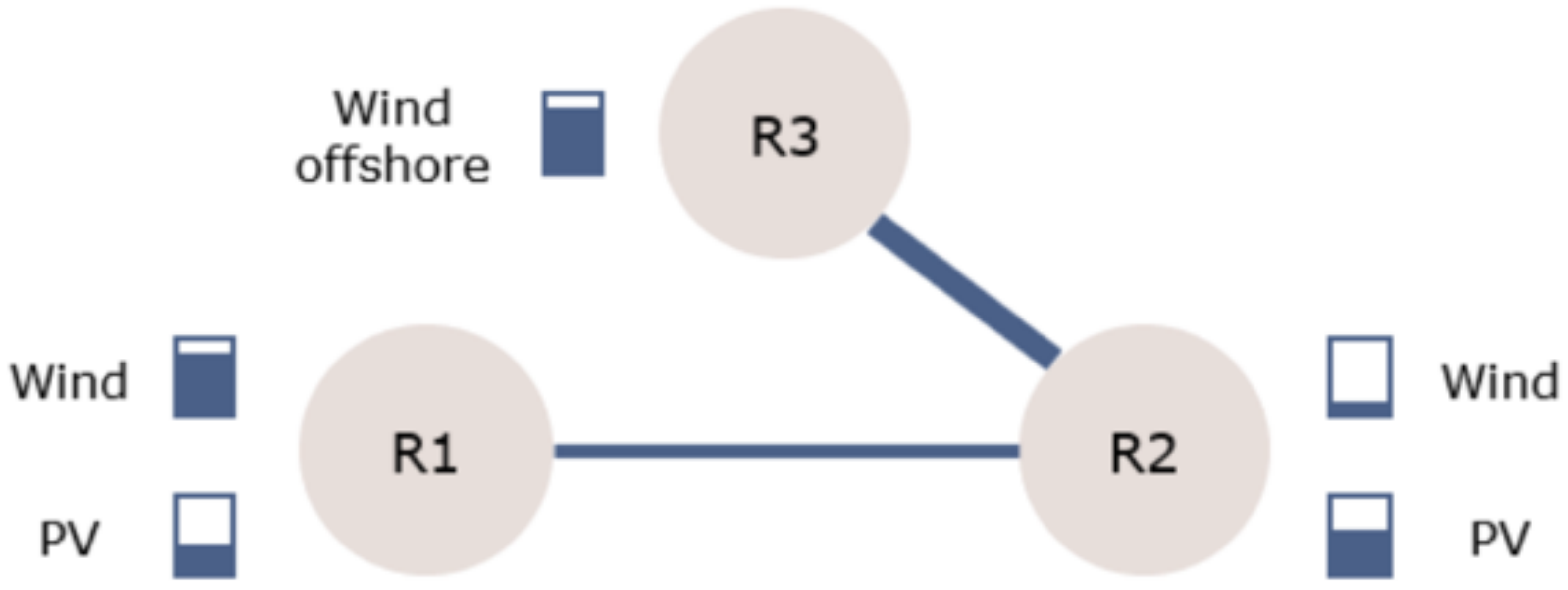
Find optimal solution → Set / update weights → Re-run with new objective 1 → Reset / update weights → Re-run with new objective 2 → 100s of diverse solutions

min cost

min sum of weighted capacity decisions
while keeping cost within n% of optimum

also minimise the use of specific technologies

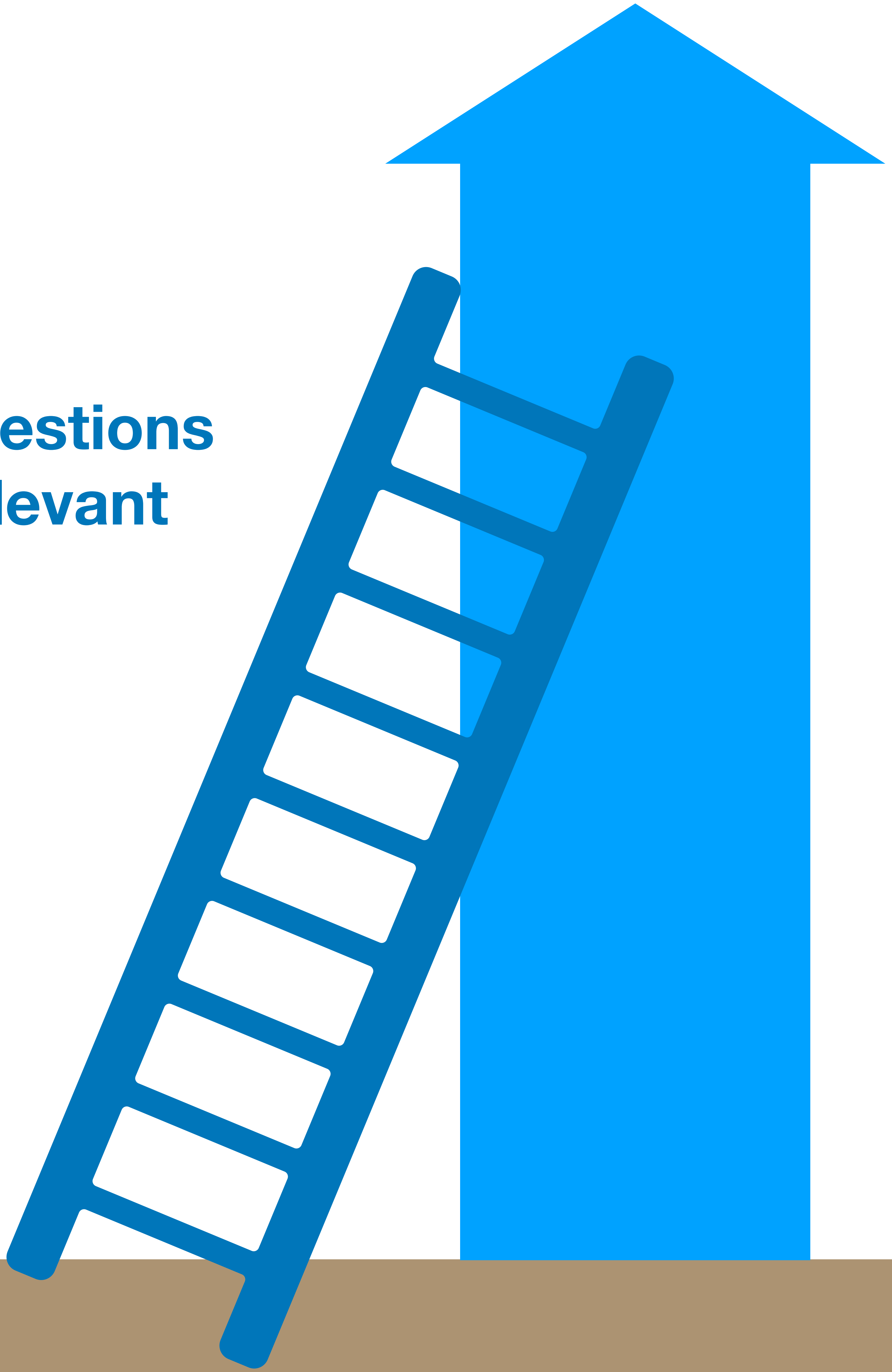
We call them SPORES



Weights: ratio between capacity of technology at a given location to its maximum capacity at that location
→ The more of something there is, the higher its weight

Lombardi et al. (2020). *Joule*. https://doi.org/gg8z6v

Ladders of practicality



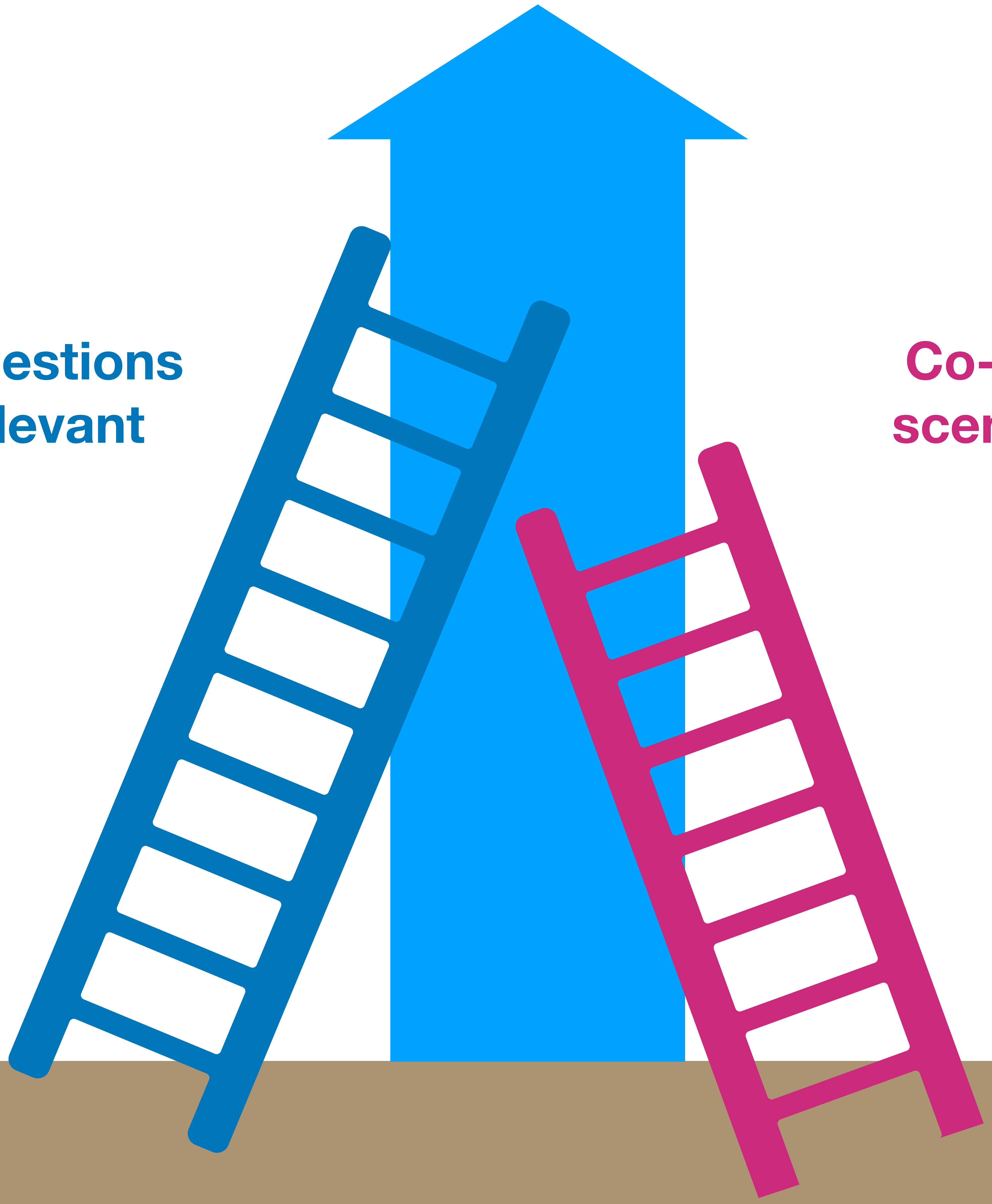
Answering scientific questions that are also policy relevant

The “loading dock” approach

Cash et al. (2006). *Science, Technology, & Human Values*. https://doi.org/drtgjc

Ladders of practicality

Answering scientific questions that are also policy relevant



Co-producing model-based scenarios directly with users

Getting models and decision-makers in the same room

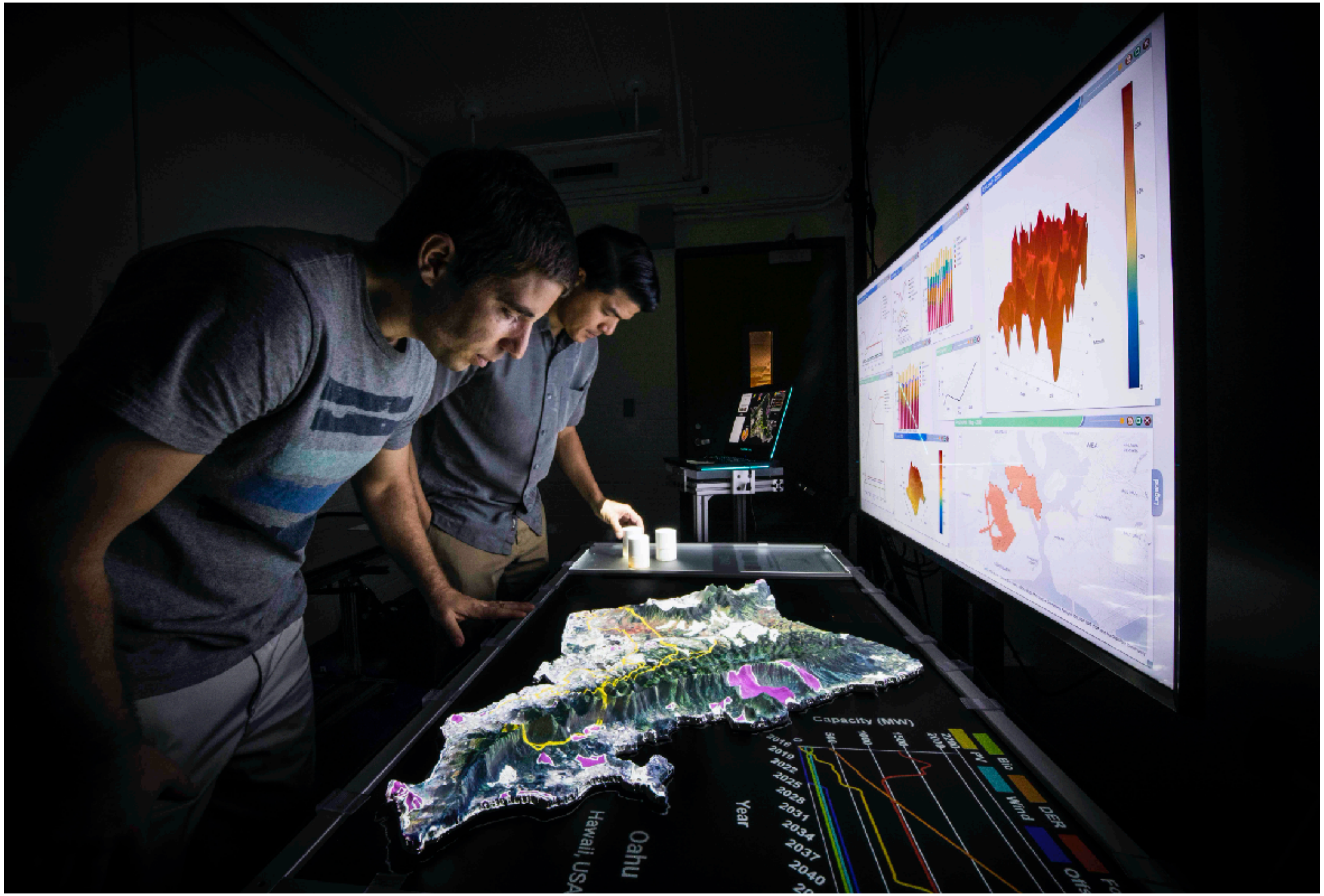


Photo © NREL

NREL ENGAGE, https://engage.nrel.gov/

Also see our own spin on this kind of approach in the European context, in the SEEDS project: https://www.chistera.eu/projects/seeds

How did they model it?

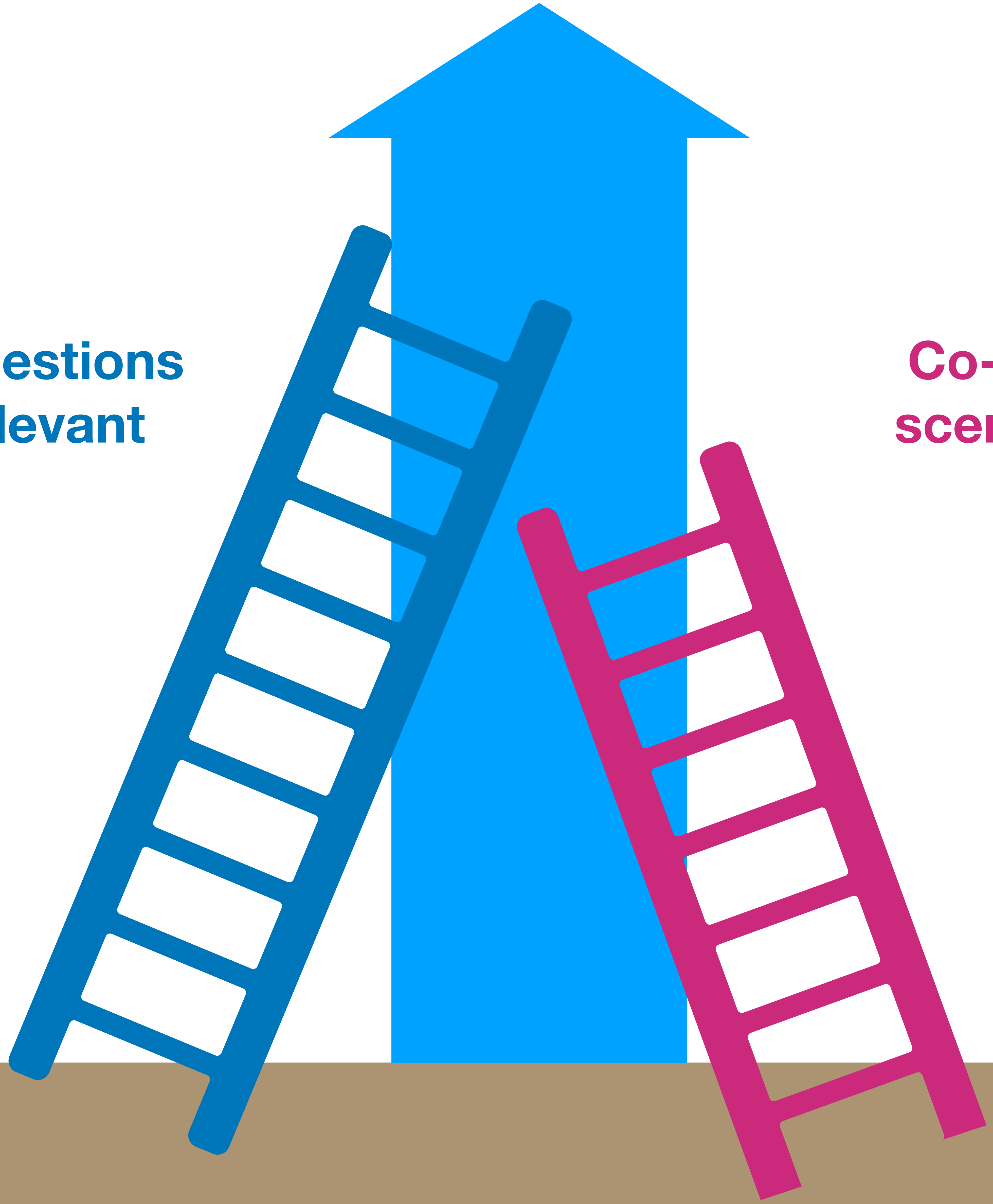
Calliope

ENGAGE modelling interface

HAVEN visualisation tool

What kinds of models help to build ladders?

Answering scientific questions that are also policy relevant



Co-producing model-based scenarios directly with users

How are models made?

- Assumptions in energy system models reflect and reproduce societal and scientific discourses (often implicitly)

Example 1 - Classification: Including or excluding certain technologies like CCS, nuclear power, or biomass.

Example 2 - Problem definition: If climate change is a market failure to account for externalities, then a carbon price is the solution.

- One should not ask: "Are the assumptions correct?"
- Instead one should ask: "What do the assumptions represent?"

Ellenbeck and Lilliestam (2019). *Energy Research & Social Science*. https://doi.org/10.1016/j.erss.2018.08.021

How are models used?

- Impact assessment
- Target setting
- Policy options design

Modelling

Policymaking

- Data and assumptions
- Study scope
- How results are used

Süsser et al. (2021). *Energy Research & Social Science*. https://doi.org/10.1016/j.erss.2021.101984

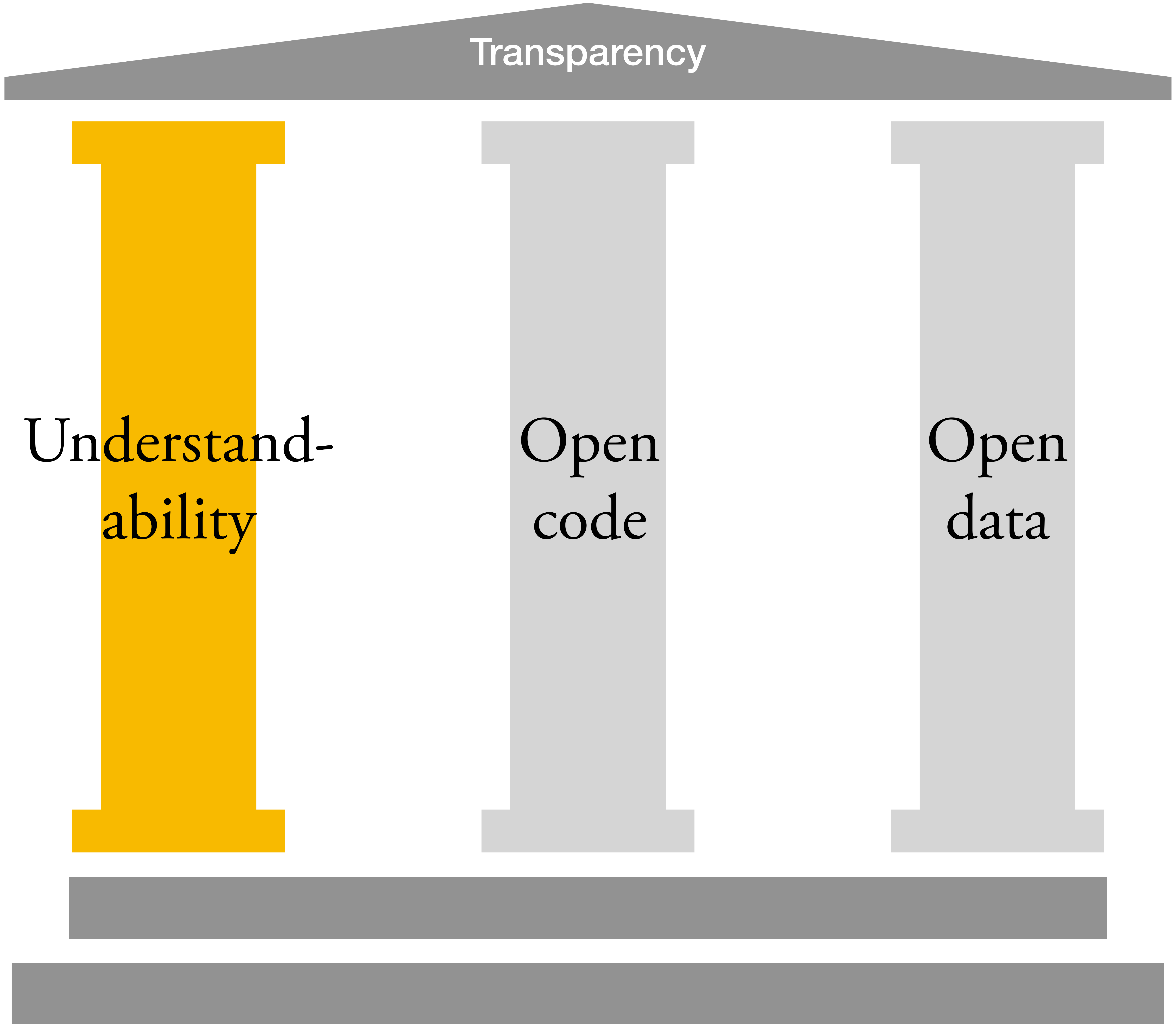
The SENTINEL project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 837089.

SENTINEL
www.sentinel.energy

Transparent is better than obscure

```
ccgt:
    essentials:
        name: 'Combined Cycle Gas Power Plant'
        color: '#FDC97D'
        parent: 'supply'
        carrier_out: 'electricity'
    constraints:
        resource: inf
        energy_cap_max: 40000  # kW
        energy_ramping: 0.8
    costs:
        monetary:
            energy_cap: 750  # USD per kW
            om_con: 0.02  # USD per kWh
```

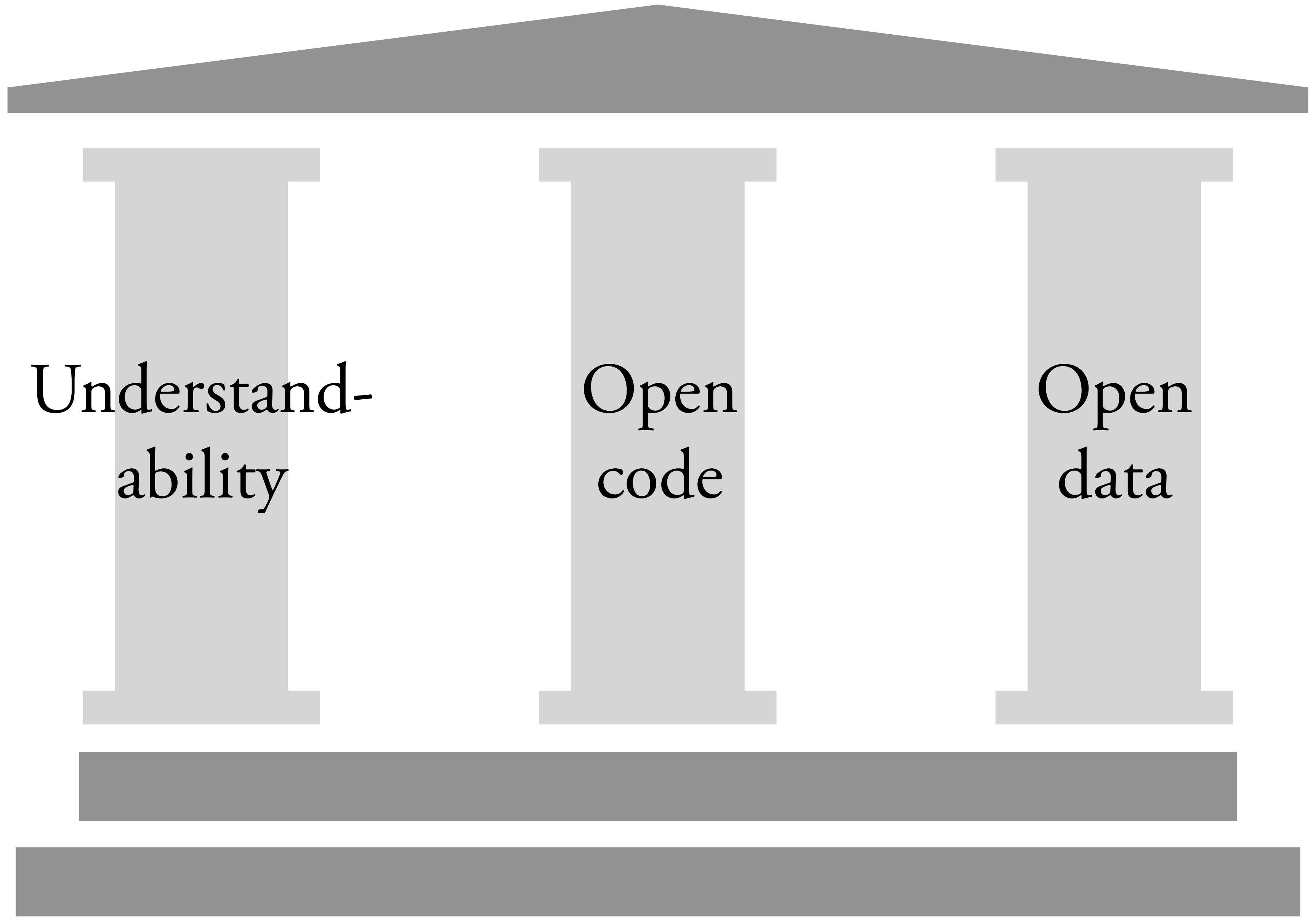
Human readability of energy models is one of Calliope's design goals

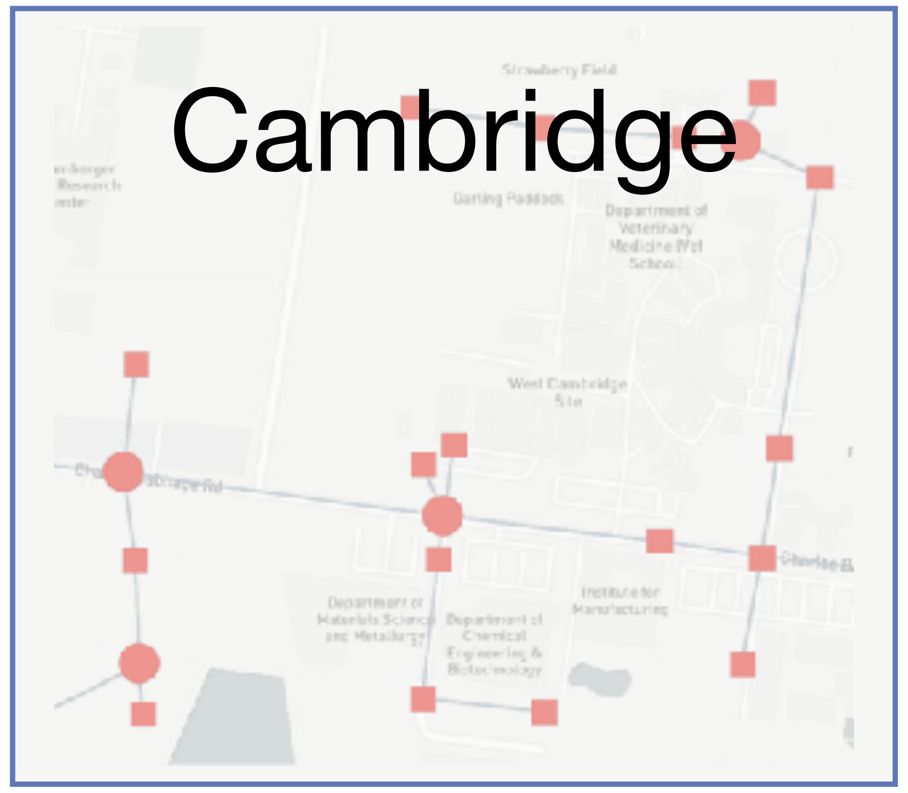


https://www.callio.pe/

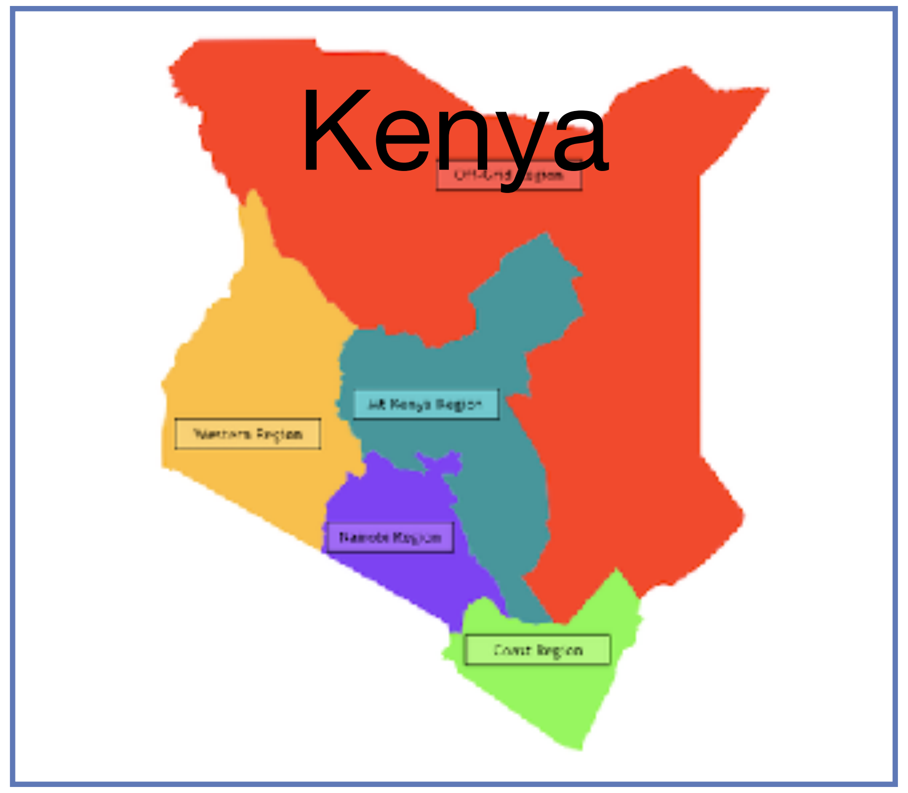
Simple is better than complex

Making it easy to build question-specific models is one of Calliope's design goals





Design a district energy system under high demand uncertainty



Impact assessment of policies for the Kenyan coffee sector

Pickering and Choudhary (2019). *Applied Energy*. https://doi.org/10.1016/j.apenergy.2018.12.037
Golinucci et al. (2020), FEEM Working Paper. https://dx.doi.org/10.2139/ssrn.3733717

What

Ideally, energy system modelling answers scientific questions that are also policy relevant

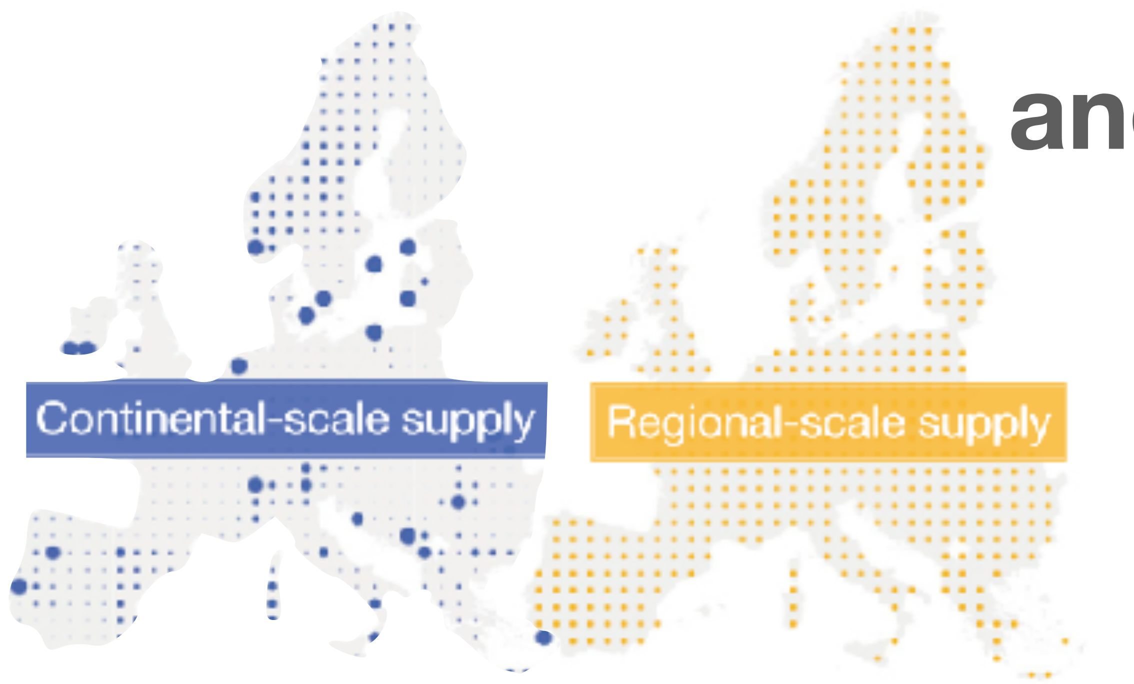
Energy system models lend themselves to being used directly in the co-production of scenarios with users

How

Transparency:
Open code and data are not enough, implicit underlying assumptions need to be communicated too

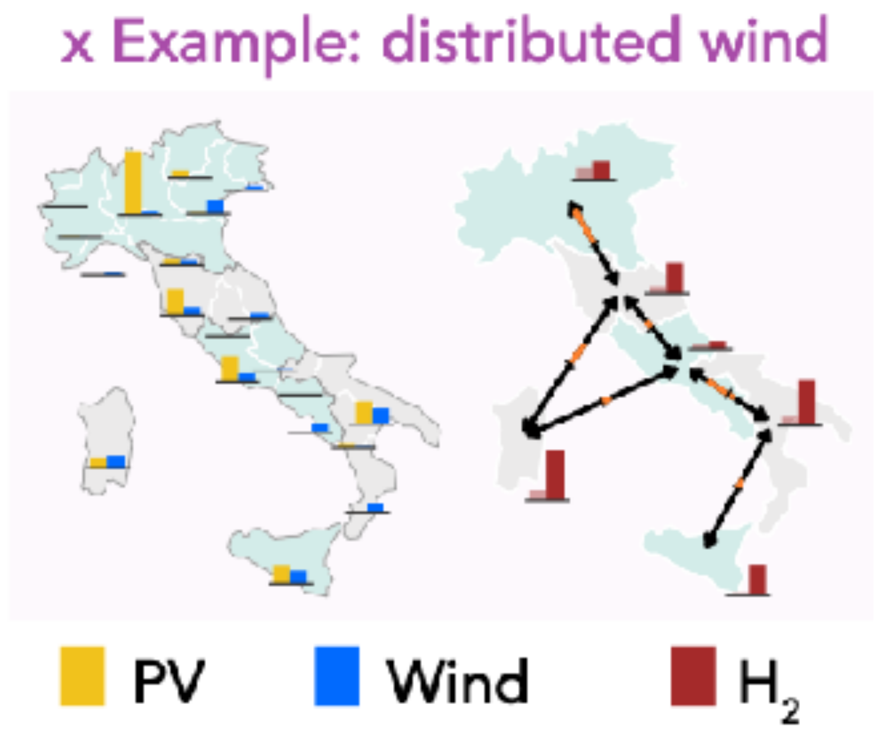
Simplicity:
Simpler, human readable models make the task of understanding these underlying assumptions easier

Examples



Scale, cost, and infrastructure trade-offs

Tröndle et al. (2020)



Spatially explicit alternatives (SPORES)

Lombardi et al. (2020)

Calliope
www.callio.pe

Thanks to:

Calliope developers including Francesco Lombardi, Bryn Pickering, Tim Tröndle

Collaborators including Diana Süsser, Johan Lilliestam, Anthony Patt

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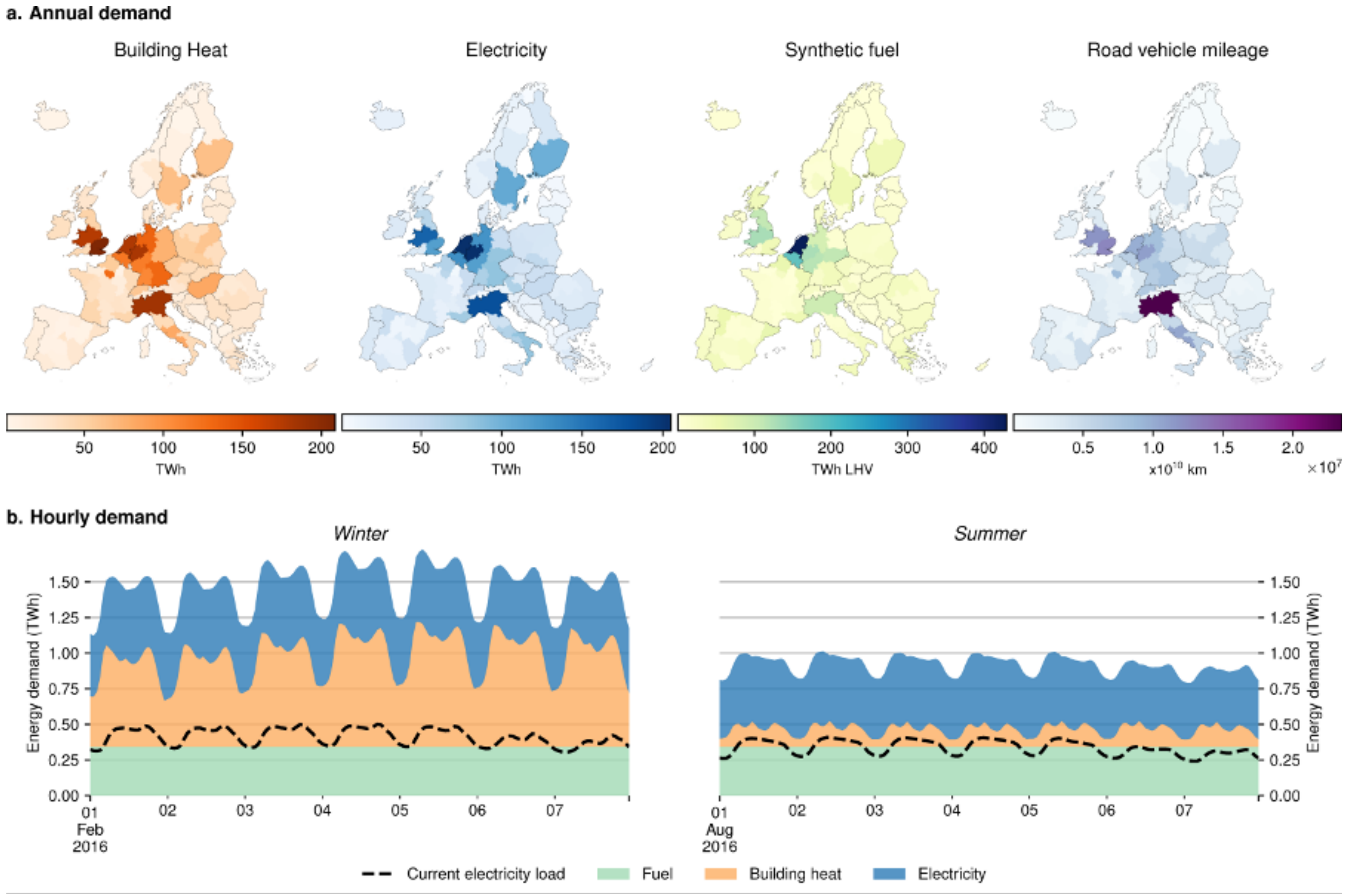
Euro-Calliope v2.0

A model of the European energy system built with Calliope

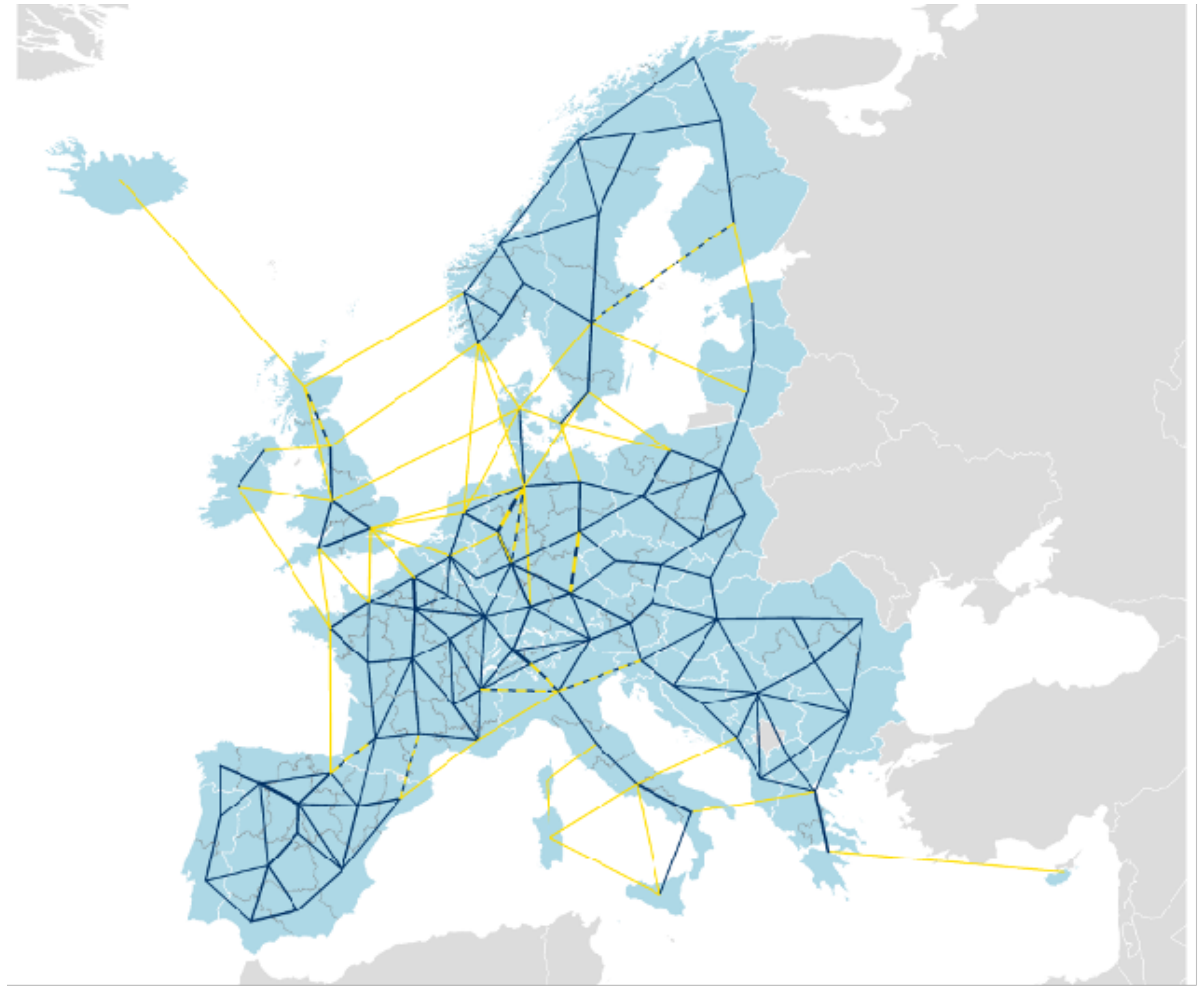


Euro-Calliope v2.0

A model of the European energy system built with Calliope

Research focus: choices and trade-offs in building a 100% renewable all-sector European energy system

- Electricity
- Household and commercial heat
- Passenger and freight transport
- Industry process heat and feedstocks (e.g. for chemicals)



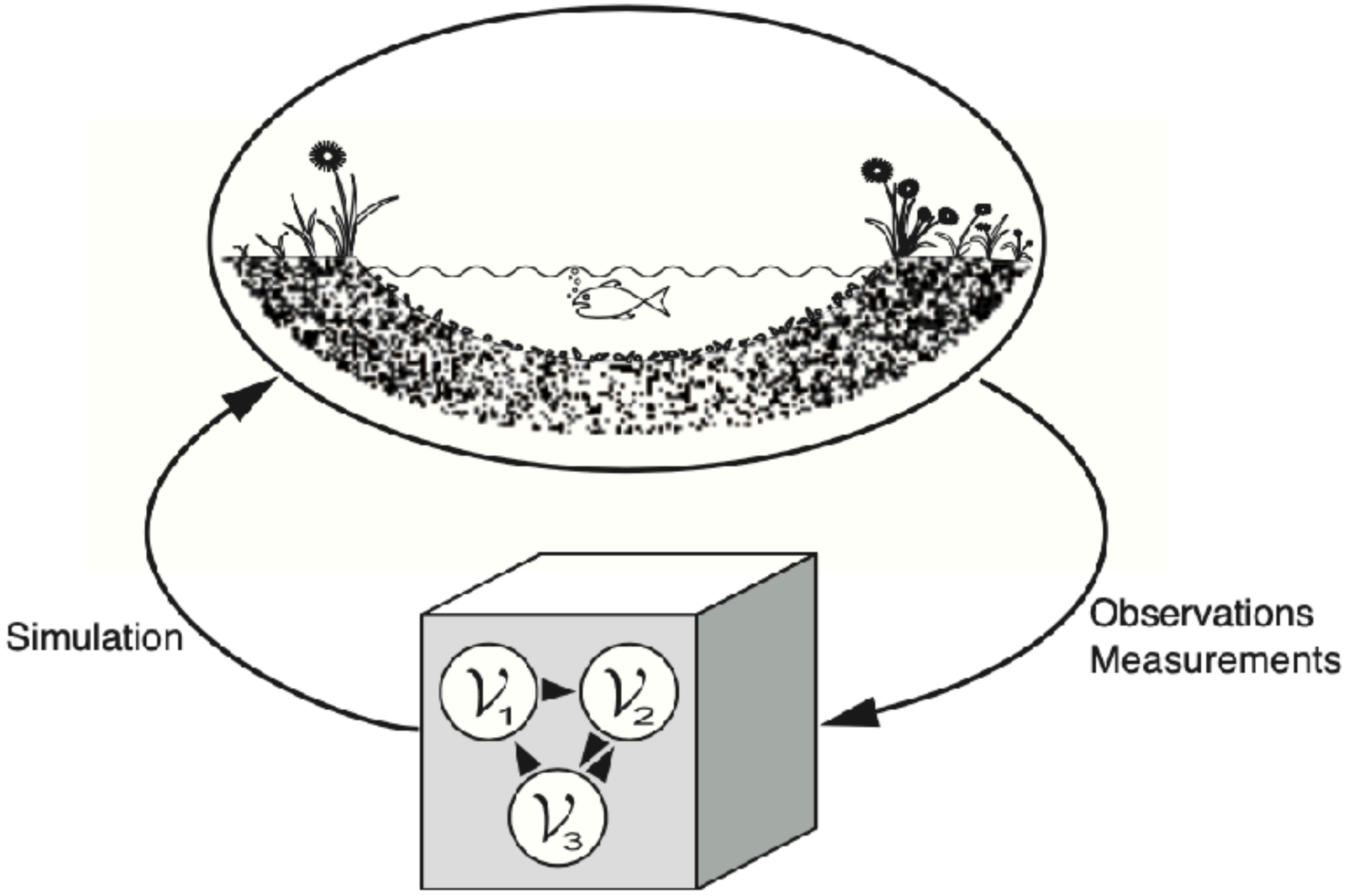
Europe modelled as 98 nodes

- PV and wind
- Hydropower
- Hourly timesteps

https://github.com/calliope-project/euro-calliope

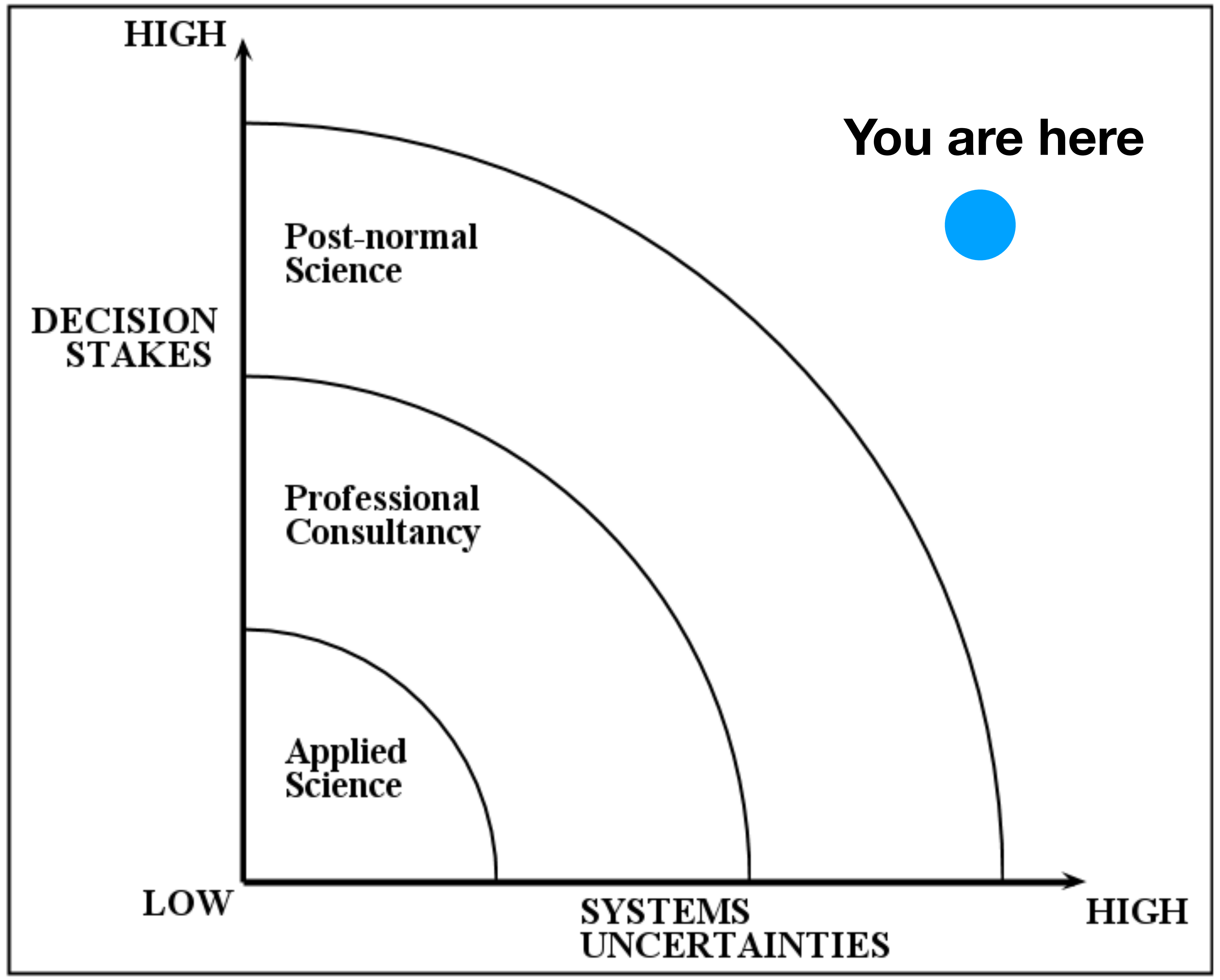
Models

Normal science



Imboden and Pfenninger (2012)

Post-normal science



Funtowicz and Ravetz