How to include social and environmental aspects in your modelling:

A summary of insights from five projects

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For today

- The complexity/holistic issue
- The projects
- Insights
- Take home messages (for your modeling)

The complexity issue

We say that the energy system is **complex**

~~Energy~~ Complex system

Unpredictable | Unreducible | Emergence

And we do models (**reductions**) to forecast (**predict?**) and **emergence**??

In **sustainability science**, we say this is a **Wicked Problem**

Then we aim to do HOLISTIC ASSESSMENTS but....

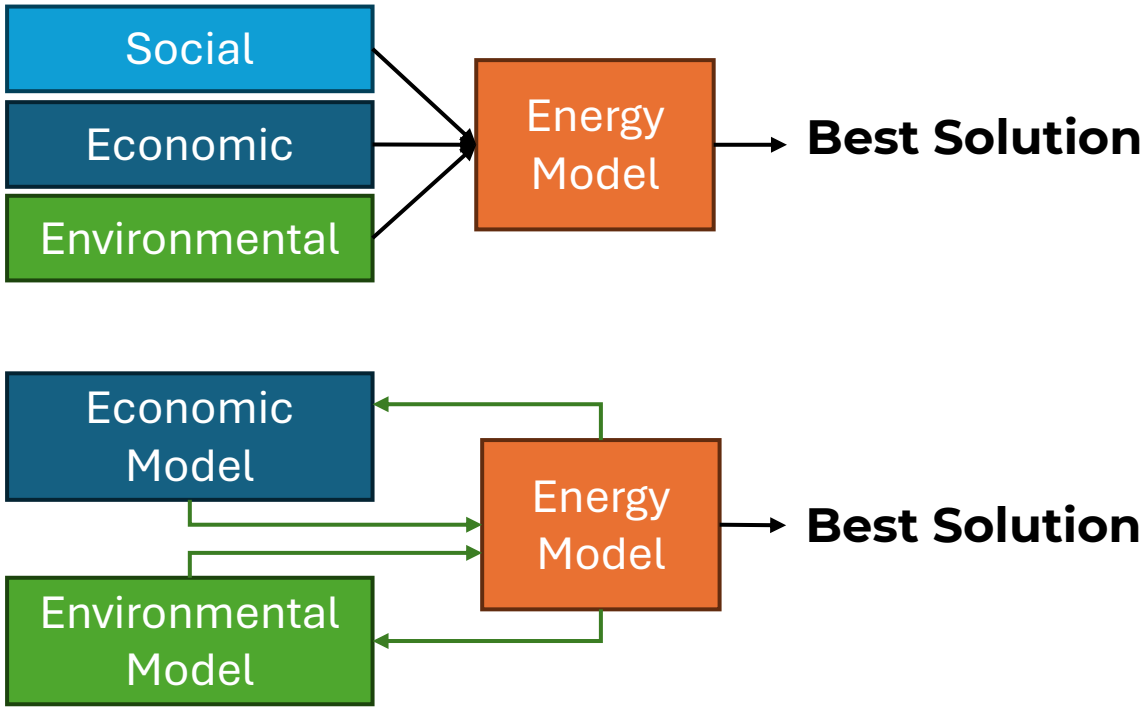
adapted from: *Dilemmas in a General Theory of Planning*
Horst W.J. Rittel and Melvin M. Webber (*Policy Sciences*, June 1973)

What is holistic assessment?

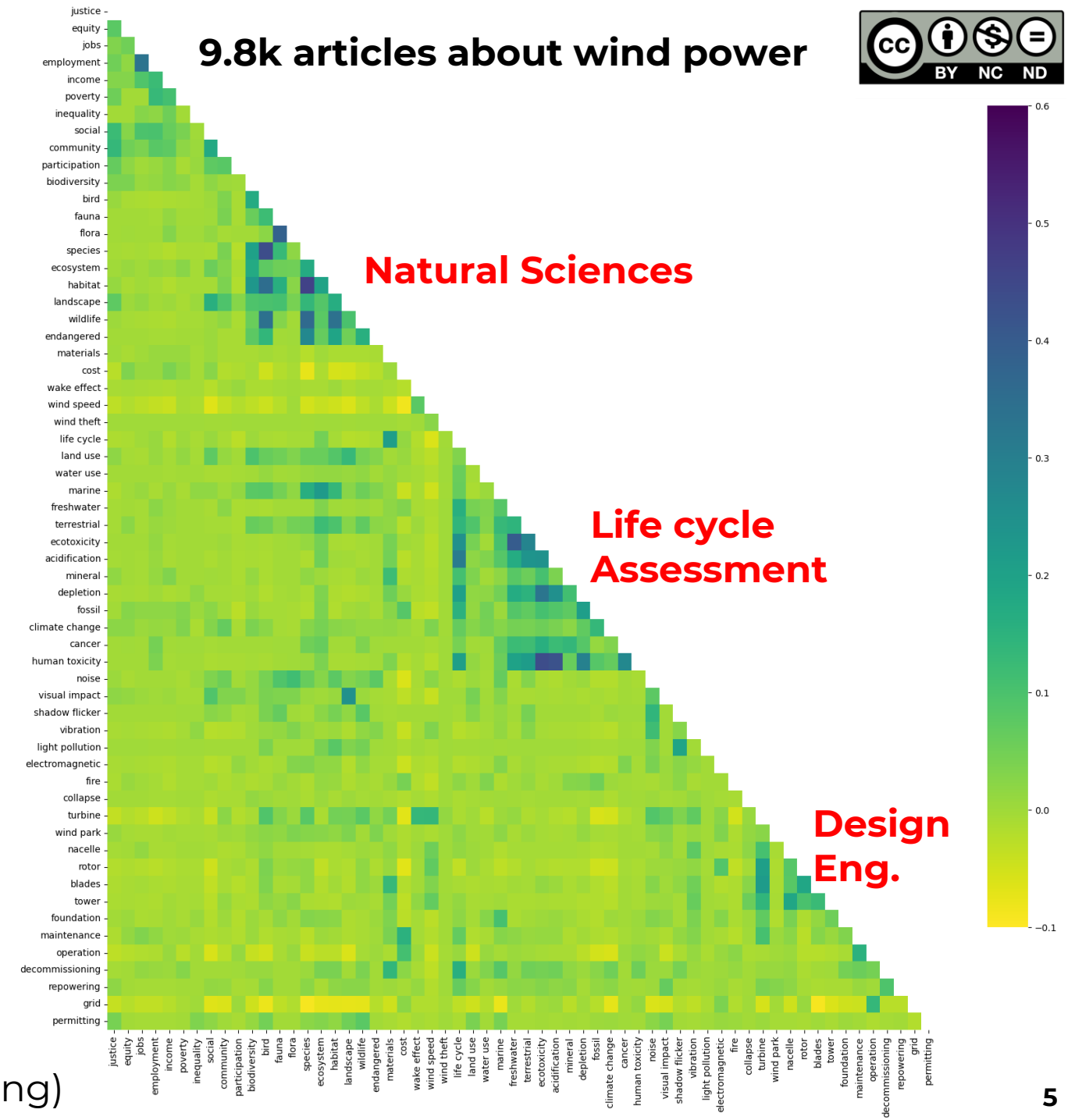
Holistic assessment?

- No answer
- Intuition that we need multiple perspectives
- Literature is also fragmented

Modelling??



(Madrid-López et al, forthcoming)



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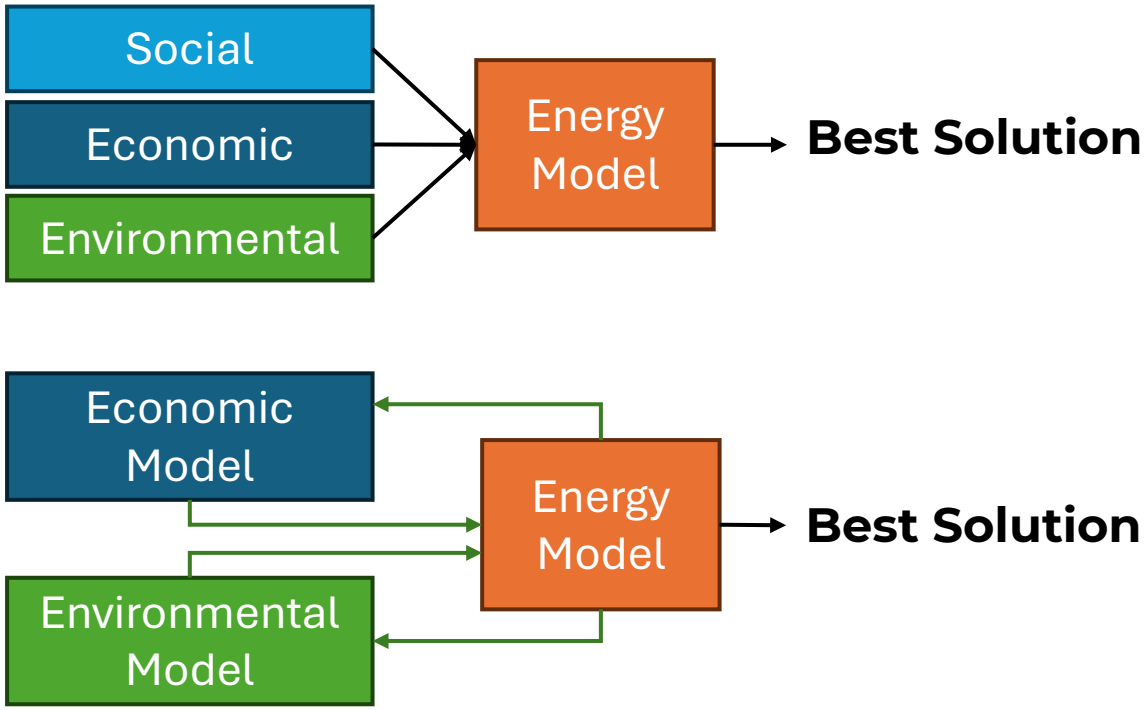

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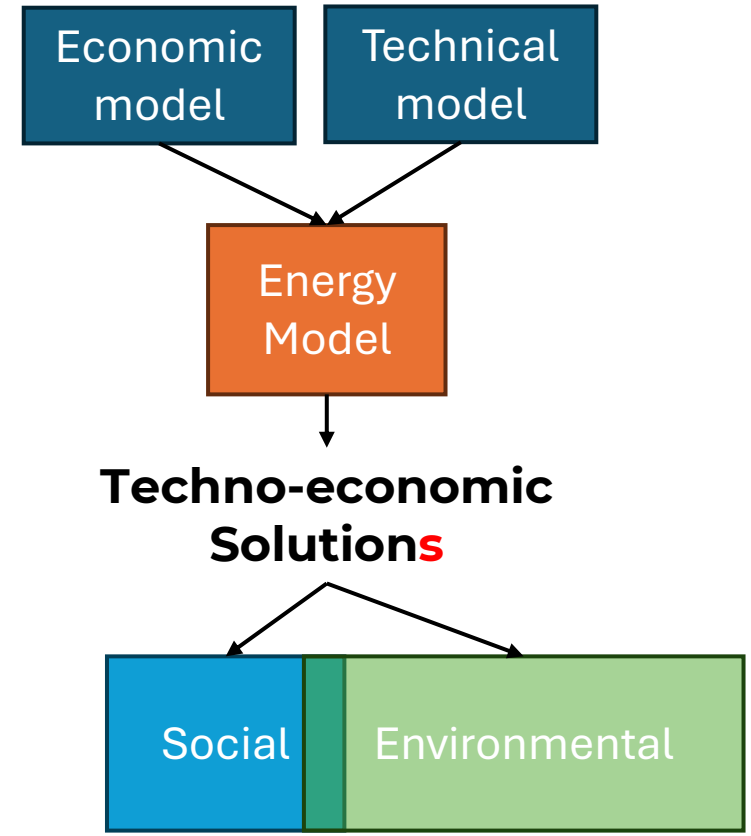
A proposal…



Holon
(Koestler, 1969)

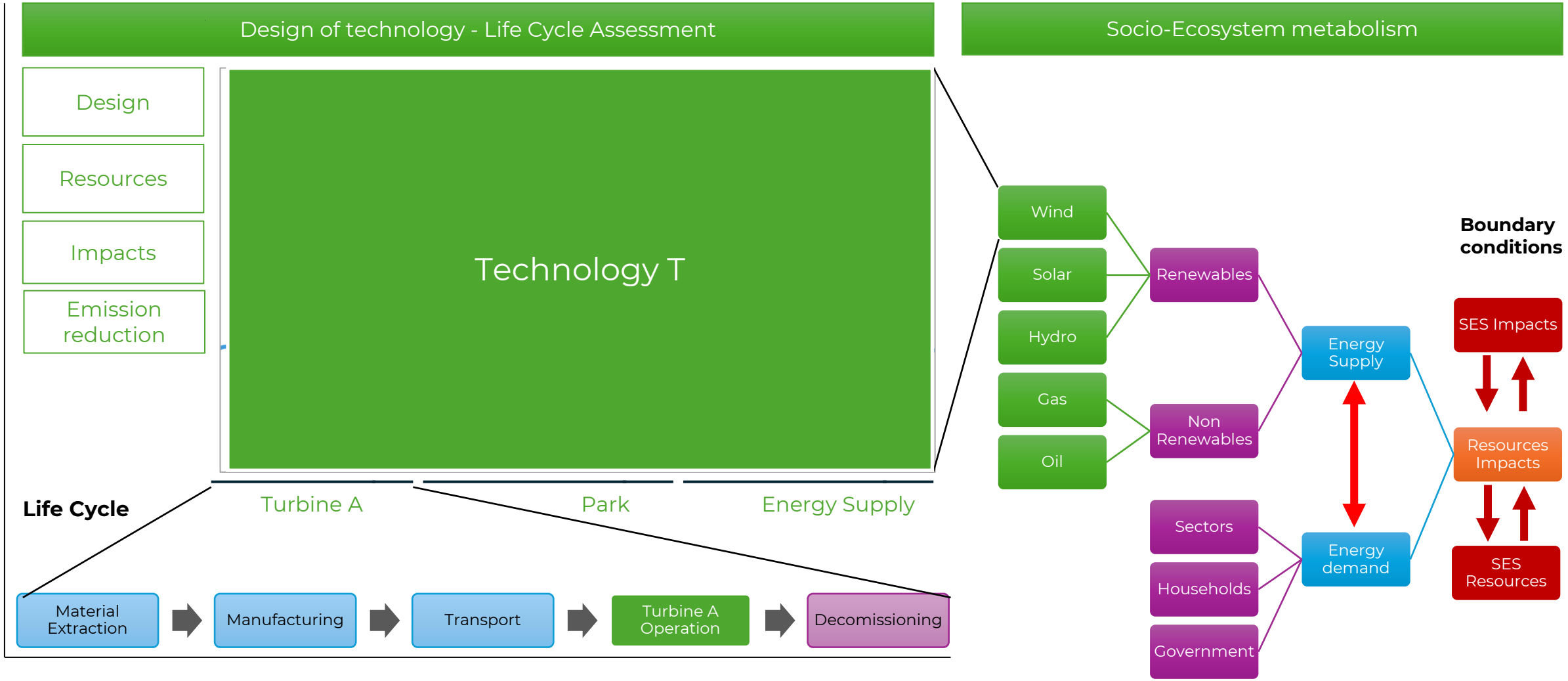
The projects

https://livenlab.org/

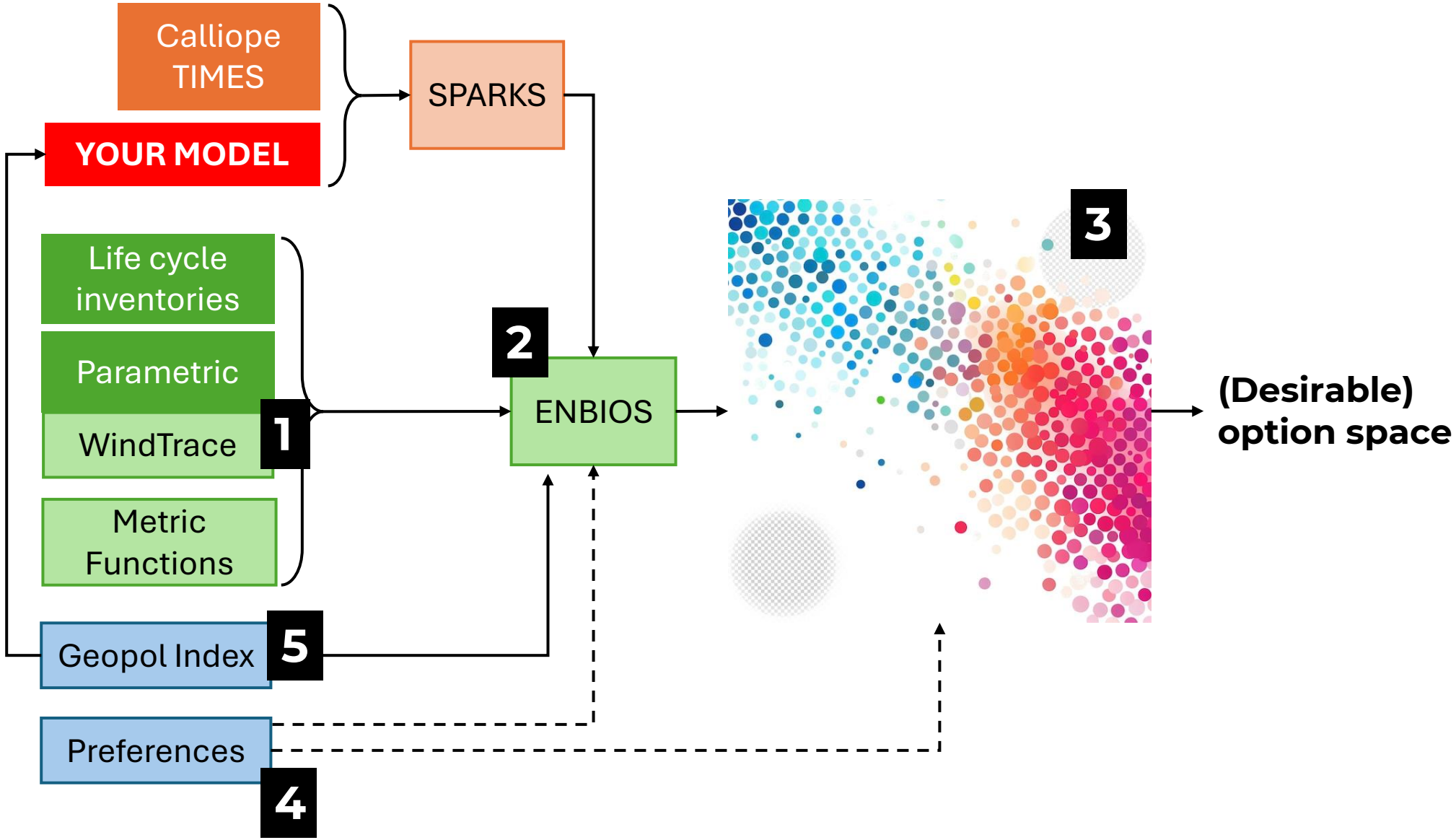
PROJECT (END)	RELEVANCE FOR YOU
SENTINEL (2022)	**ENBIOS**: **Contextualized life cycle assessment module *(C Madrid)*** for softlink with Calliope framework (S. Pfenninger)
LIVEN (2024)	**ENBIOS python package *(R. Soleymany)***; Separation of **onsite and offsite life cycle inventories *(M. Sierra)*; regionalized assessment** methods ***(C. Madrid)***; Correlation rural and infrastructure ***(C. Pérez)***
SEEDS (2024)	**Environmental option space + uncertainty *(A de Tomás)*** for suboptimal SPORES (F. Lombardi) with Calliope (S. Pfenninger) framework, based on social values (I. Campos et al).
ETOS (2025)	**Calliope ESOM for Spain *(A.de Tomás)***; **Geopolitical vulnerability** index for ESOMs ***(Y. Kisyova)***; **Environmental displacement** analysis ***(A.C. Finkelstein)***
JUSTWIND4ALL (2025)	**WindTrace: Python parametric builder & DB** of life cycle inventories for turbines ***(M. Sierra)*** **WindSES**: Holistic assessment set of **metrics based on socio-ecological relations *(C.Madrid)***
LIVEN2 (2028)	ENBIOS **Softlink with TIMES *(C Mantilla)***; **Qualitative public perception** in ESOMs ***(C. Madrid)*** **SPARKS: Python workflow connecting ENBIOS with ESOMs. *(A.de Tomás)***
COMPASS (2029)	**ENBIOS_OWF**: Python socio-ecological impacts to insert in optimization of OWF ***(C. Madrid);*** **Preference set for impact multicriteria & ranking *(C. Madrid);*** **WindTrace_OWF *(M. Sierra)***

Socio-ecological

ENBIOS joins LCA and Socio-ecosystem metabolism (MuSIASEM) to asses **energy scenarios/configurations** (modelled or not)



A workflow for complexity



1. Input data matters

Miquel Sierra

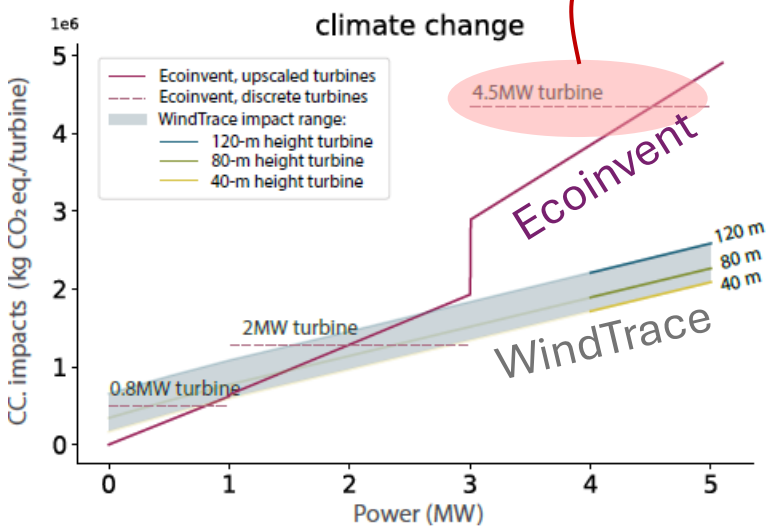
Created **WINDTRACE**, and modeled the **mass of each material as a function of turbine and park parameters**.

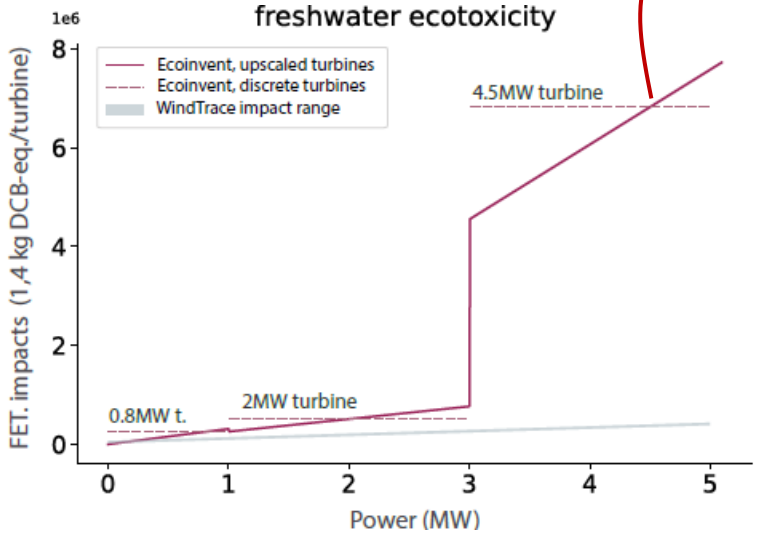
(Sierra-Montoya et al, 2025, JIE)

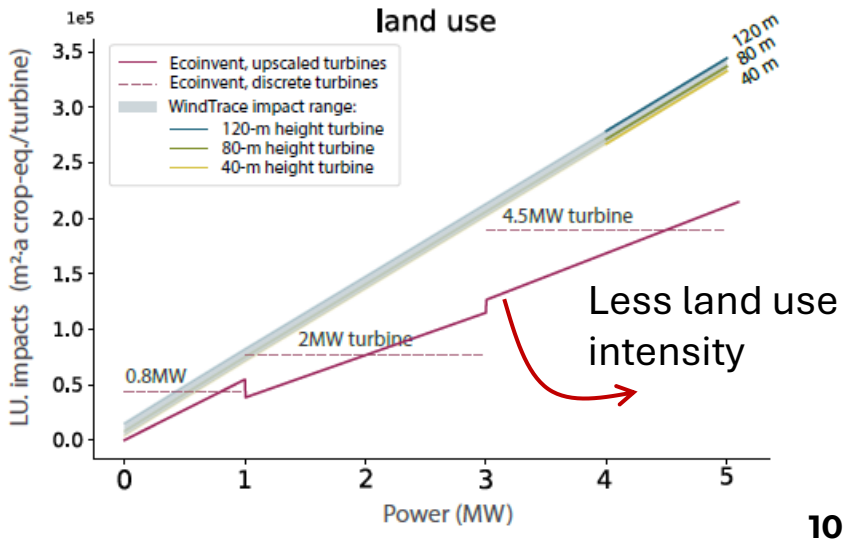
Over or under estimations are significant for impacts when fixed databases are used

Cement tower

EoL: incineration of copper







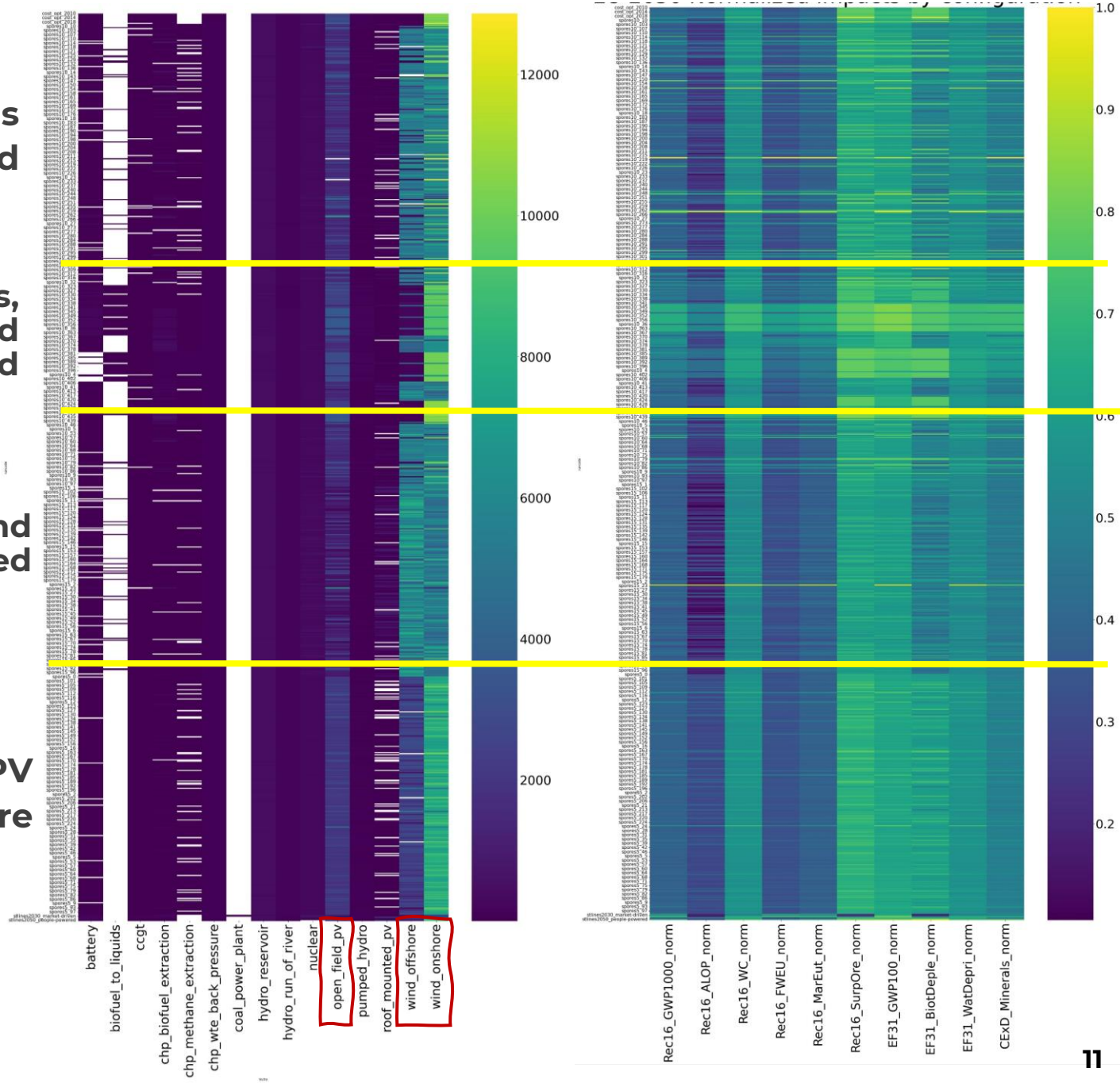
Less land use intensity

2. Socioecological Trade-offs with ENBIOS

Impacts in their own units are OK to understand trade-offs

(Madrid-López et al, forthcoming)

Case	Better	Worse
A. Fossils Mixed	Lower Land occupation	Higher global warming
C Wind Mixed	Lower impacts	Dependency
D PV Onshore	Diverse	Biodiversity loss

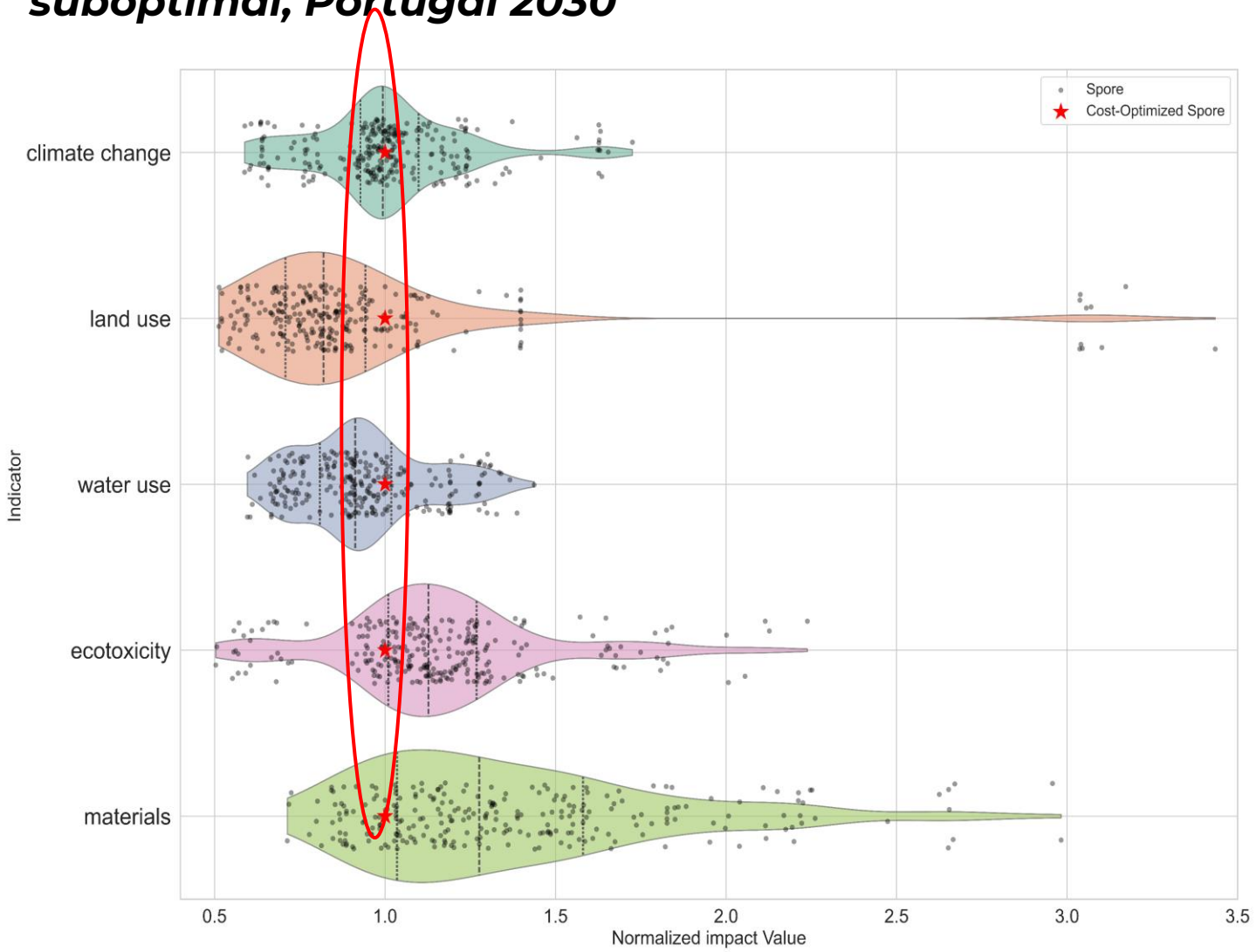


Ca. 900 Scenarios (Pickering et al 2022)

3. Environmental option spaces

Alexander de Tomás

***Environmental option space** of technoeconomic suboptimal, Portugal 2030*



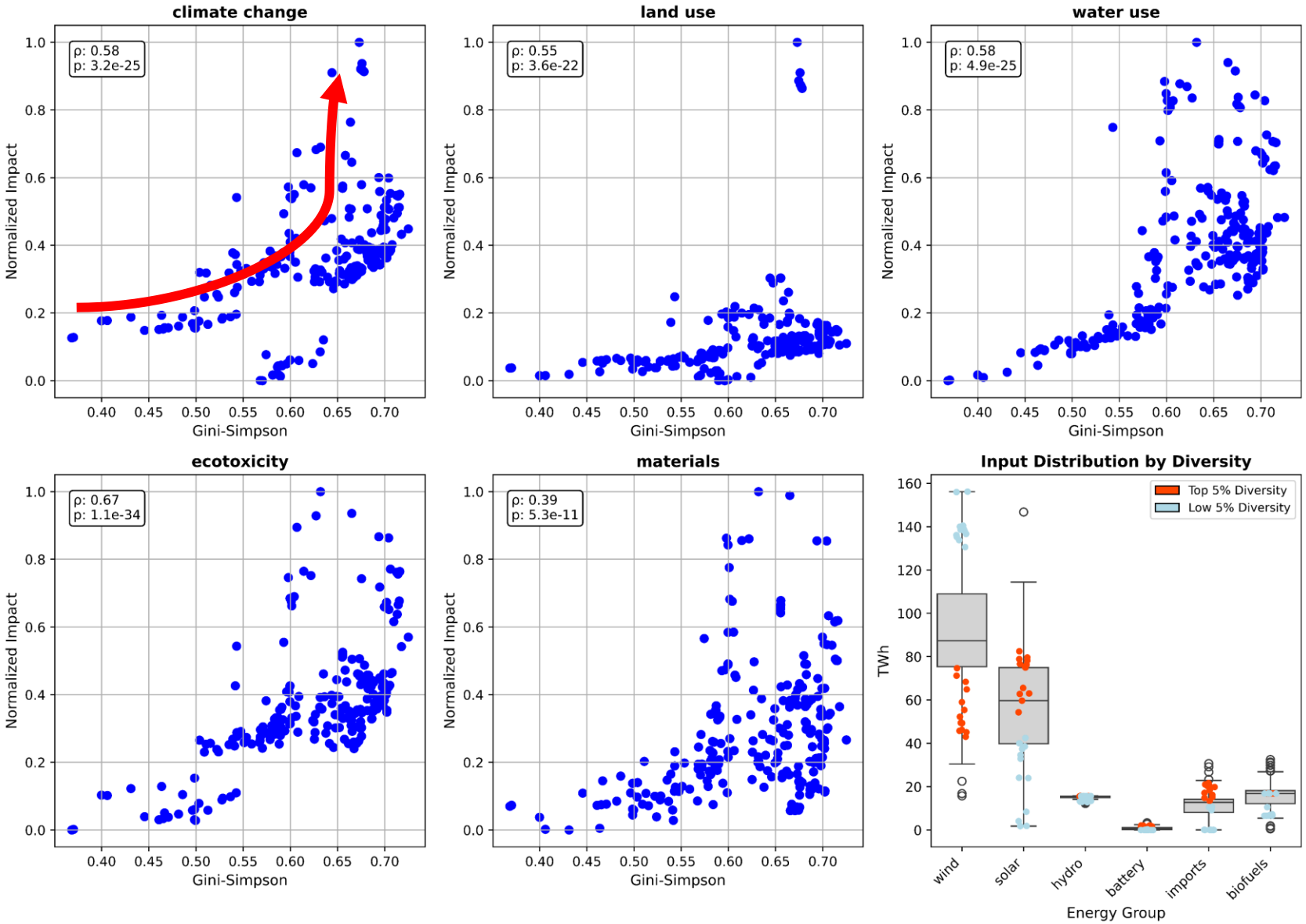
Option spaces better cover the complexity of the impacts. Climate change is not lower, but material use increases

De Tomás et al, 2025, Applied Energy

3. Trade offs in the option space

Alexander de Tomás

Relation between energy mix variability (Gini-Simpson Index) and environmental impact



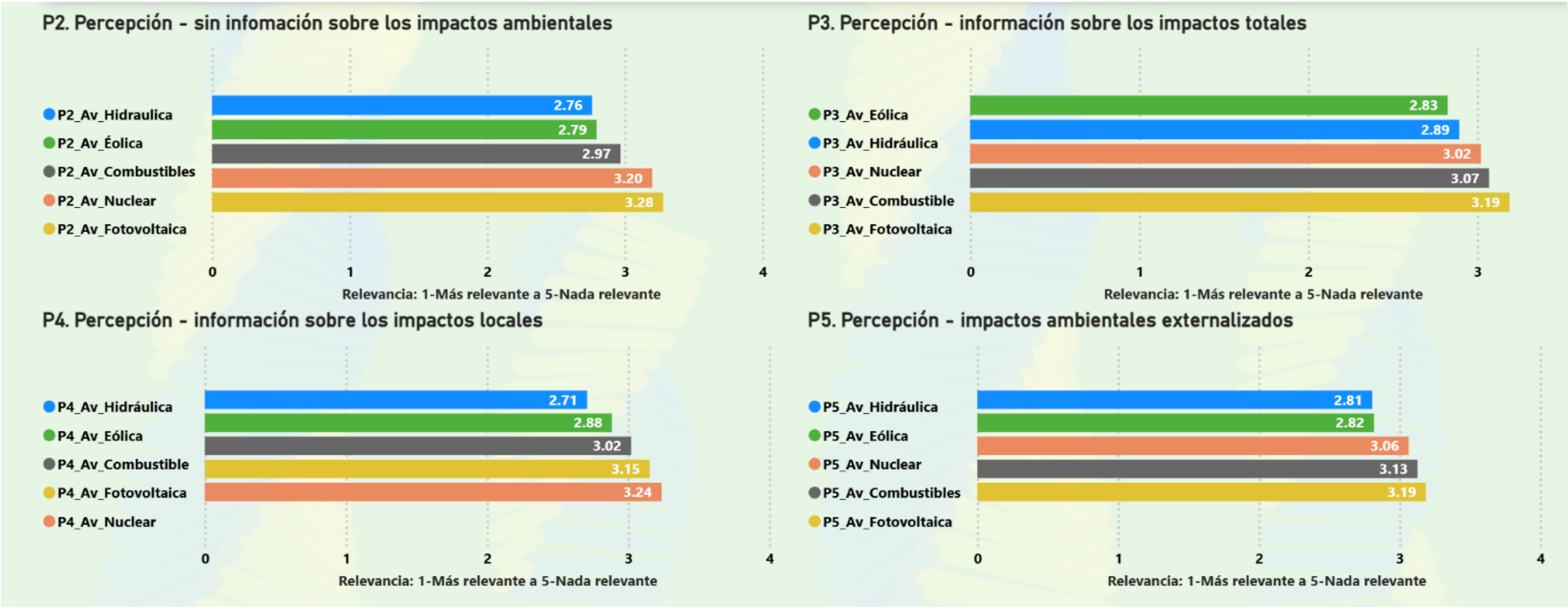
Increased energy system resilience (diversity) comes with increased impacts

De Tomás et al, 2025, Applied Energy

4. Preferences change results

Understanding life cycle impacts changes preferences. Hydro better and nuclear worse for local

Preferred technology without impact information (P2), total impacts (P3), Local impacts (P4), External impacts (P5). Spain 2024. n=3000.

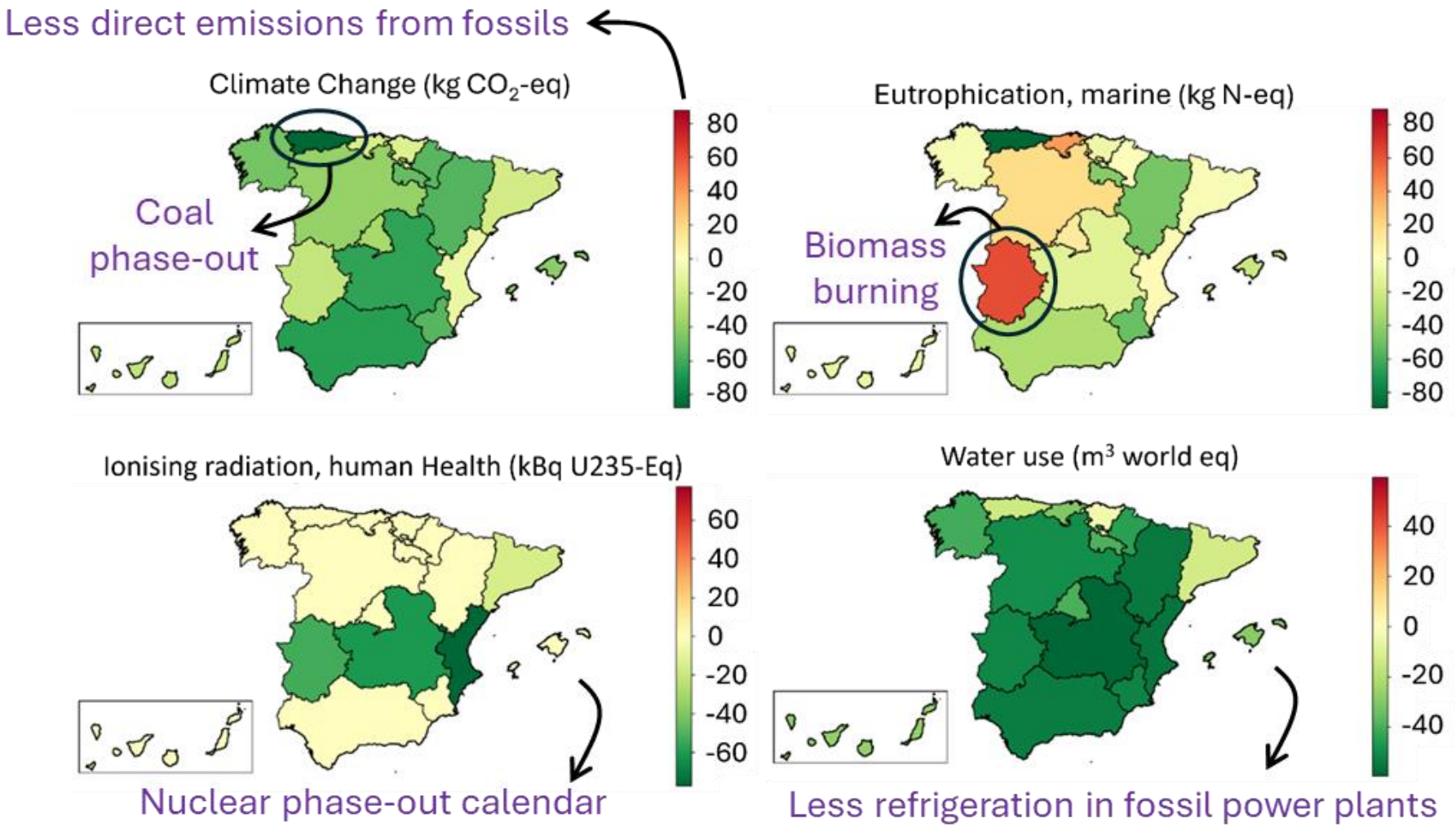


(Madrid-López & Kisyova, forthcoming)

4. Distribution and justice

Miquel Sierra

Distribution of ONSITE impact burden. Spain NECP 2030 VS 2024



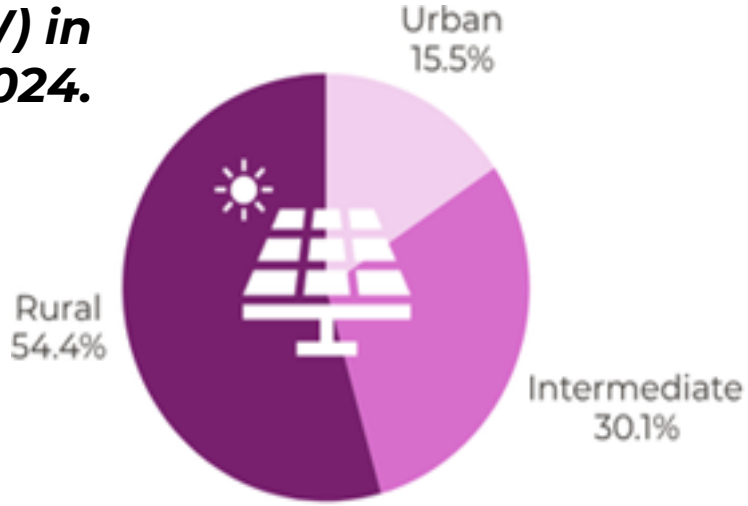
An issue of distributive justice:

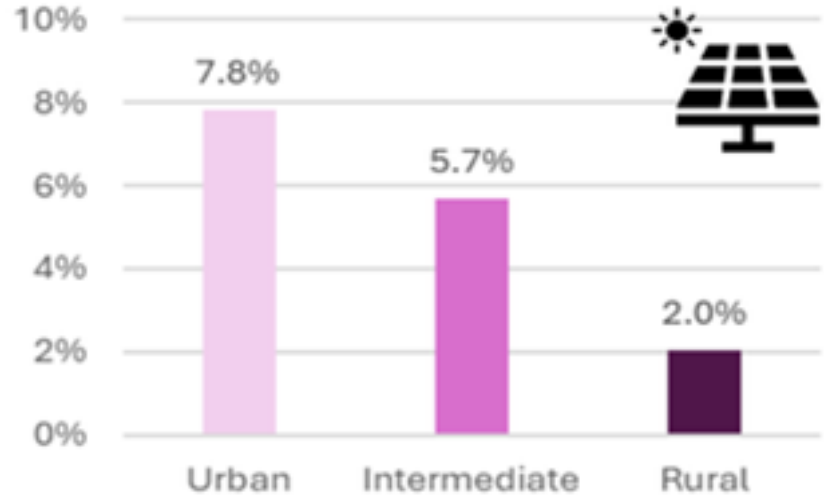
- **Location of the technology matters**
- **Unequal distribution leads to perception of injustice**
- **Lack of acceptance can make models results invalid**

4. Understanding (preferred) locations

Cristina Perez

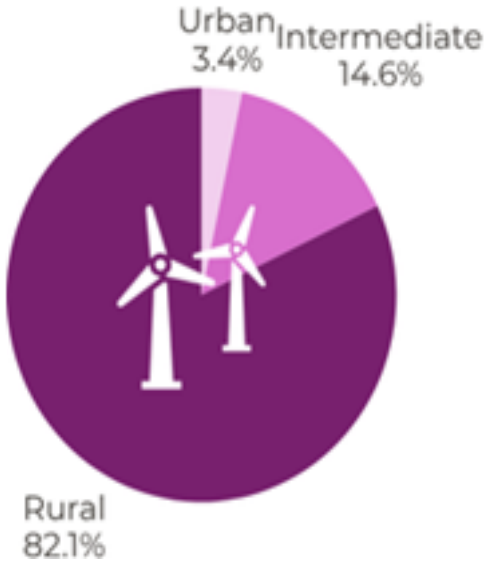
Distribution of big projects (>10MW) in the urban/rural range. Spain 2024.

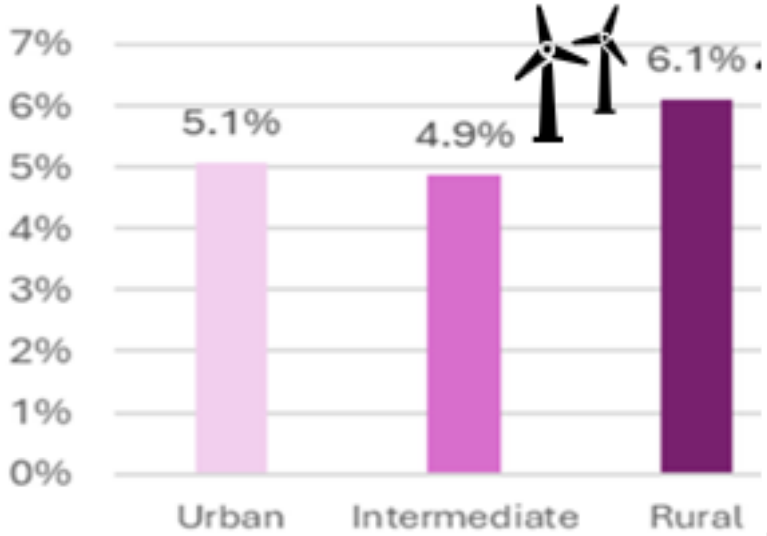




Large-scale renewable projects are unevenly distributed :

- **Most in rural areas but**
- **only 2% of rural areas host solar projects**
- **only 5% of urban areas host PV projects**





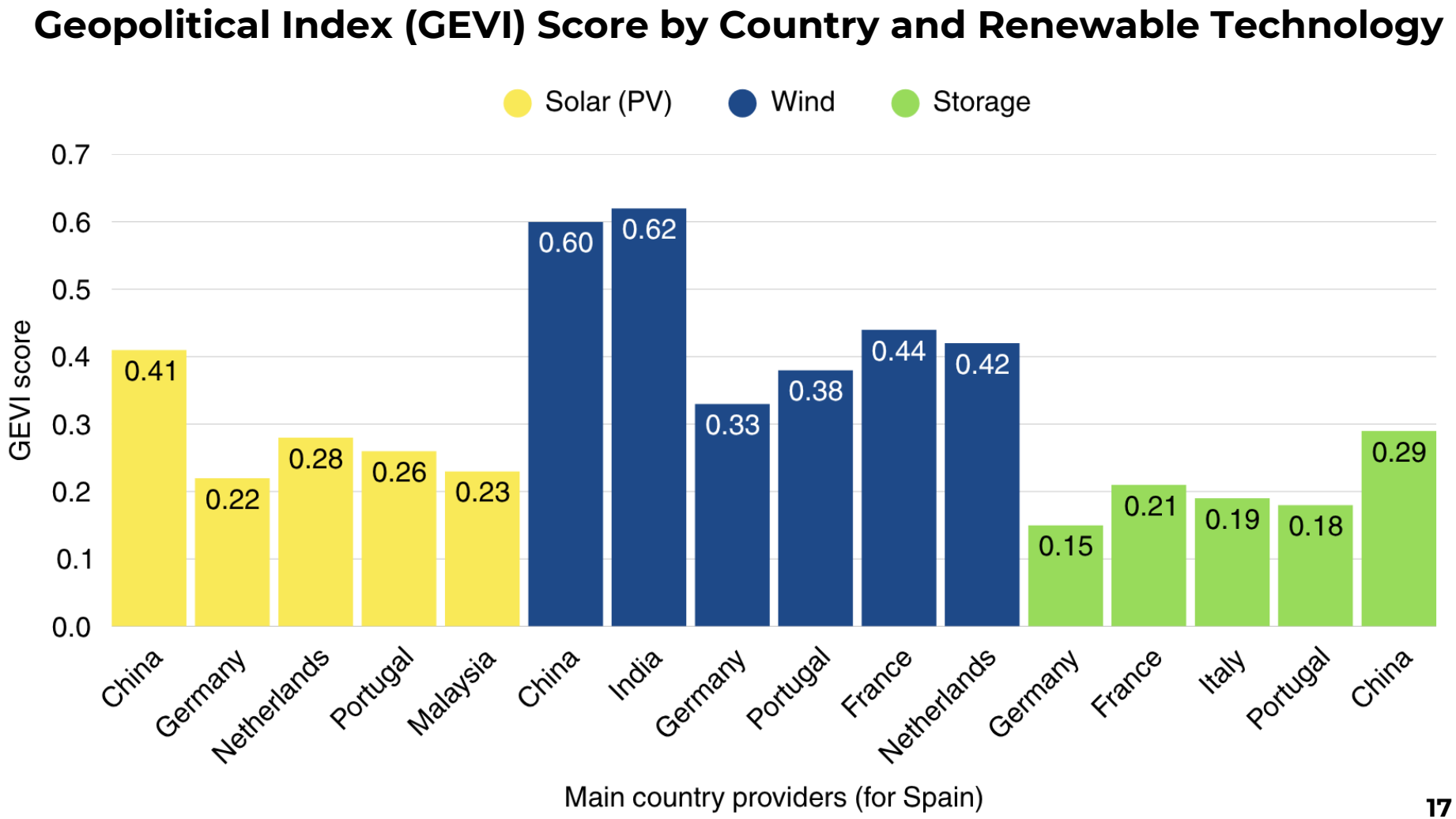
(Pérez-Sánchez et al, forthcoming)

5. Understanding geopolitics

Yoana Kisyova

Wind from China or India will reduce Spain's energy sovereignty more than photovoltaics from China

- **Dependence on Raw Material Imports**
- **Trade Restrictions**
- **Raw Material Concentration**
- **Dependence on Technology Imports**
- **Geopolitical Tensions**

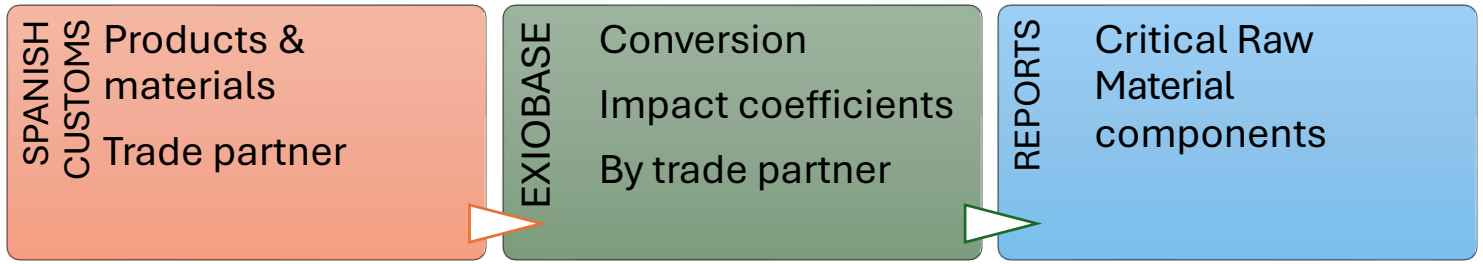


5. Displaced impacts

Alejandro C. Finkelstein

The transition has to avoid shifting impacts from EU to the world because climate change is global

Connecting Trade Data by product with EXIOBASE



Finkelstein et al. In Review. Ecological Economics

3,000 gasoline-powered cars

Displaced impacts related to imports of Wind ...e-related materials. Spain 2021.

CRMs	Product	Trade partner	Import value (thousand euros)	G... house gas issions (t ...O2 eq.)	Total blue water consumption (Mm3)	Used domestic extraction of non-ferrous metal ores (kt)	Land use (km2)
Nd	Wind Turbine 850231 (HS)	China	28,423 €	14,912	0.61	2.2	28.3
Pr		India	16,563 €	8,690	0.36	1.3	16.5
Dy		Germany	10,095 €	5,296	0.22	0.8	10.1
Tb		Portugal	1,902 €	998	0.04	0.1	1.9
		France	276 €	145	0.01	0.02	0.3

Take home messages

To deal with complexity and reach a SUSTAINABLE (not only clean) energy system…

Holistic modelling must include socio-ecological relations

Is not a matter of including more and more parameters

Parameters might change with the case

Explore new workflows

IA Suites and all-inclusive energy models are not the only alternatives.

Respect semantics and analytical scales and levels

There is no unique solution

We need to explore spaces to understand our options

Optimals can be dangerous and lead to problem shifting

How to include social and environmental aspects in your modelling:

A summary of insights from five projects

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