# Can energy system models save the world?
# A cautionary tale

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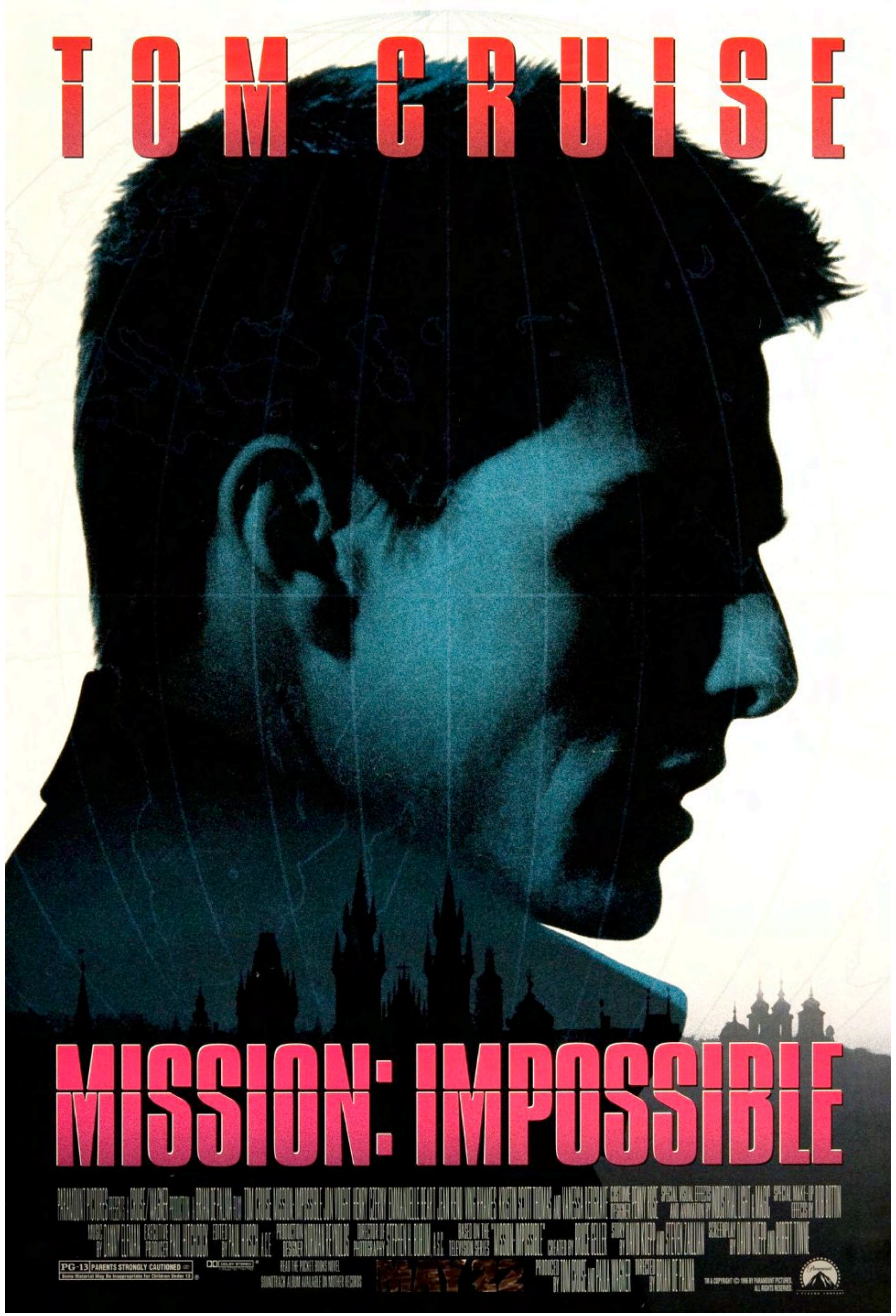
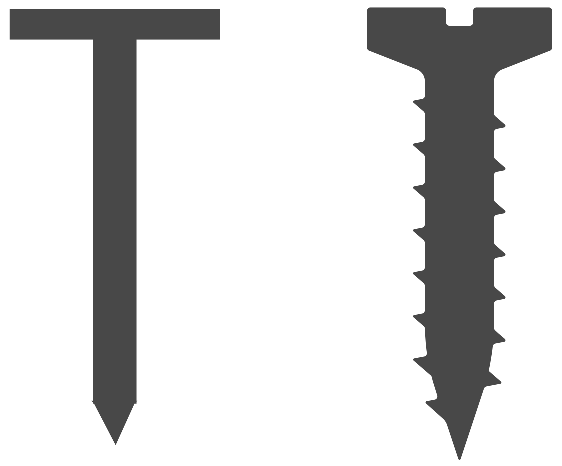
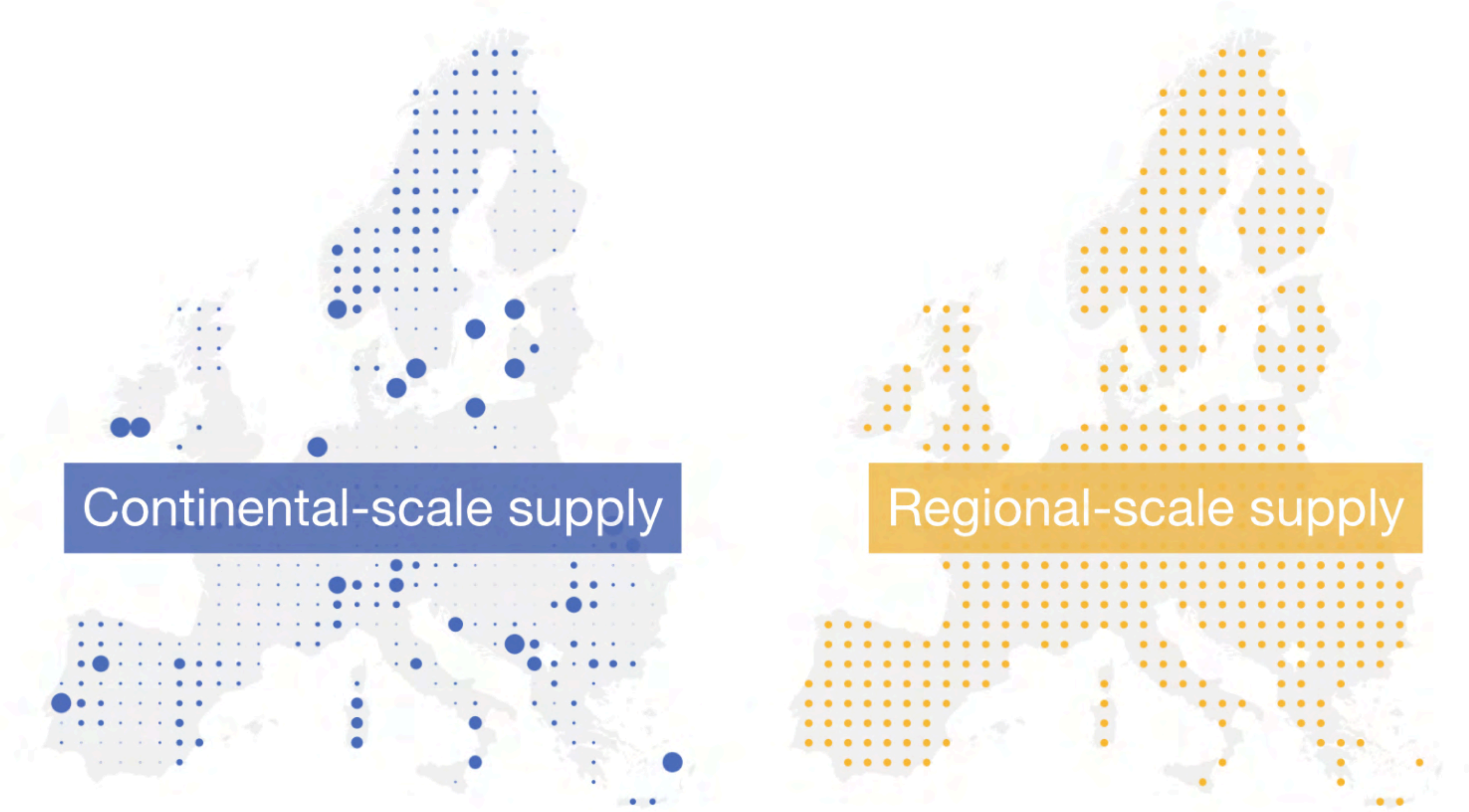

TOM CRUISE
MISSION: IMPOSSIBLE



# The mission:
# Design a feasible climate-neutral energy system

# The tool:
# An energy system model

100% renewable electricity supply at best locations or locally in regions



# Is electricity self-sufficiency viable?

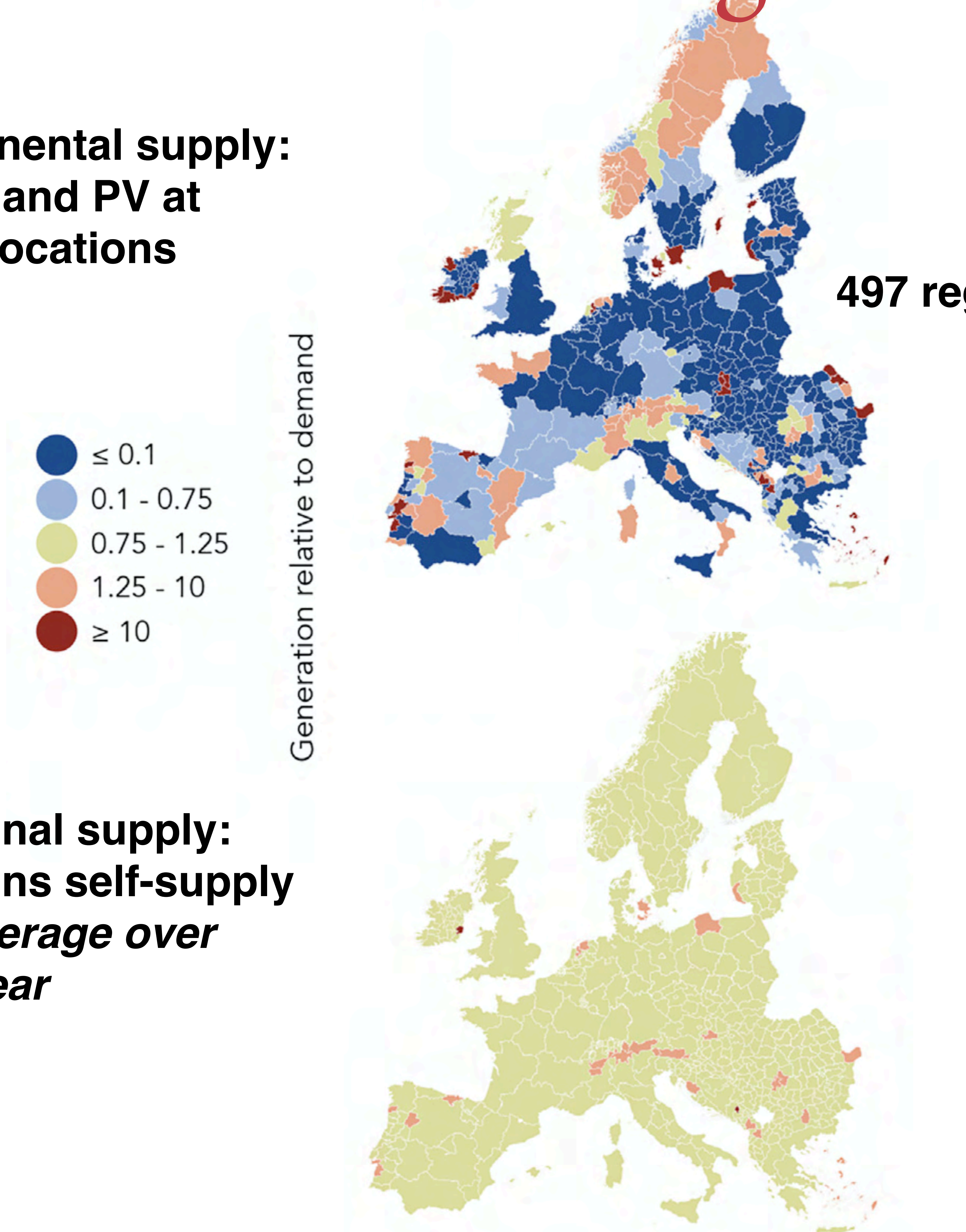
(a slide from 2019 - back with a vengeance)

"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 electricity 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**

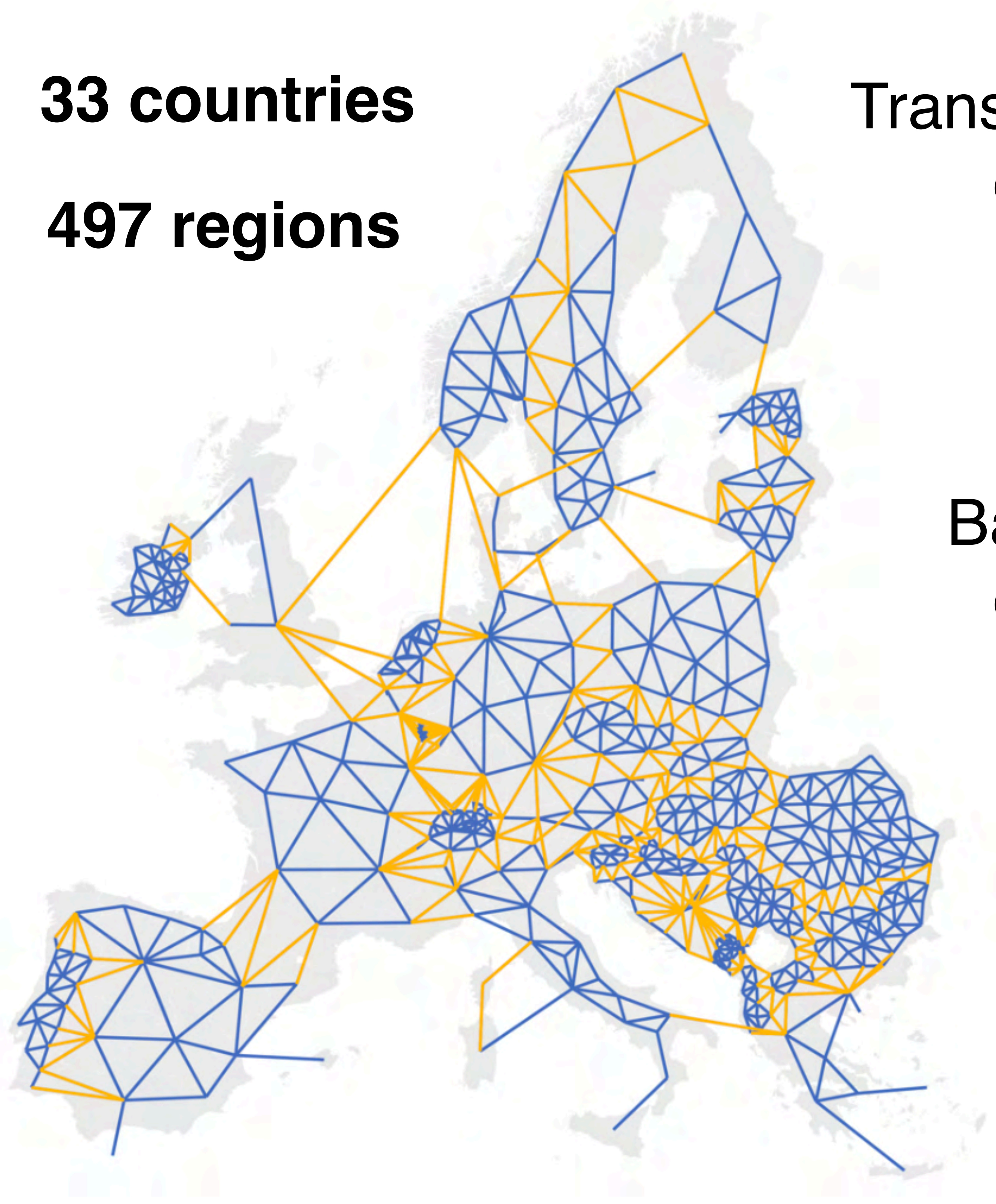
What if I don't want to build so many new transmission lines?

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

# Less integrated systems are possible, but cost more

**33 countries**

**497 regions**



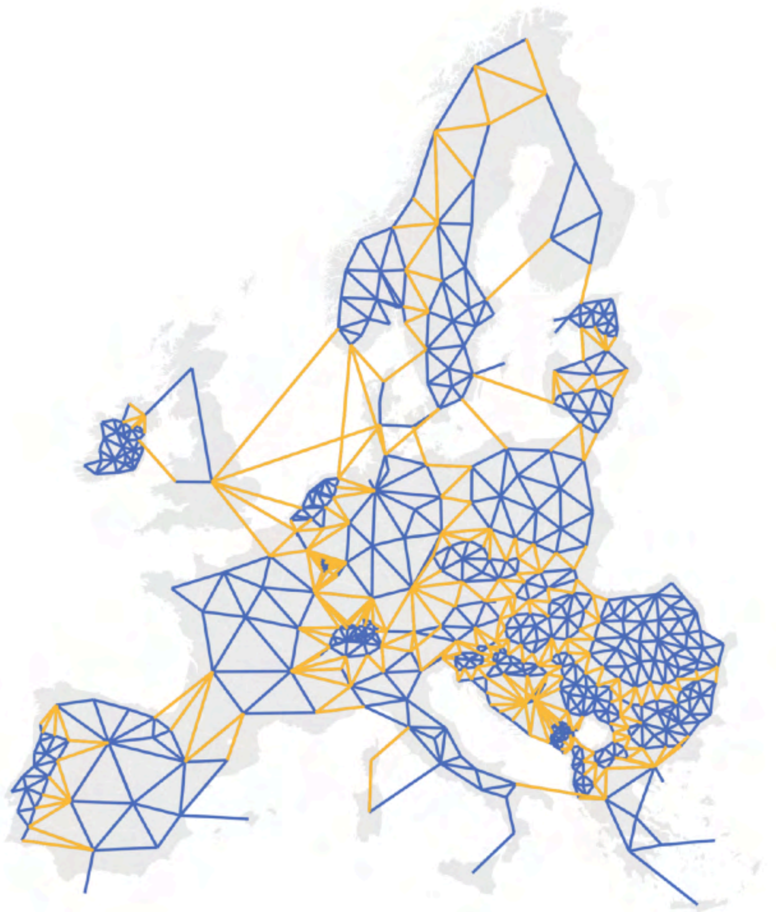
| | Continental | Countries self-sufficient on average | Regions self-sufficient on average | Countries cut off | Regions cut off |
|---|---|---|---|---|---|
| Transmission capacity | 100% | 120% | 80% | 50% | 0% |
| Balancing capacity | 100% | 116% | 121% | 138% | 151% |
| Cost | 100% | 107% | 122%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

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

# Underlying model: Euro-Calliope, power system only

Tim Tröndle

**Spatial resolution**



497 first-level administrative units

**Technologies**

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

**Sensitivity analysis**

- 10 weather years
- Uncertainty in technology costs, capital cost, bioenergy availability
- Sampling a surrogate model

**Objective function**

Minimise total system cost

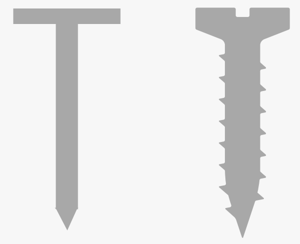
**Temporal resolution**

4 hours, single year, 2007–2016

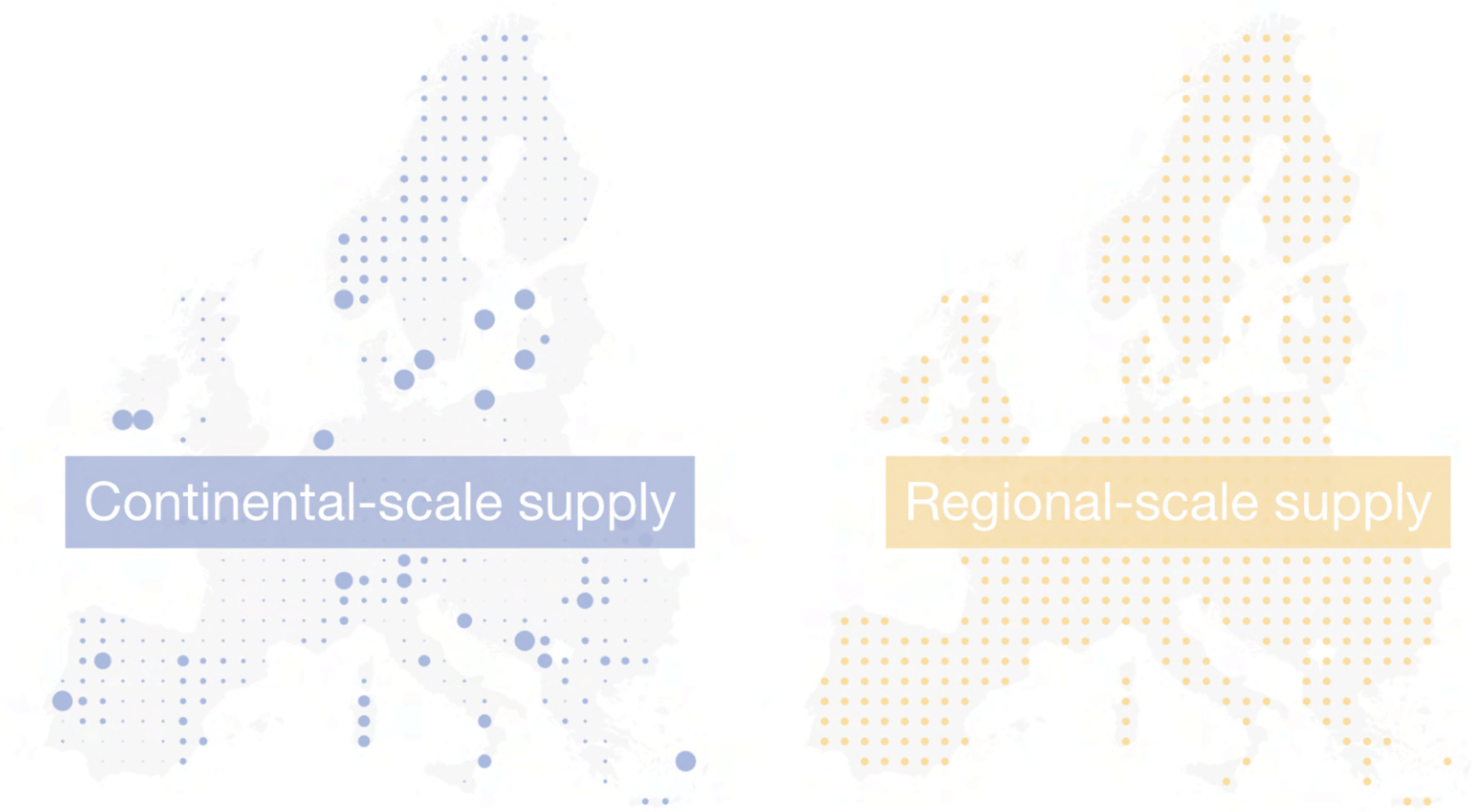
**Fully open + reproducible**

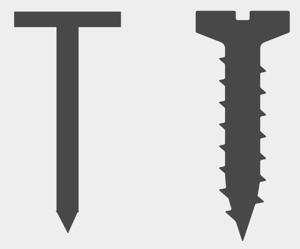
github.com/calliope-project/euro-calliope

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

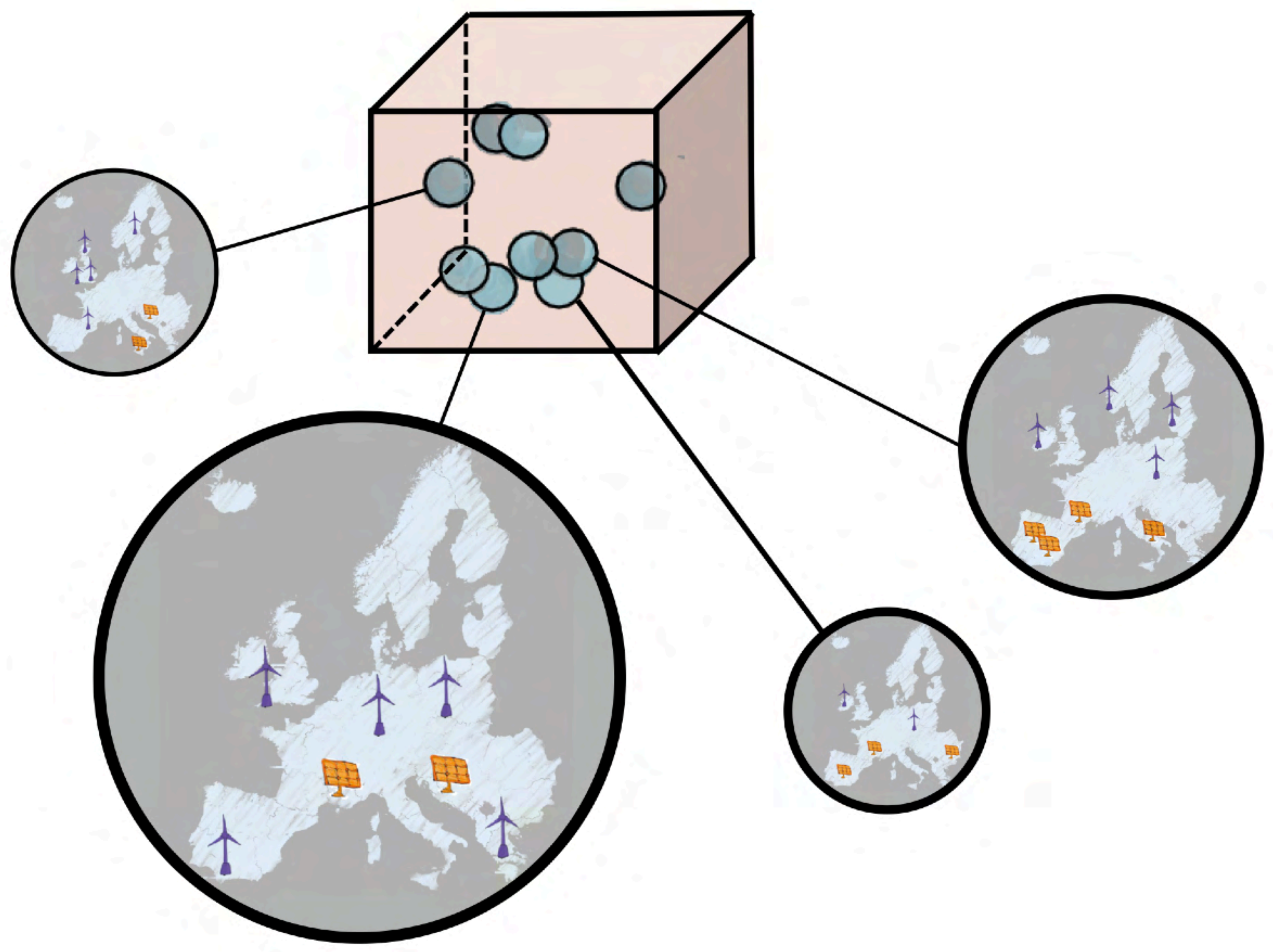


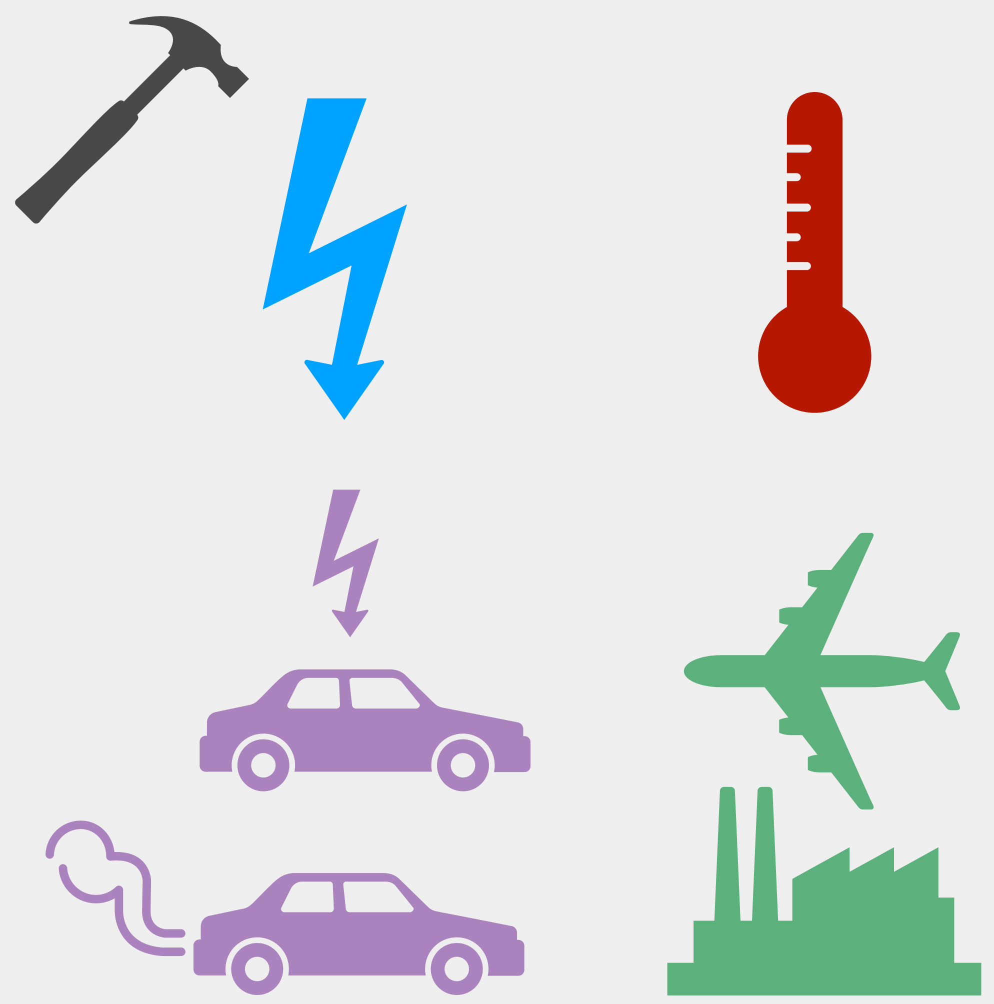
100% renewable electricity supply at best locations or locally in regions



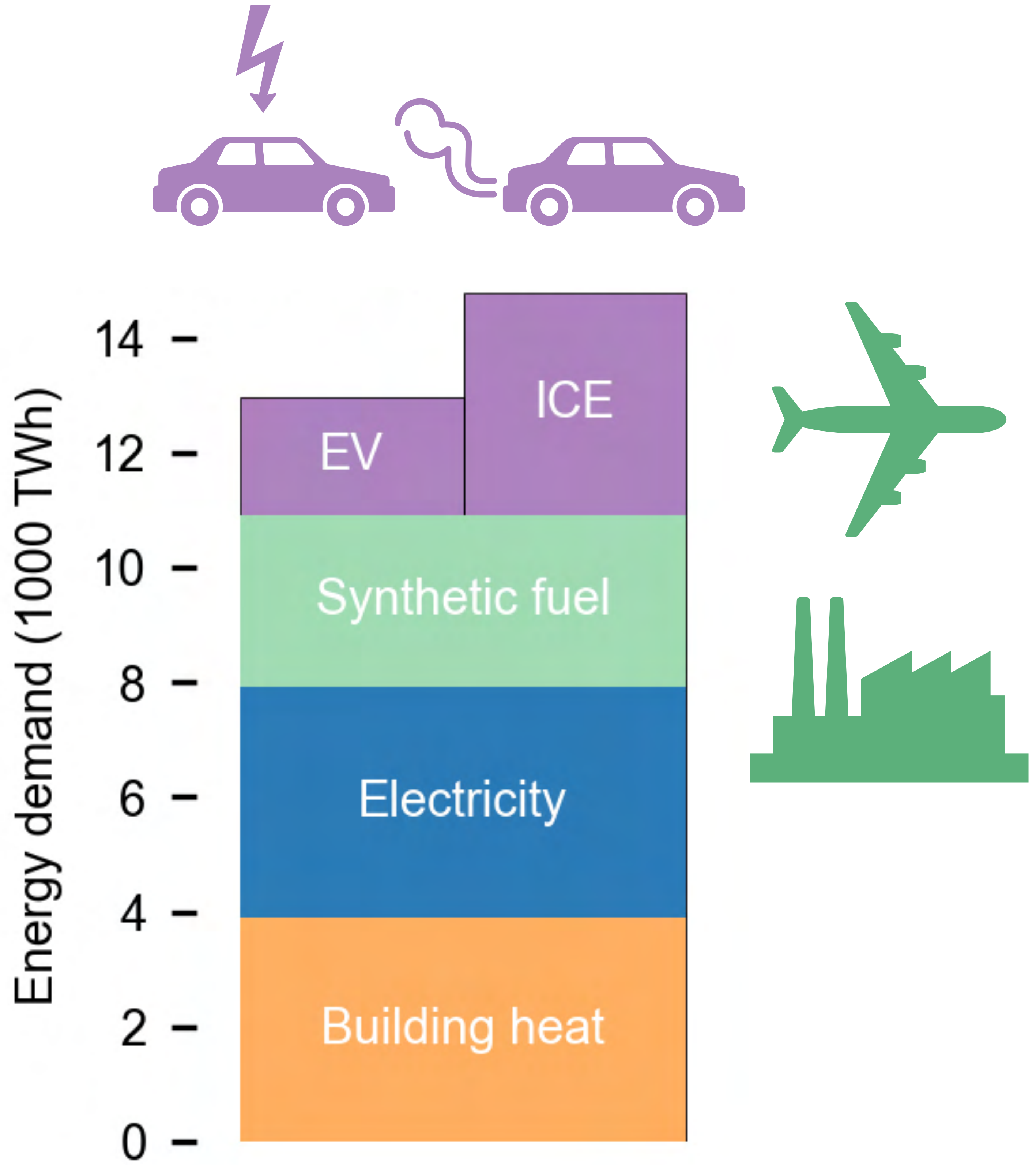
Technically feasible and cost-effective options (○) for an energy self-sufficient, carbon-neutral Europe



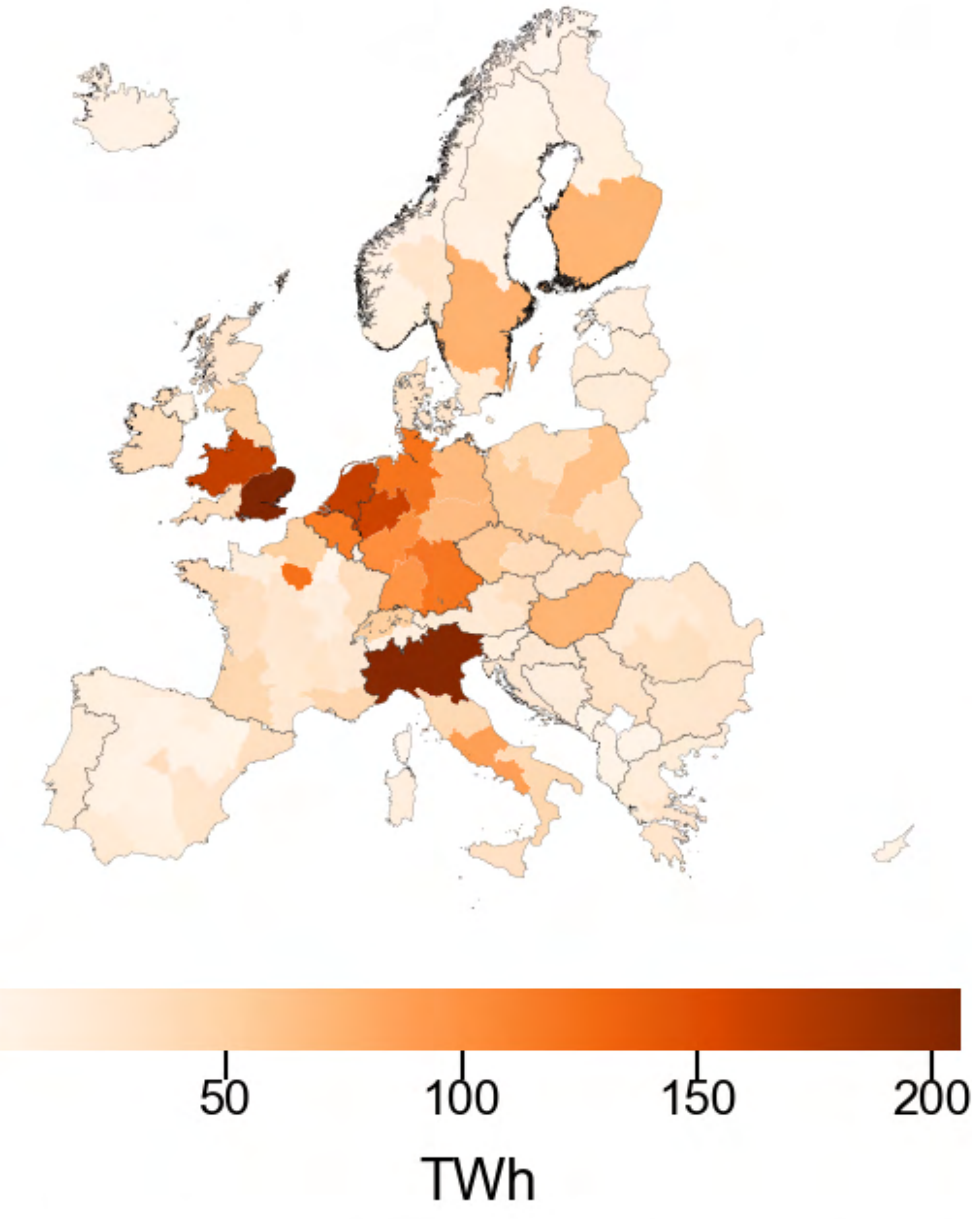


Bryn Pickering

# Sector-coupled Euro-Calliope

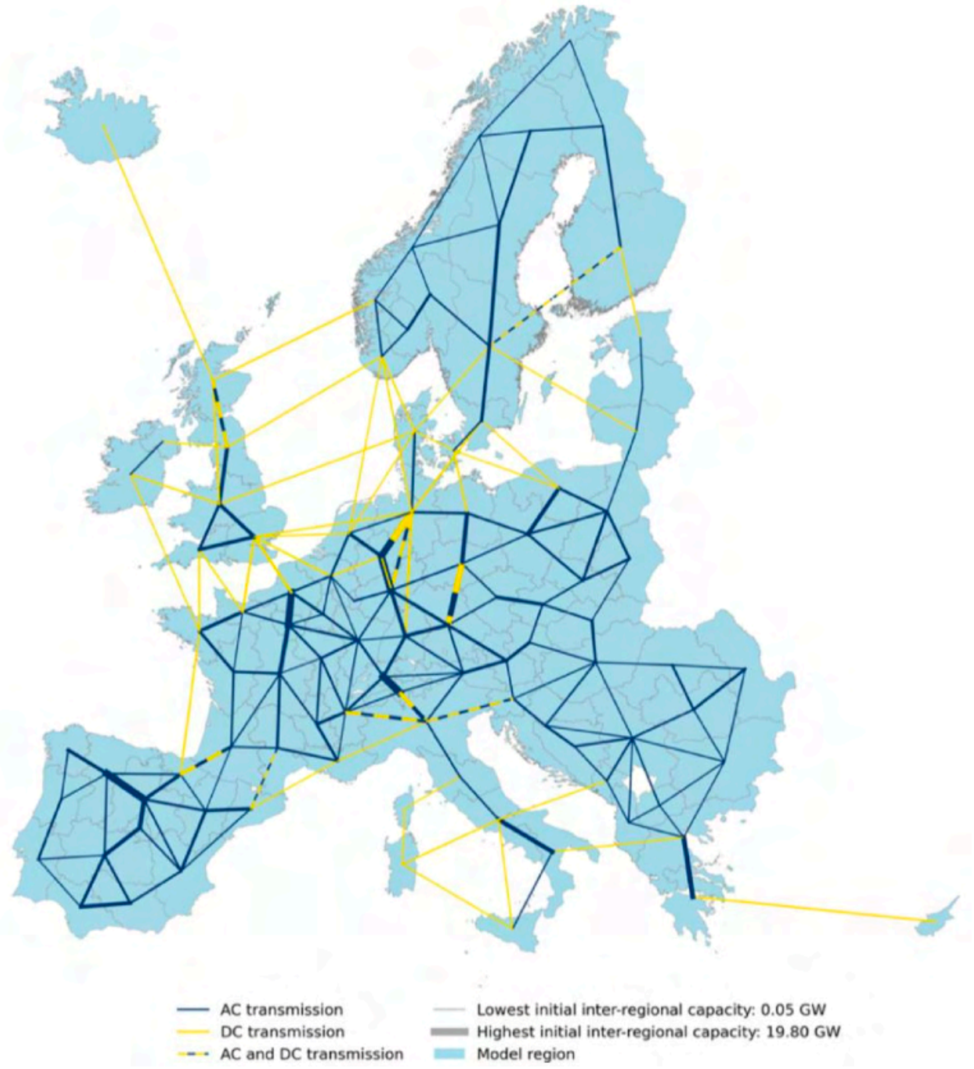


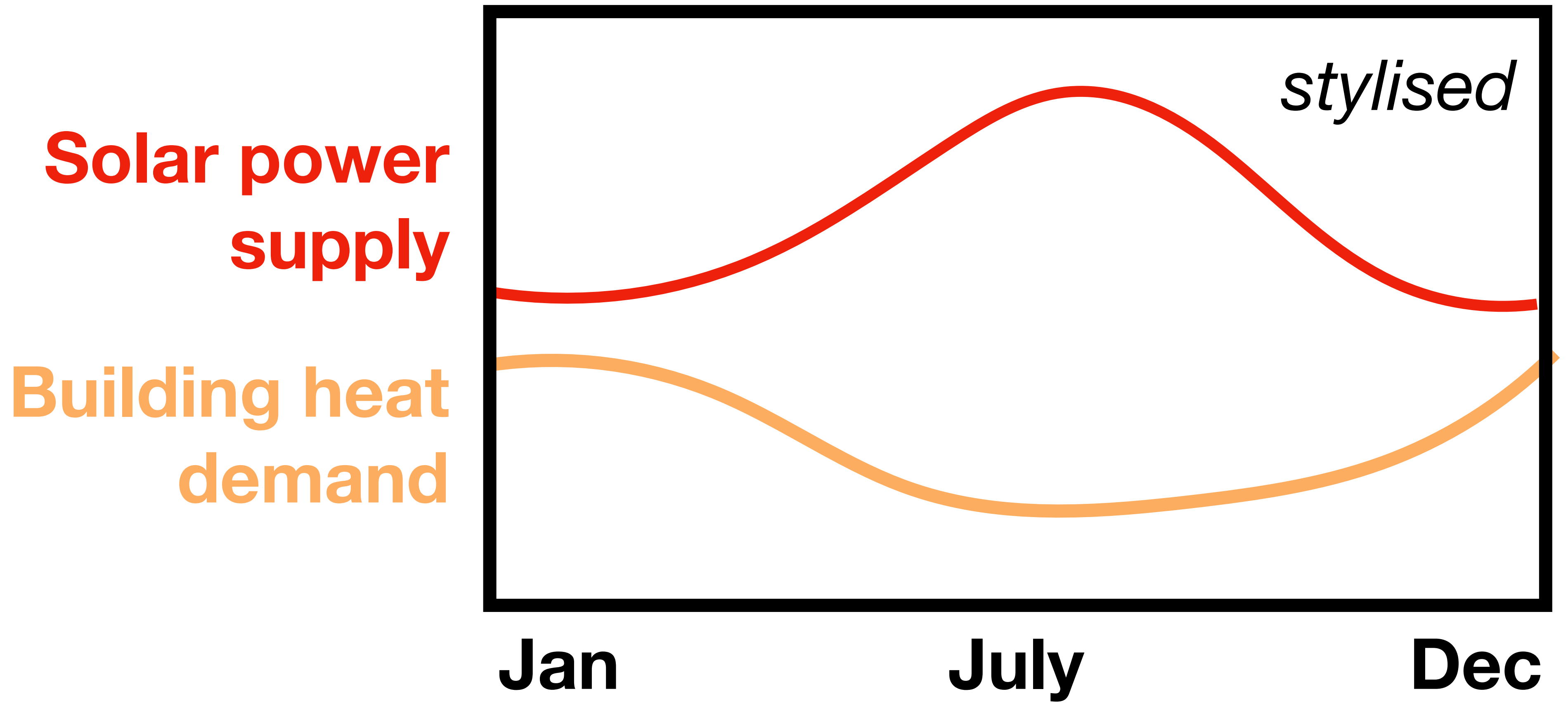

**Demand for all energy in all sectors across Europe, + industrial feedstocks**




**Regional distribution of demand: e.g. building heat**

**Technologies for energy supply, conversion, transport, and their possible locations**

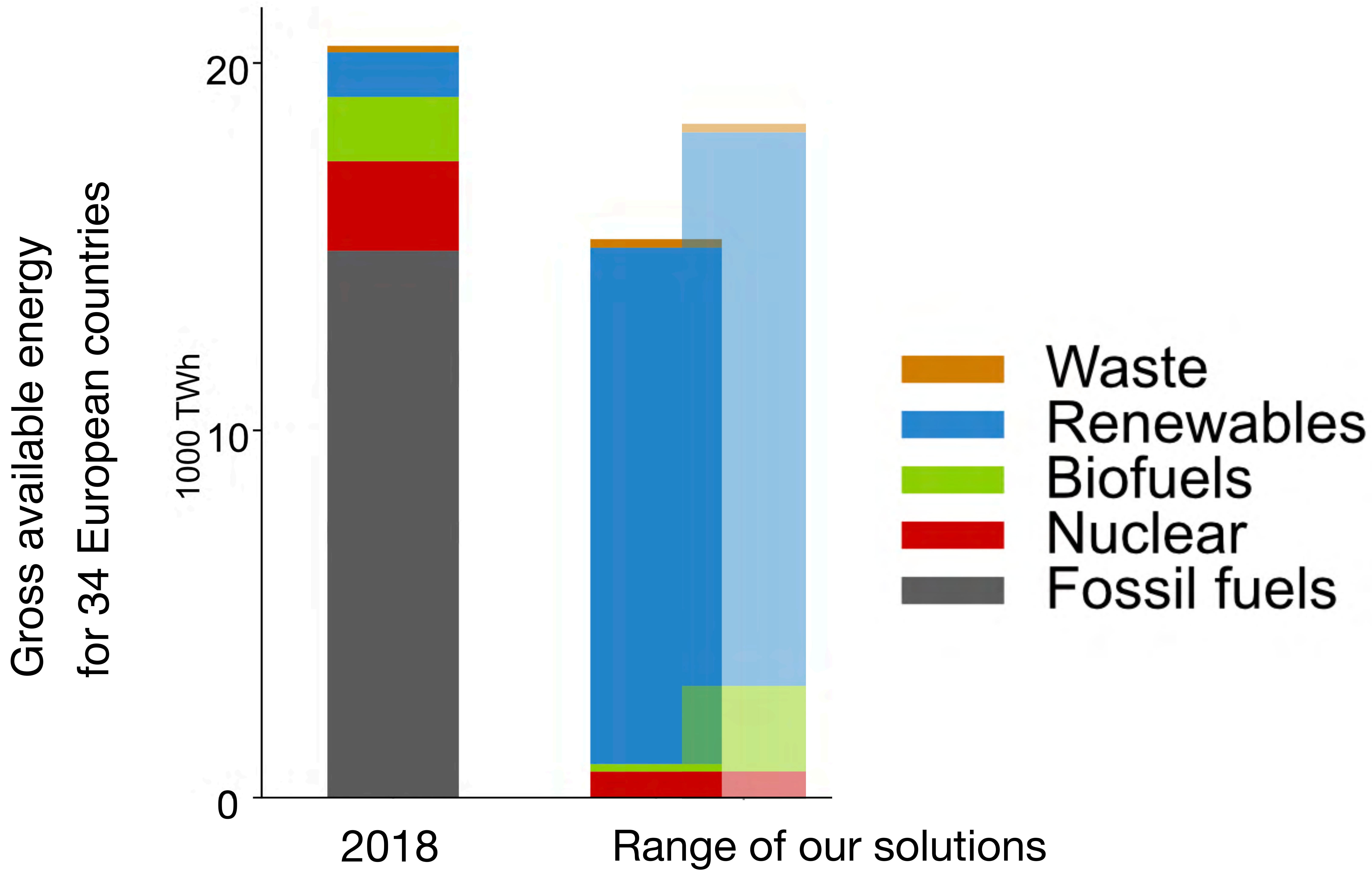



**Time-varying (hourly) supply and demand**

Pickering et al. (2022). *Joule*. https://doi.org/jbd7

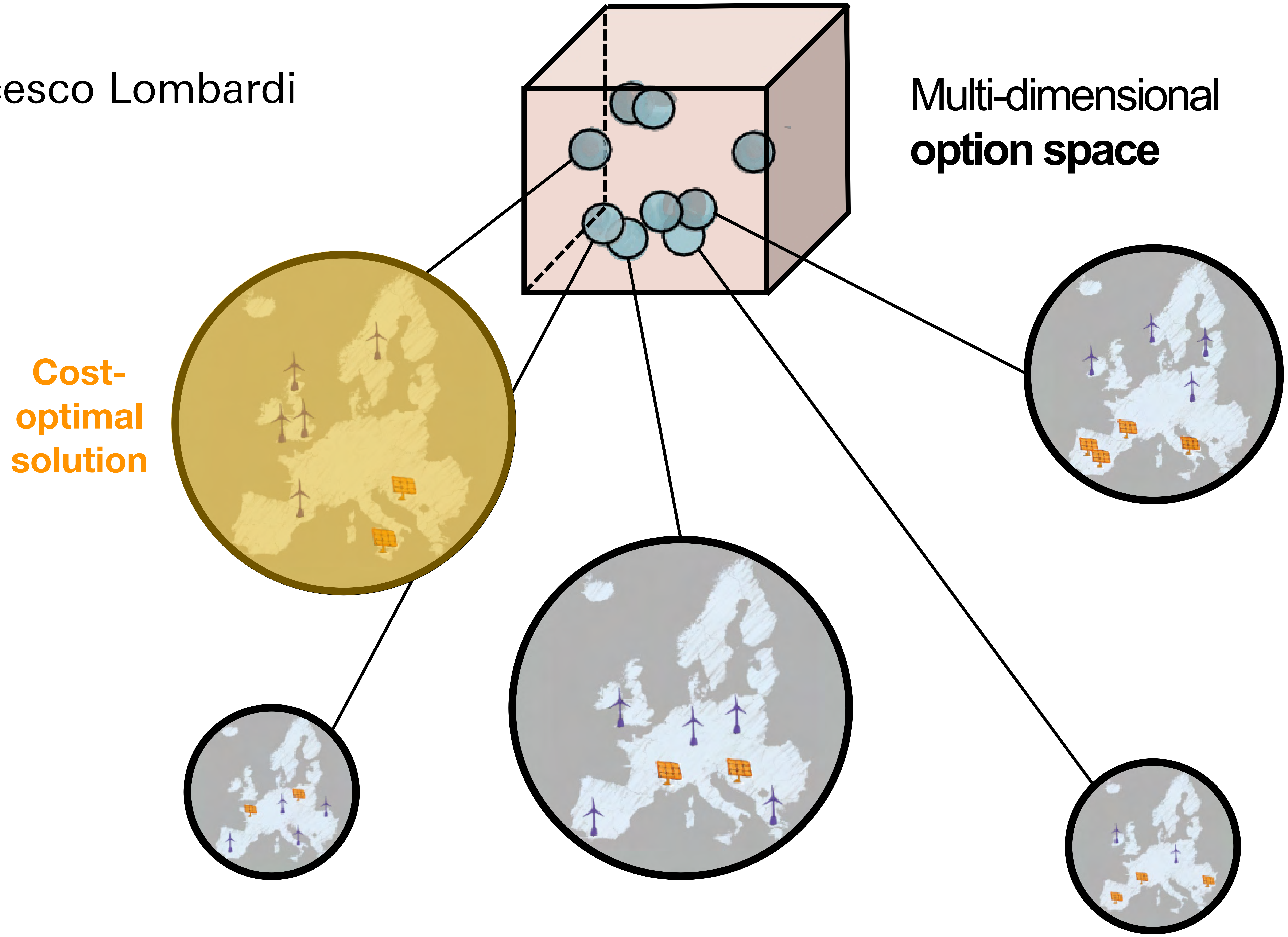
# European energy supply without imported fuels or electricity



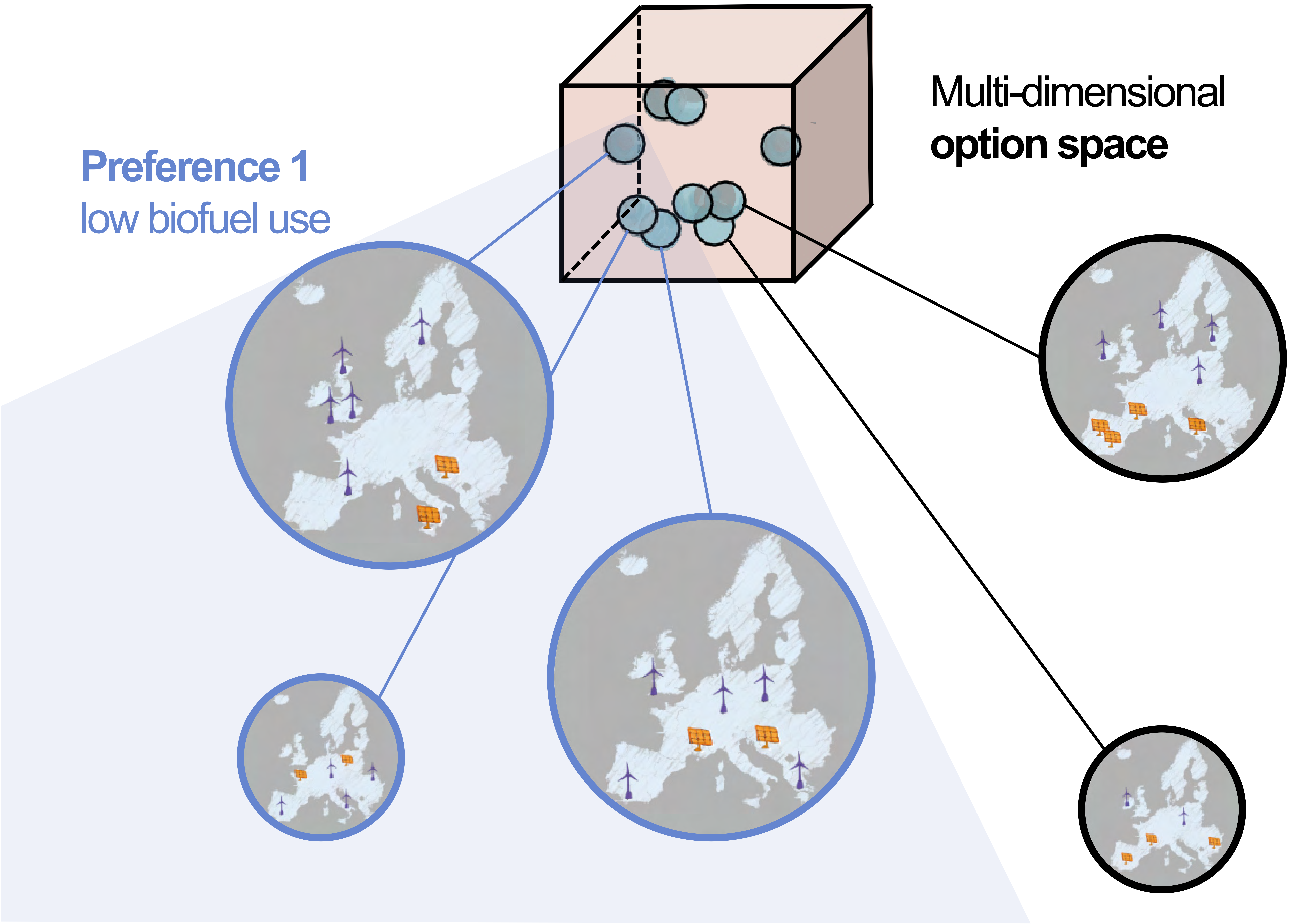

Pickering et al. (2022). *Joule*. https://doi.org/jbd7

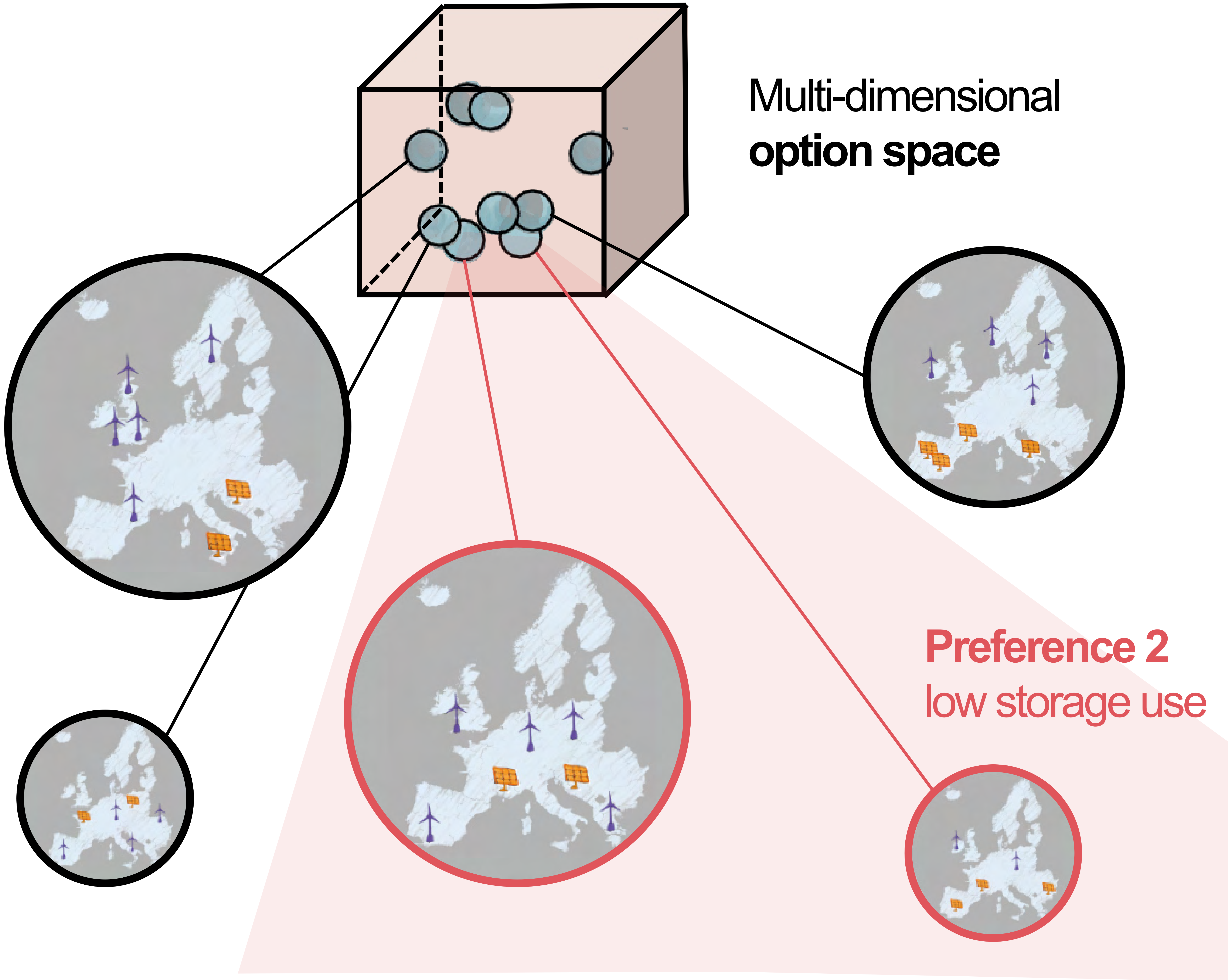
# SPORES: an algorithm for near-optimal results

Francesco Lombardi

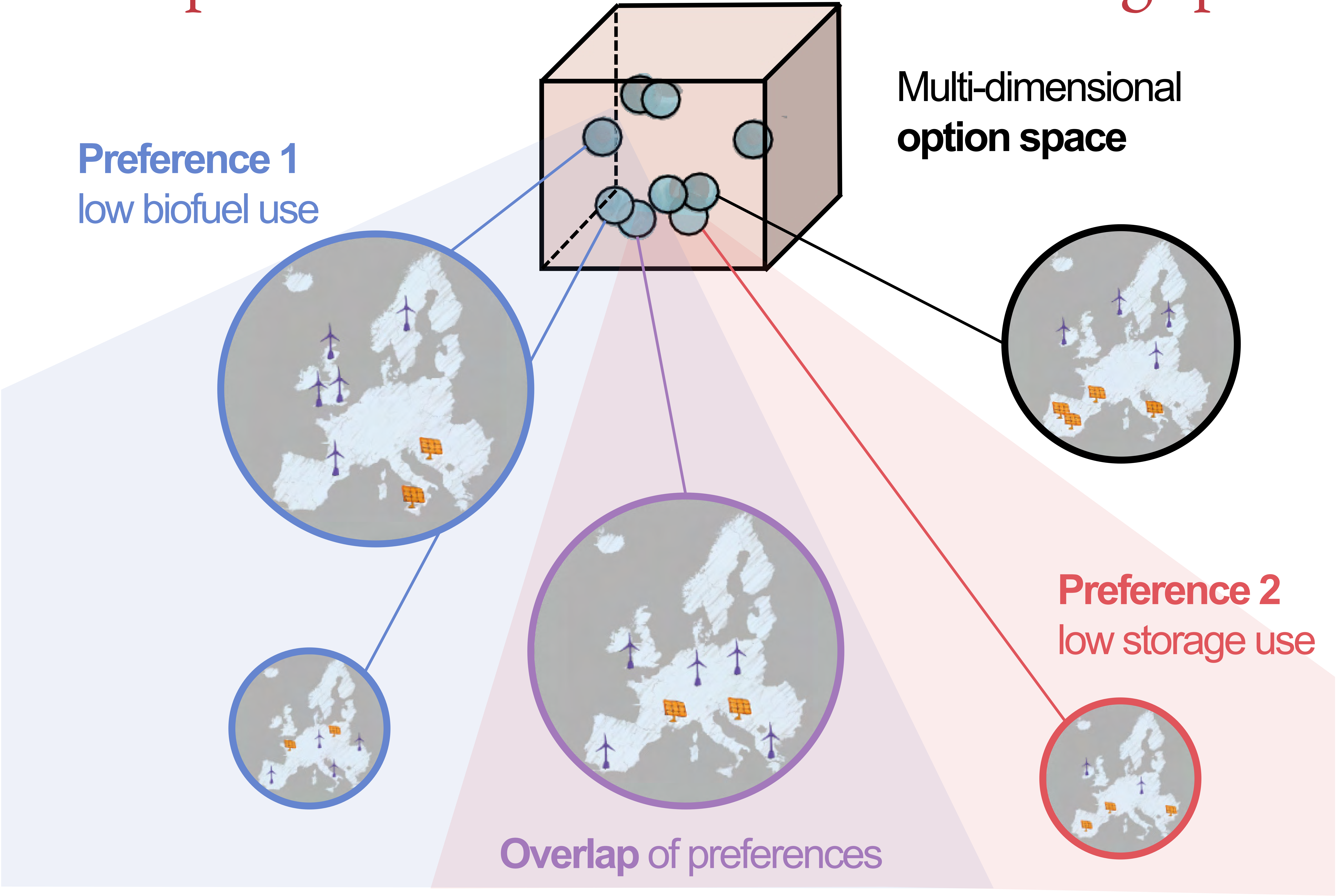


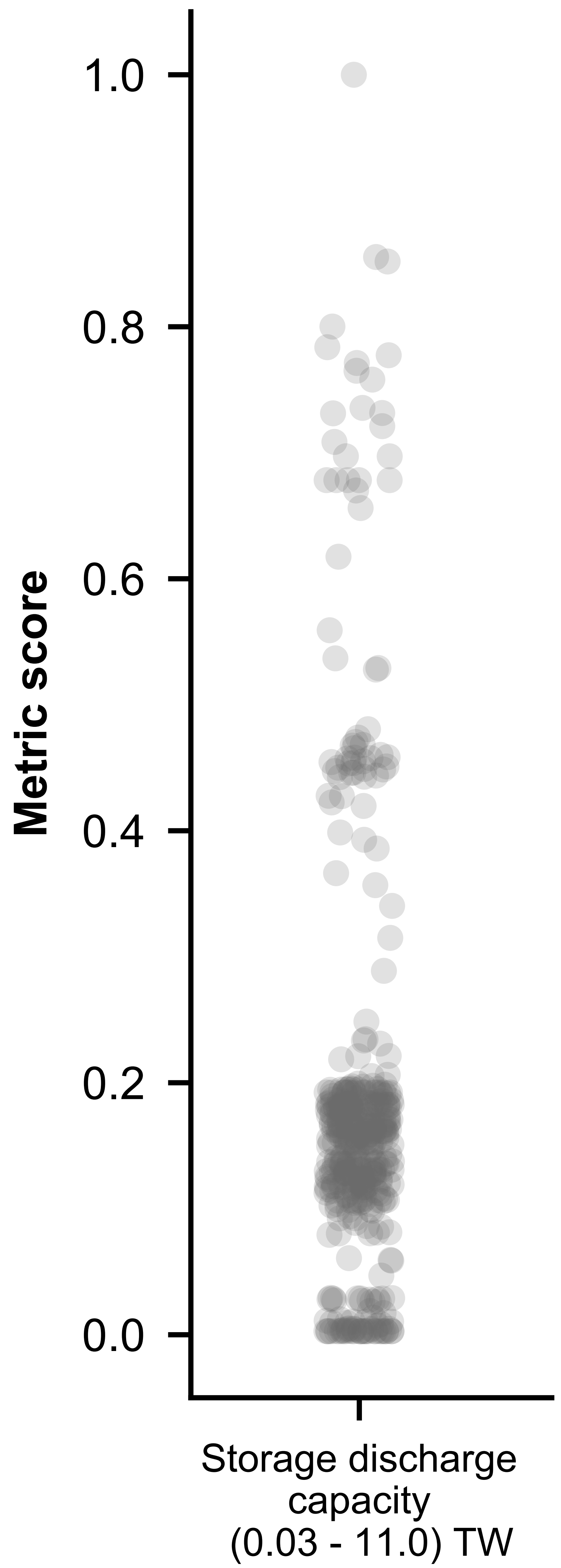

Algorithm first published: Lombardi et al. (2020). *Joule*. https://doi.org/gg8z6v


Preference 1
low biofuel use
Multi-dimensional
option space


Multi-dimensional
**option space**
Preference 2
low storage use

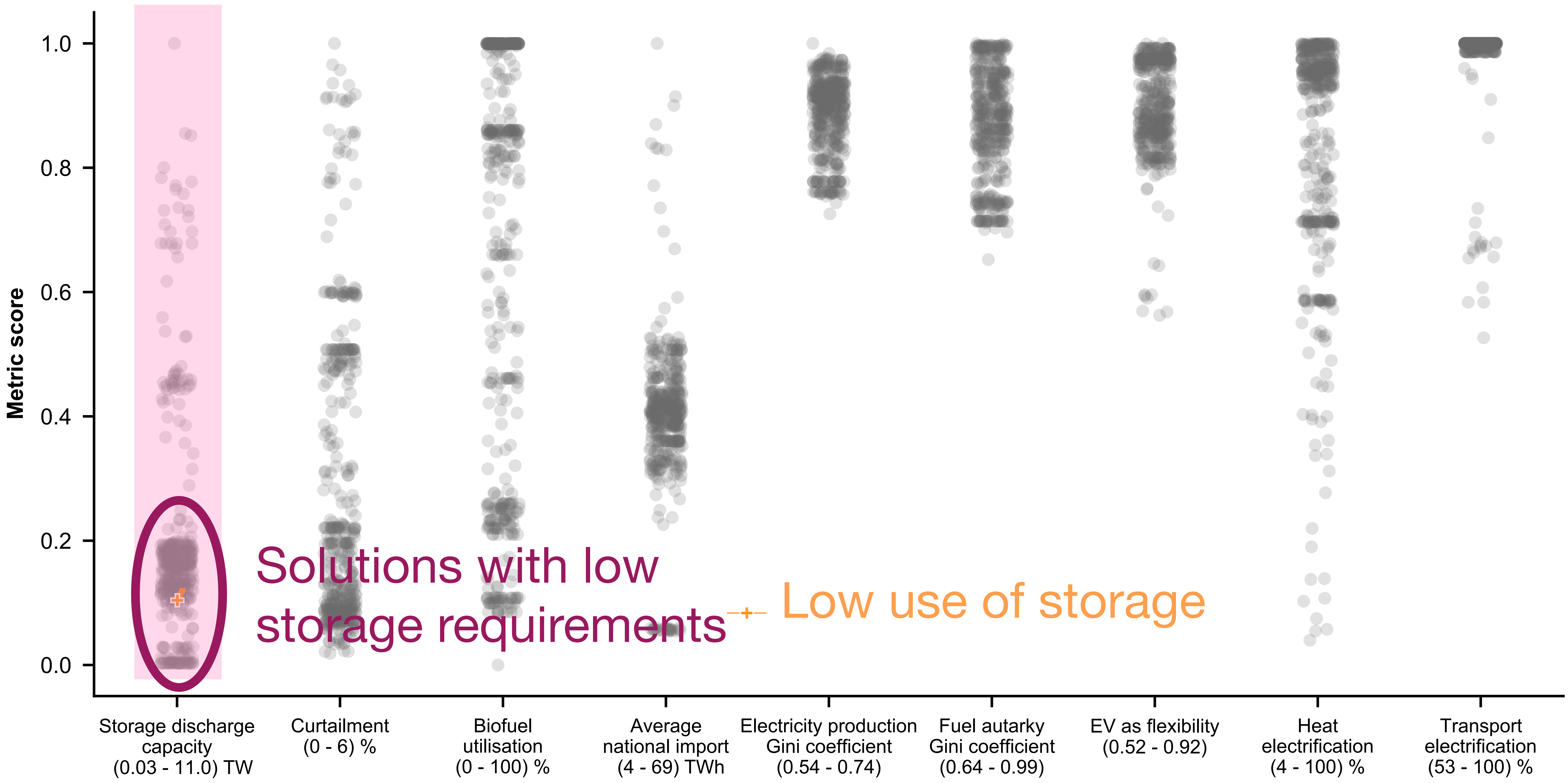
# Almost anything is technically possible, but preferences restrict the spatial and technical maneouvering space



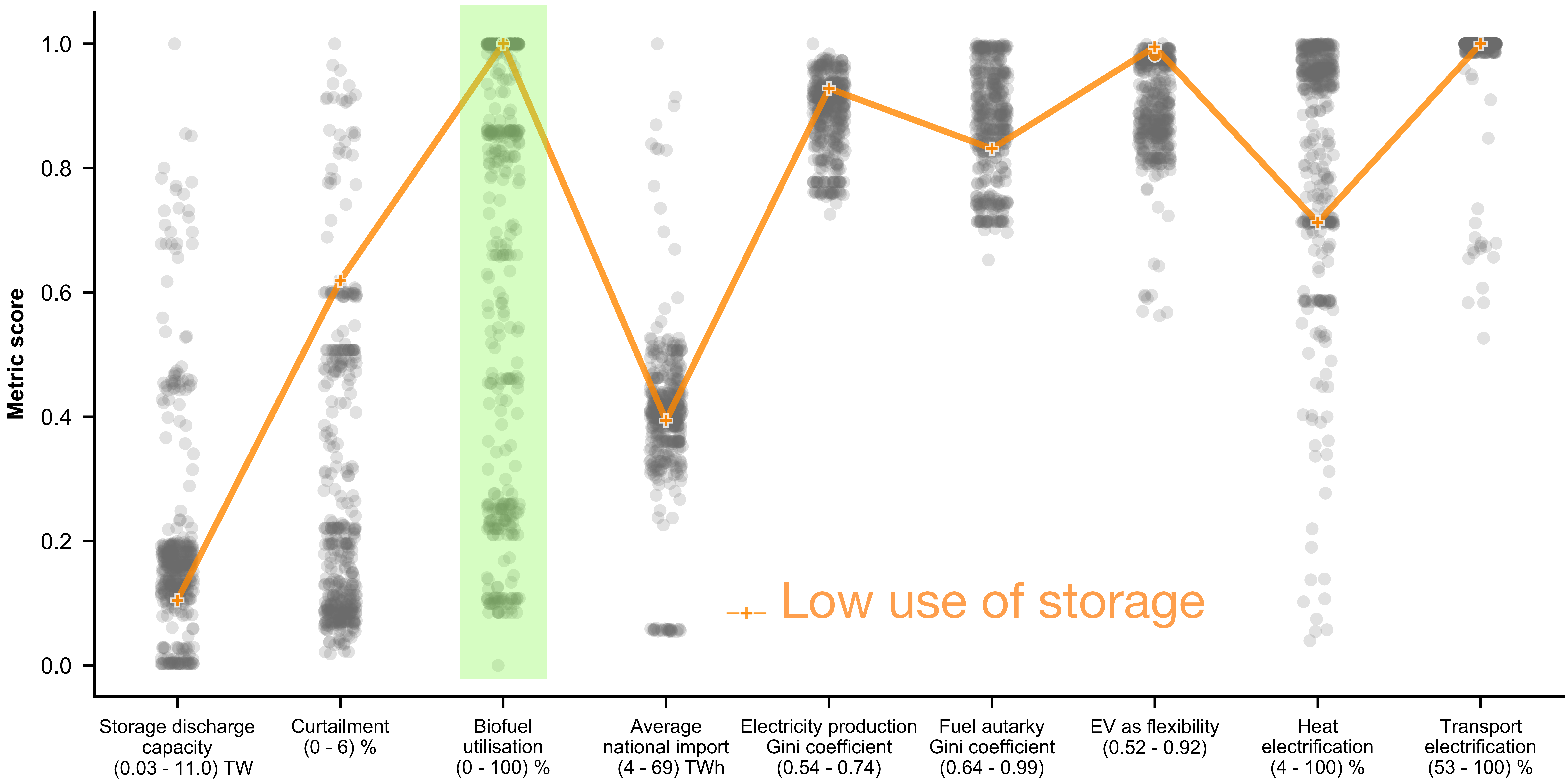



Pickering et al. (2022). *Joule*. https://doi.org/jbd7

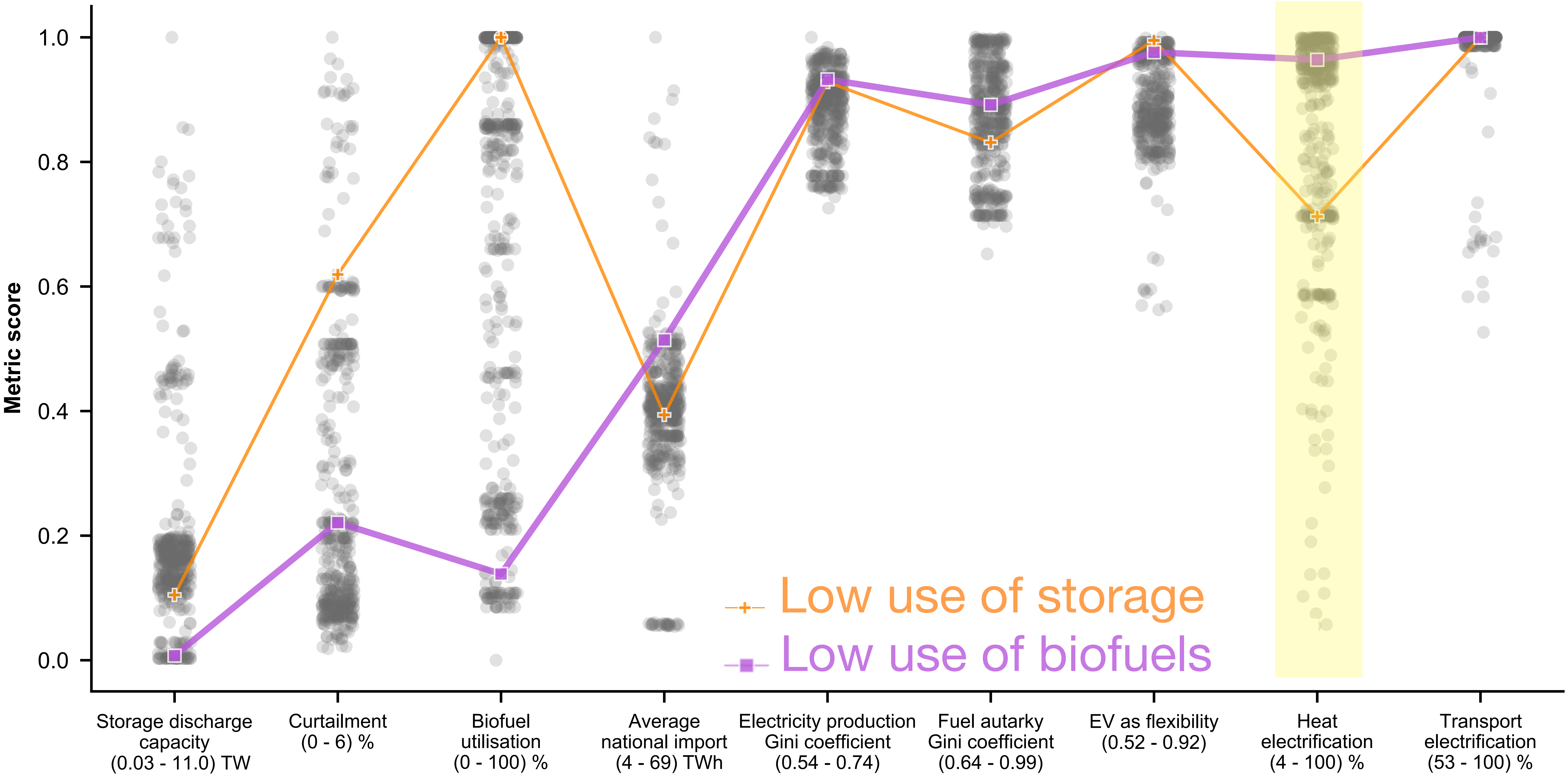
# Storage capacity needed



# Biofuel utilisation



## Heat electrification



# Low biofuels

# Low storage

Result number 17

Total grid expansion + 1.5 TW

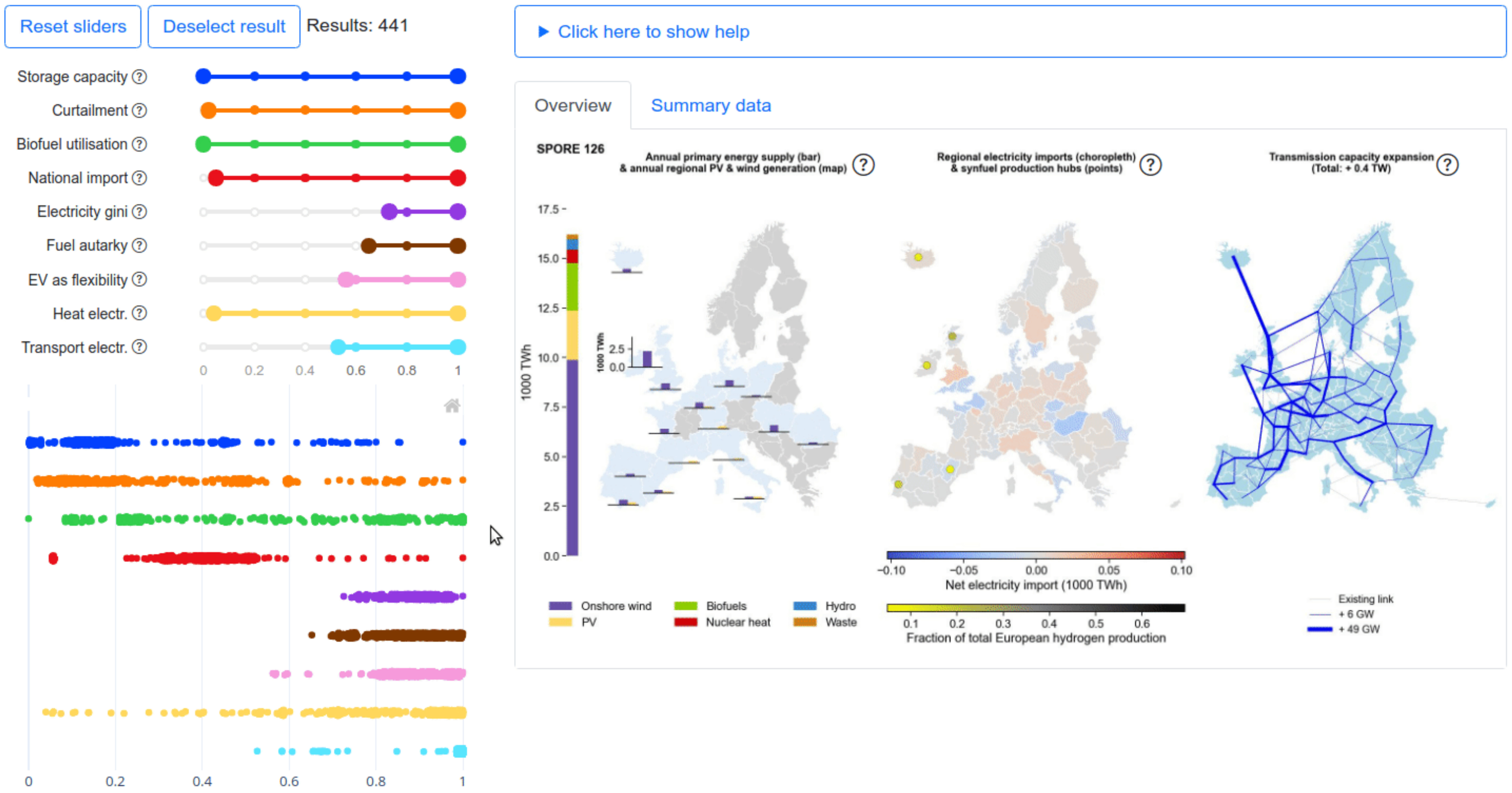
Result number 158

Total grid expansion + 1.3 TW

Result number 110

Total grid expansion + 0.7 TW

Pickering et al. (2022). *Joule*. https://doi.org/jbd7

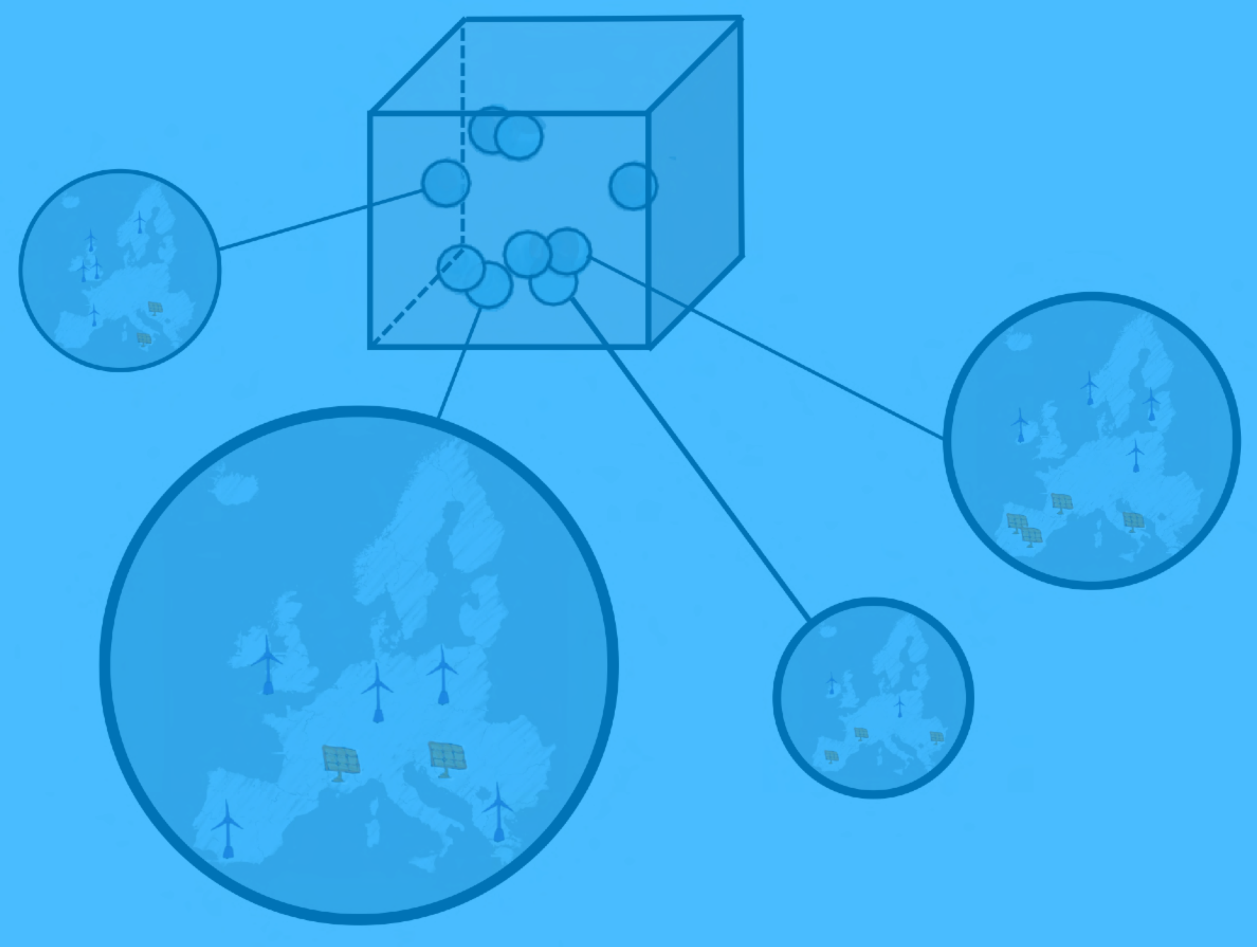


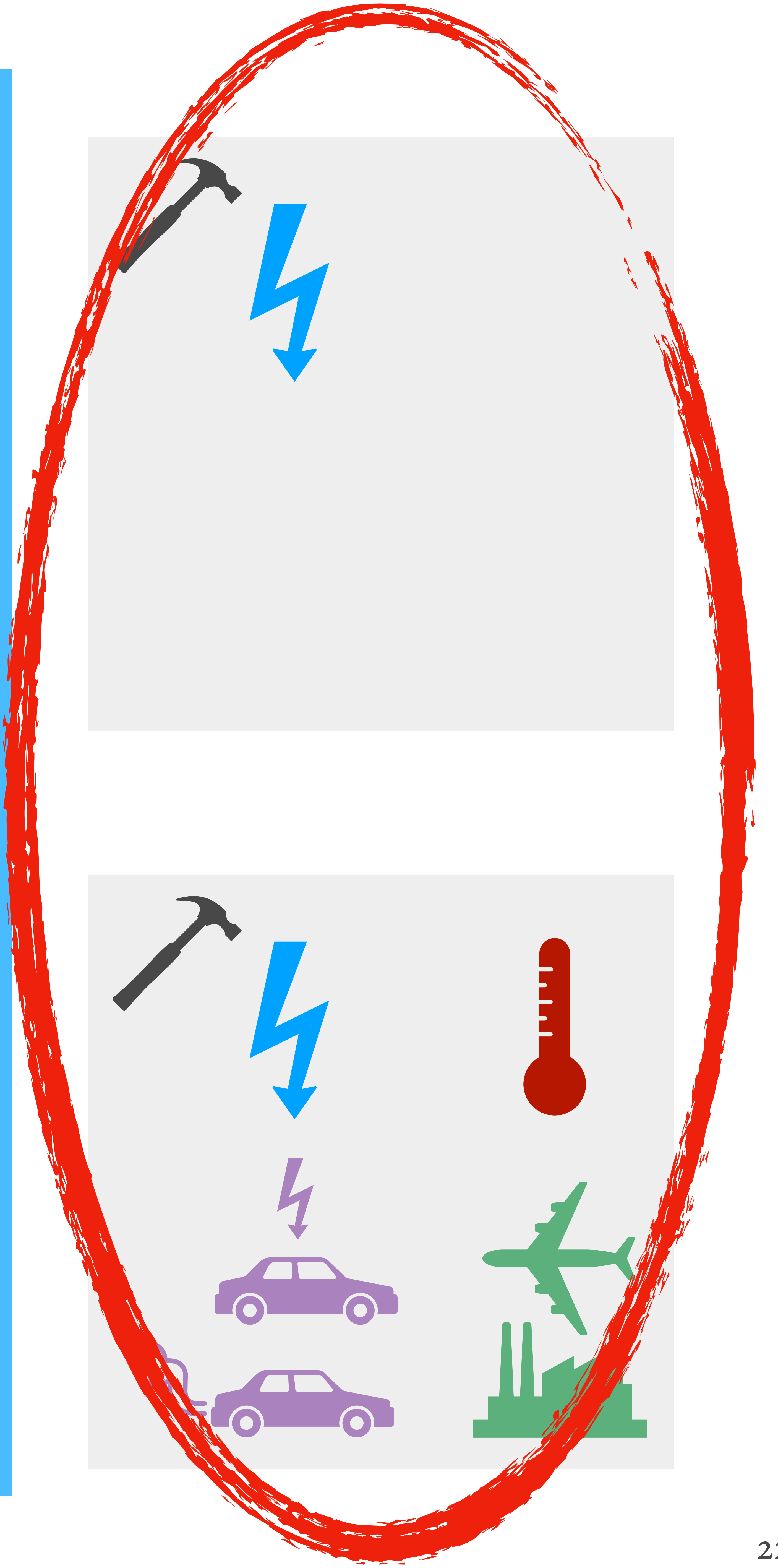

Explore results yourself: https://explore.callio.pe/

100% renewable electricity supply at best locations or locally in regions


## Trade-offs between different decisions

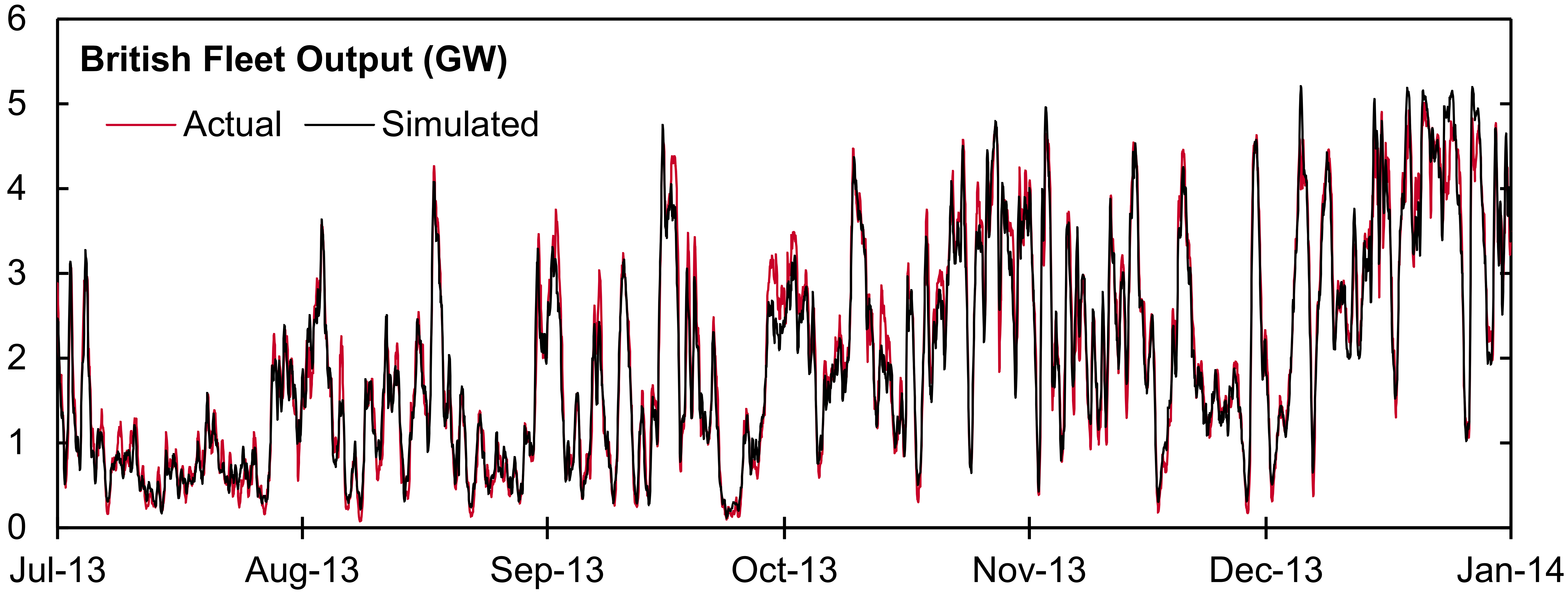
Technically feasible and cost-effective options (◯) for an energy self-sufficient, carbon-neutral Europe





# Assumptions inside such a model: renewable generation

Simulating the UK wind fleet with first generation Renewables.ninja model:
$R^2 = 0.95$

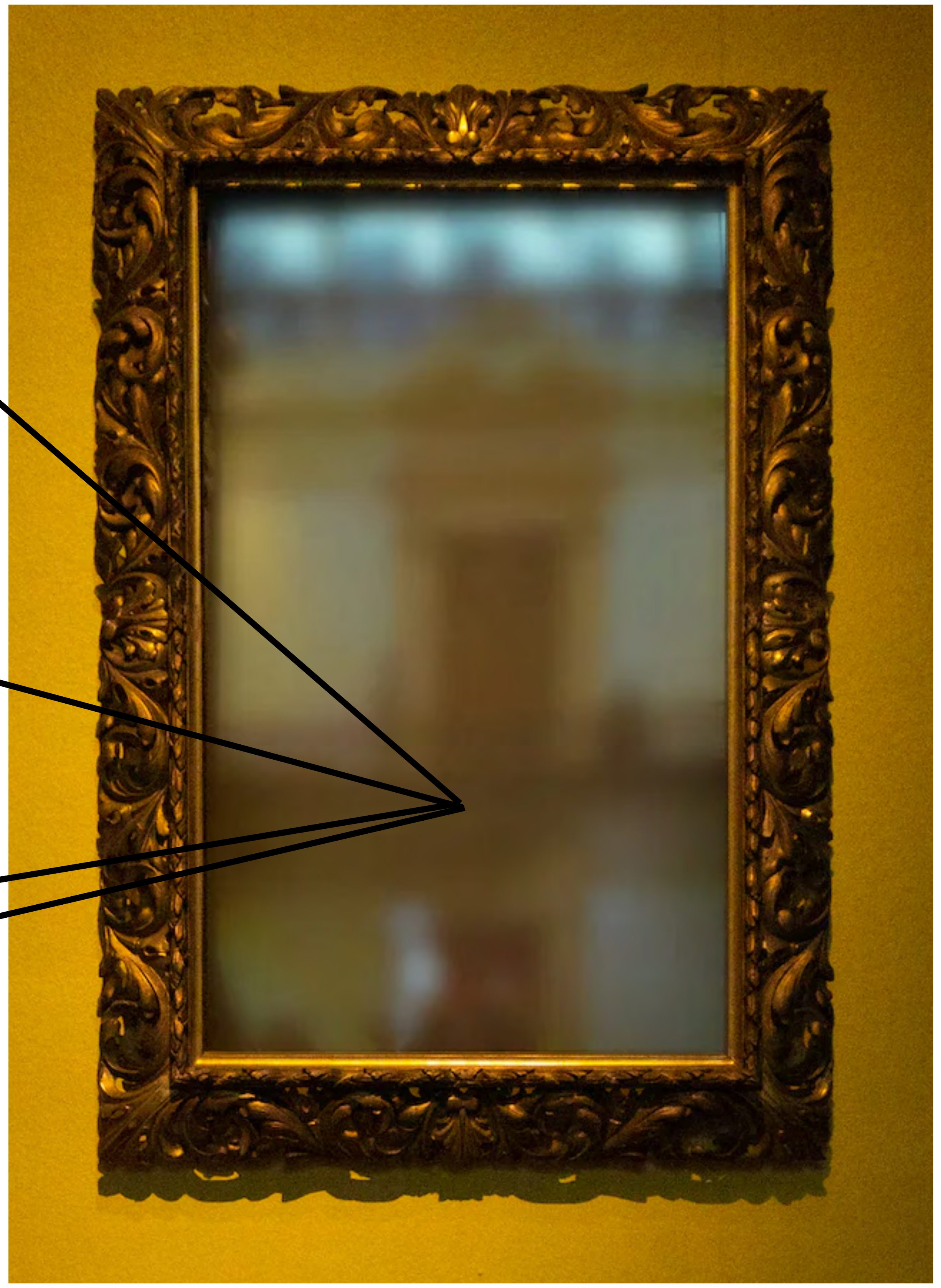



www.renewables.ninja

Staffell and Pfenninger (2016); actual data from Elexon & National Grid

# Assumptions inside such a model: “economics”

My own assumptions



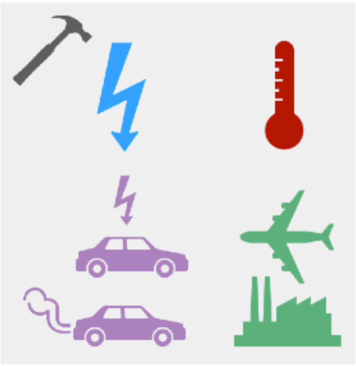
All-knowing
all-powerful
dictator
that ruthlessly
picks the
cheapest solution

# Assumptions inside such a model:

Are we missing crucial facets of the energy transition?

# Challenges

- resolving time and space



- addressing the growing complexity of the energy system
- balancing uncertainty and transparency
- integrating human behavior and social risks and opportunities

+ environmental factors

Pfenninger et al. (2014). *Renewable and Sustainable Energy Reviews*. https://doi.org/f526xf

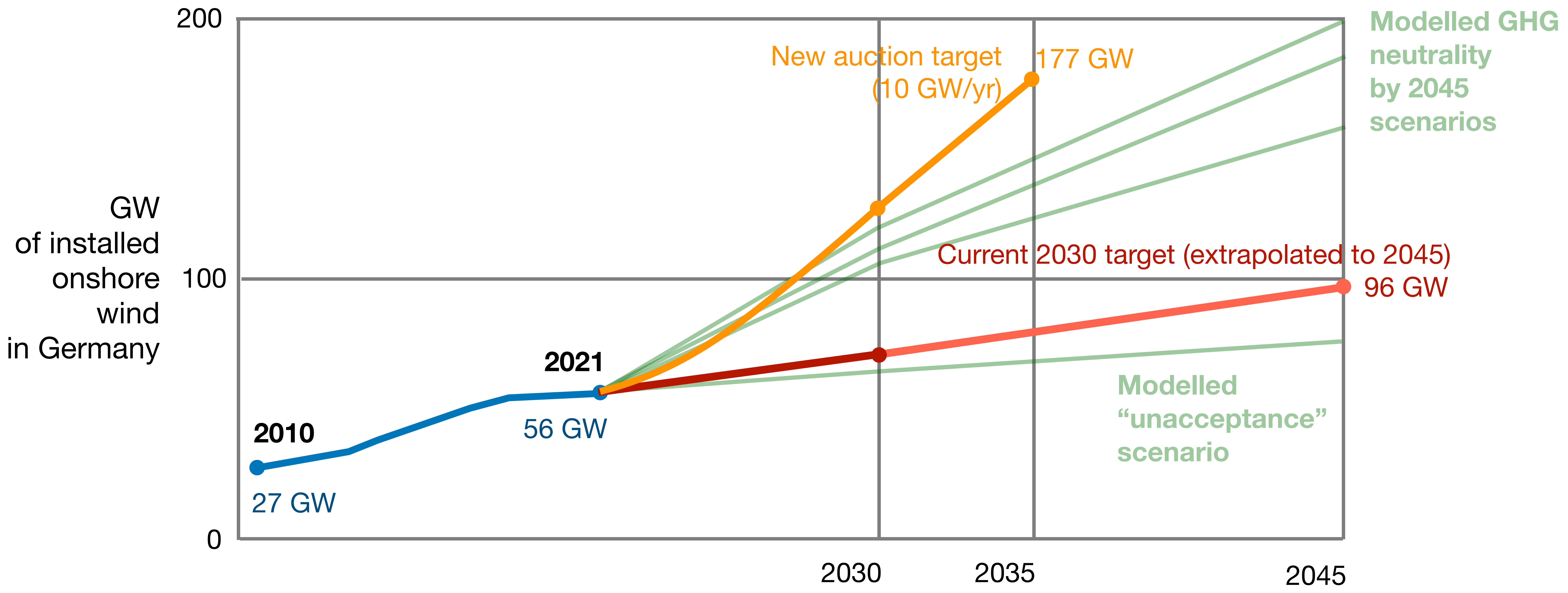
# Challenges: social, environmental, and other limits

- Current EU-wide building renovation rate ~1% per year
- If 3% renovation rate from 2027, -77% to -100% EU space heating and cooling energy demand by 2060 possible



Chatterjee et al. (2022), https://doi.org/10.1007/978-3-030-99177-7_7

# Challenges: social, environmental, and other limits

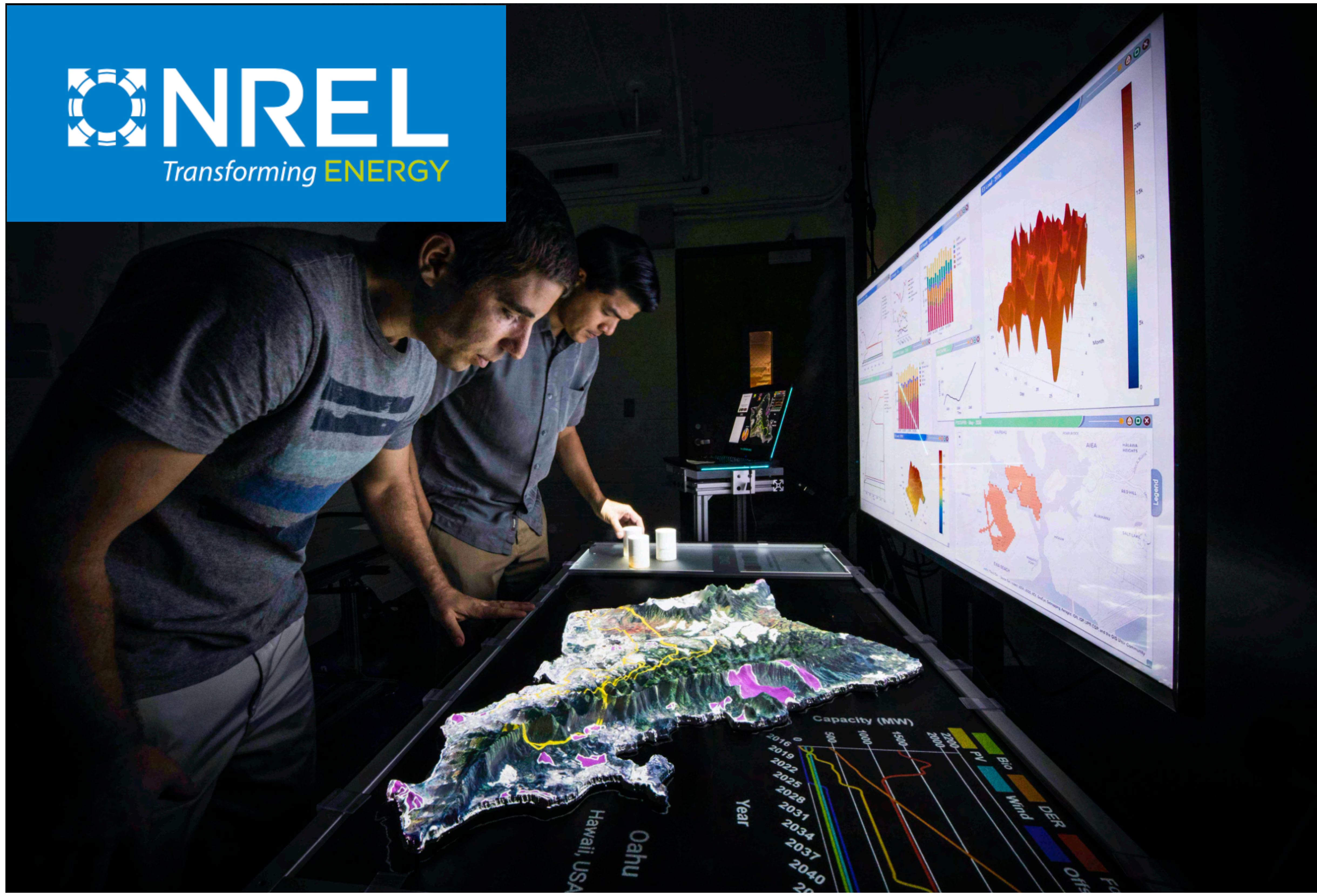



Süsser et al. (2022), *Energy Research & Social Science*, https://doi.org/10.1016/j.erss.2022.102775

# Loading dock vs co-production

Photo © NREL


**“Loading dock” approach**




**Co-production approach**

Cash et al. (2006). *Science, Technology, & Human Values*. https://doi.org/drtgjc ; NREL ENGAGE, https://engage.nrel.gov/

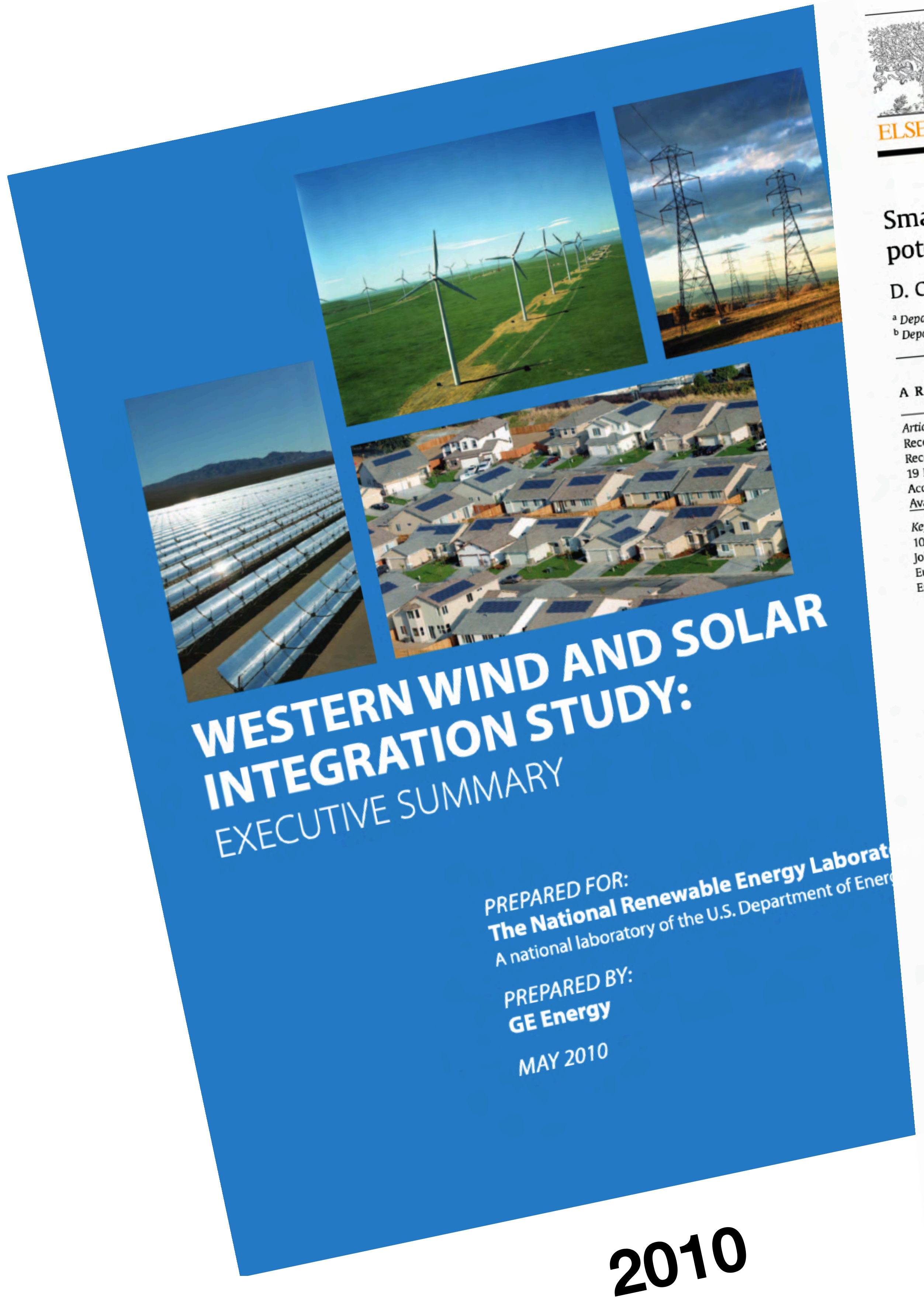
# SEEDS: Building a "human-computer loop"


Image: Debora Conceição Firmino De Souza, Tallinn University. Early wireframe prototype, https://seeds-project.org/

Trade-offs between different decisions

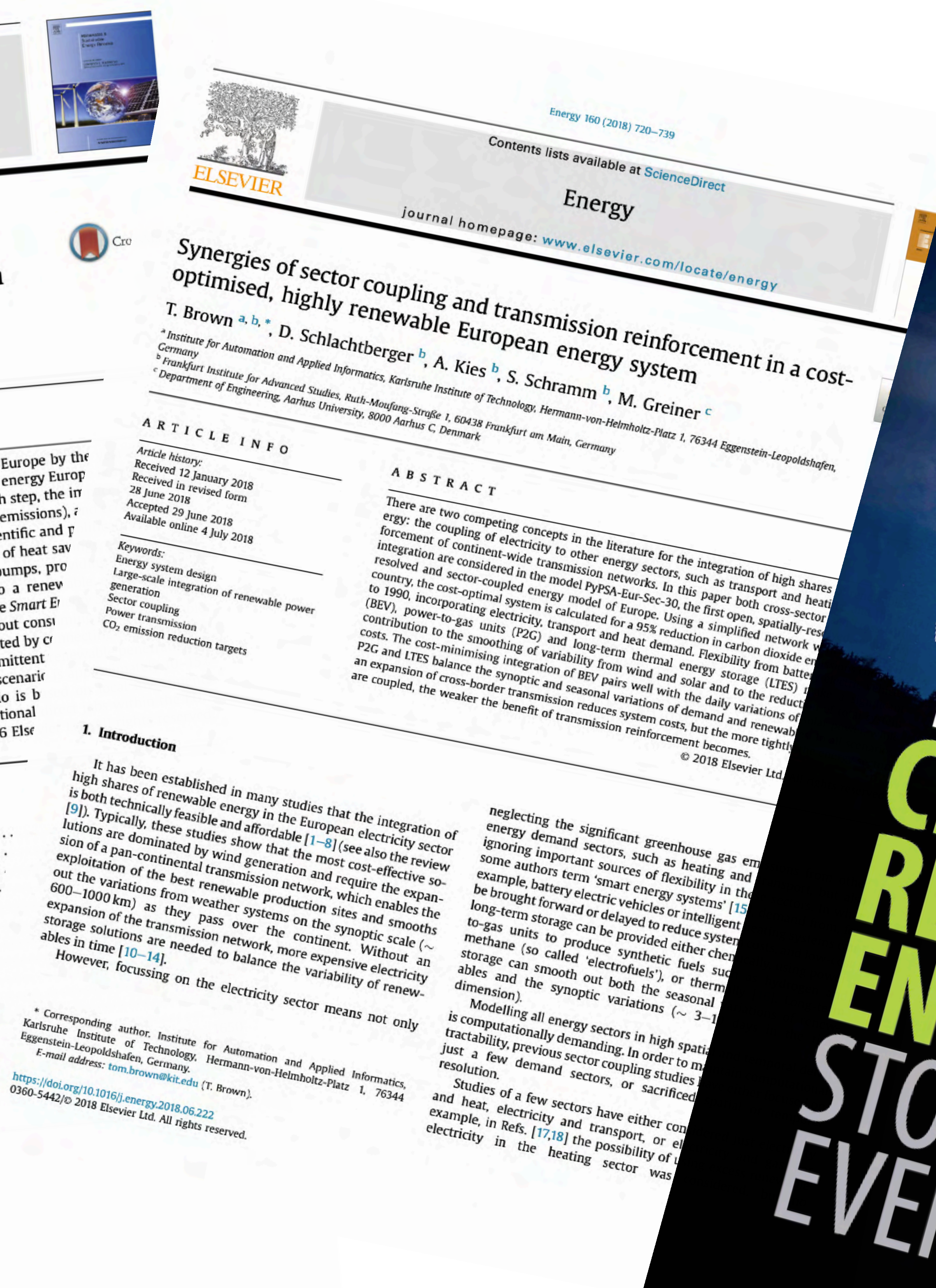
(to reach net-zero goals while navigating social, environmental, and other limits)

# So: can energy system modelling save the world?

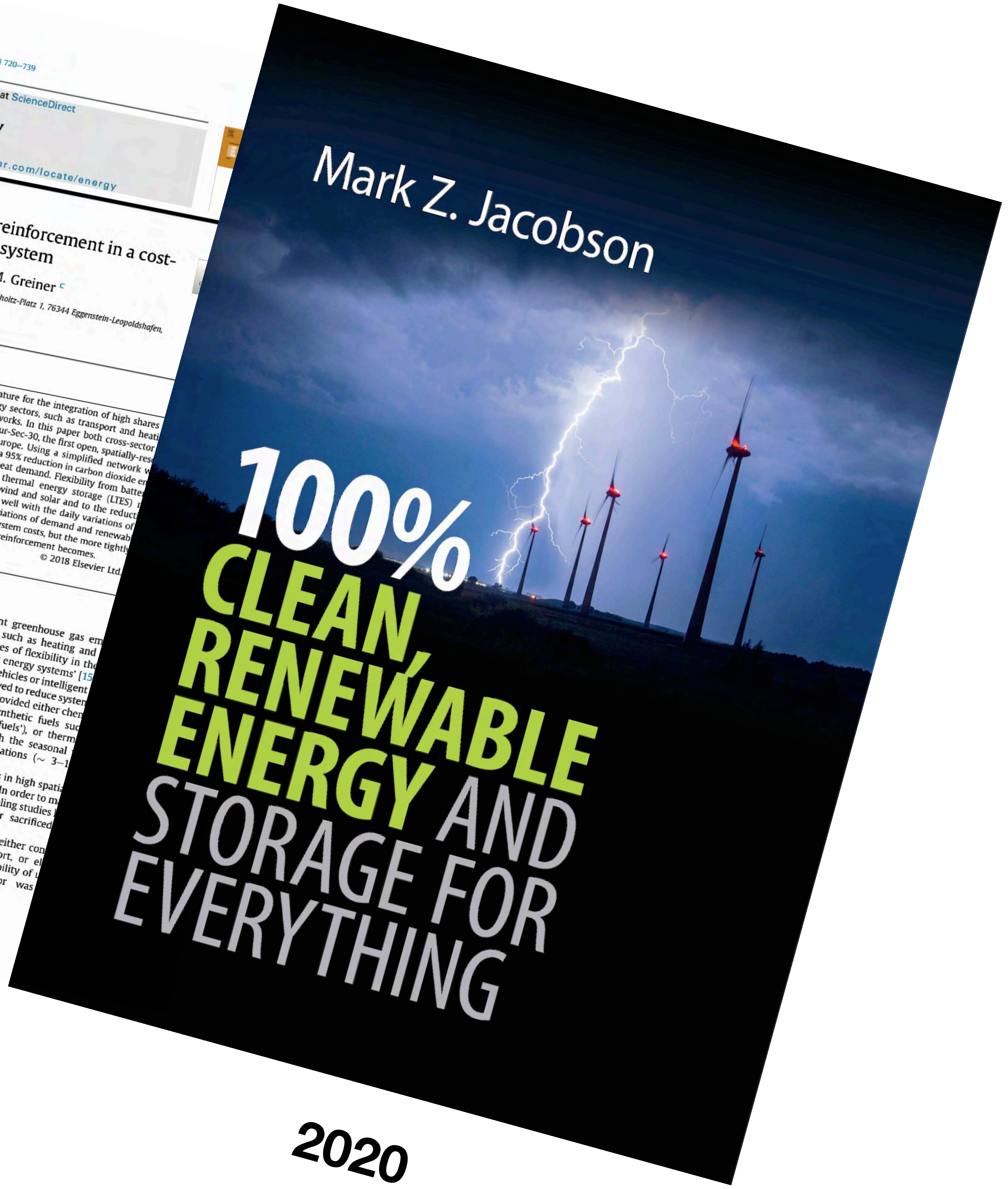



2010


2016

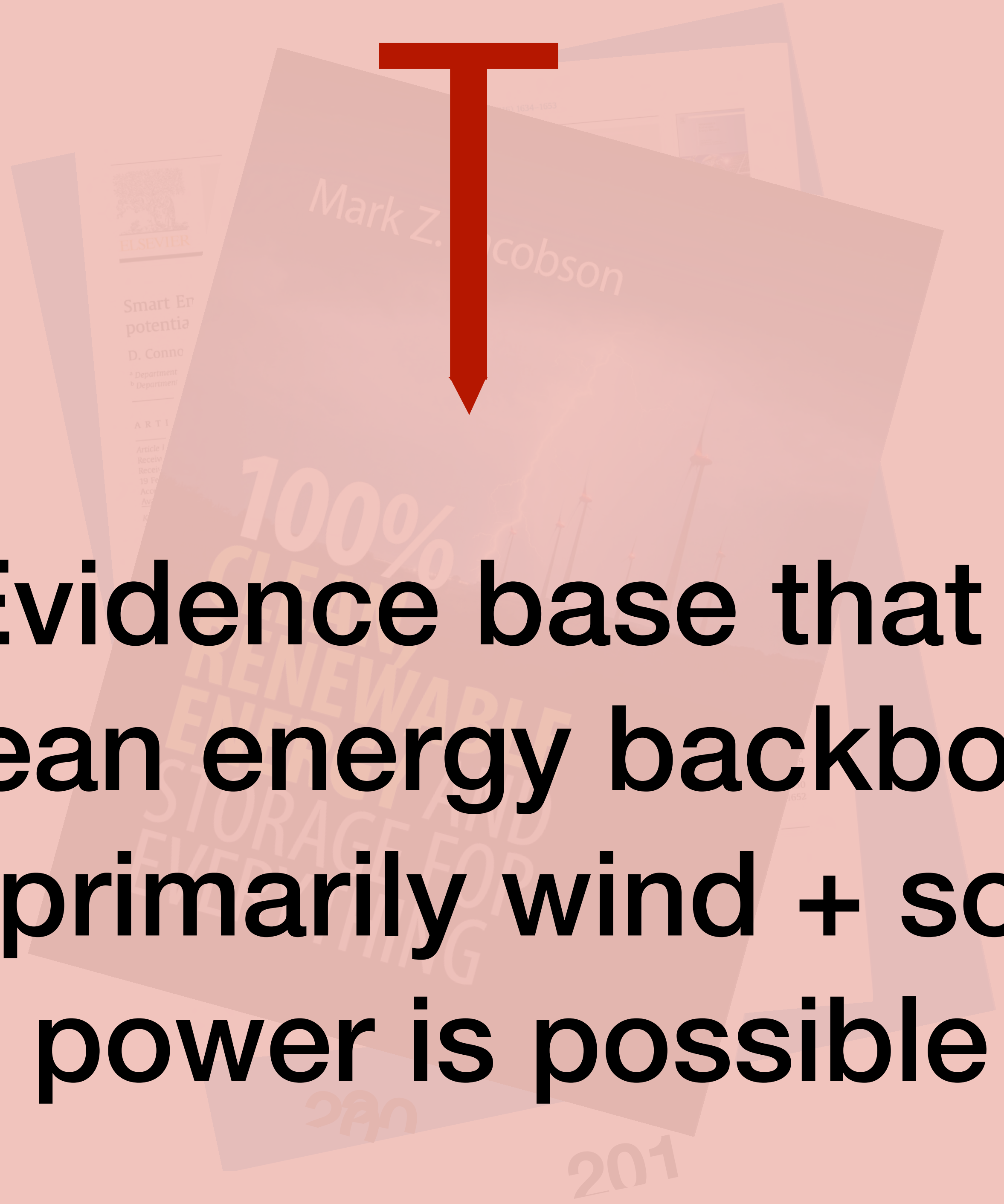



2018




2020

# So: can energy system modelling save the world?



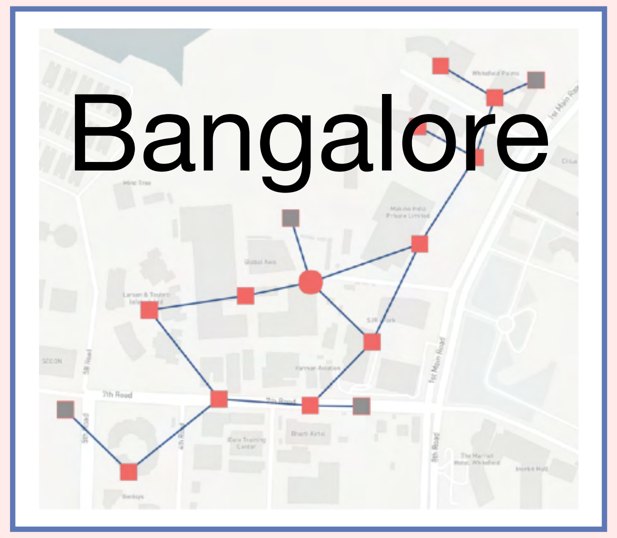
Evidence base that a "clean energy backbone" of primarily wind + solar power is possible

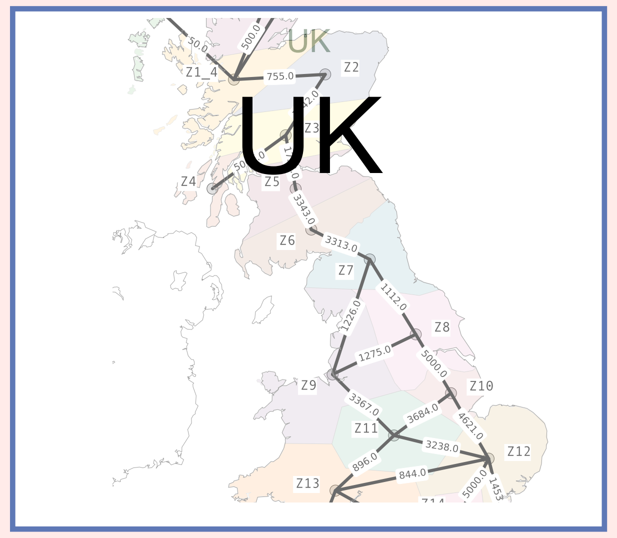
Trade-offs between different decisions

More generally: performing **experiments in a model world** that help people understand the **space for decisions in the real world.**

Calliope open-source energy system modelling software
www.callio.pe

Scale-independent, e.g.:





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Renewables.ninja wind and solar simulations
www.renewables.ninja

Used at >300 institutions in >65 countries (as of early 2021)

Major updates in October

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