Navigation tools for the energy transition: from technology to the environment to people

André Bardow
ETH Zurich
ESI Seminar, 30 November 2022

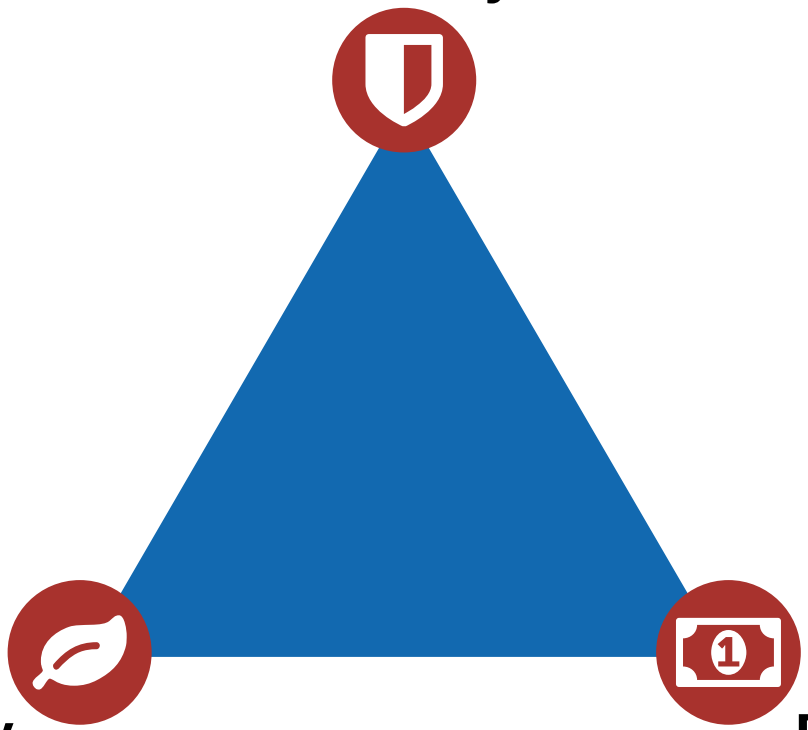
The “Energiewende”

https://www.bee-ev.de/service/pressemitteilungen/beitrag/energiewende-im-braunkohlerevier-umsetzen

Why the Energy Transition ? The Energy trilemma

availability of sources
ensuring transport of energy

Security

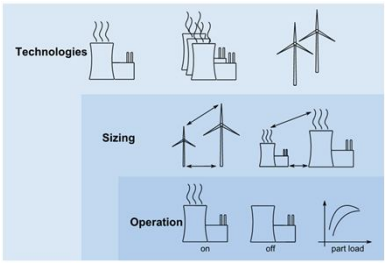


Sustainability
climate protection
life cycle

Equity
price development
competition

Navigation tools for the energy transition

Energy systems



Complex question

Hitchhiker's guide

The Ultimate Question of Life, the Universe, and Everything

Computing

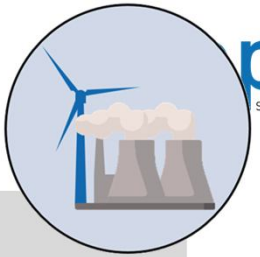
Computing Power & Time

„Deep Thought"

7.5 million years

⇒ Efficient algorithms for design of energy systems needed

SecMOD: Combining energy system optimization and LCA



pse
SYSTEMS ENGINEERING

Christiane Reinert

Sarah Deutz

Nils Baumgärtner

David Shu

SecMOD

First open-source software framework to integrate LCA and energy system optimization!

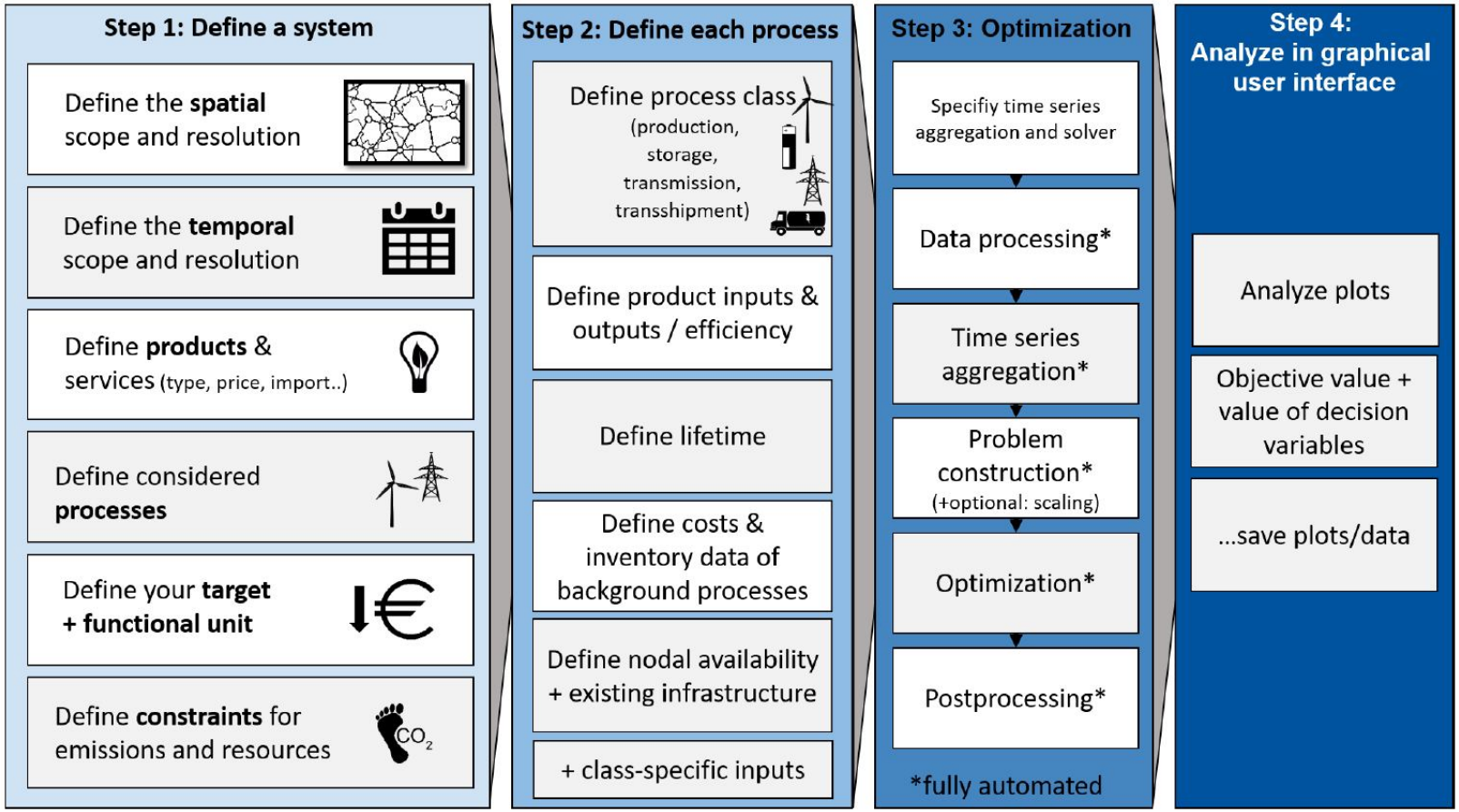
SCAN ME

User-friedly application at multiple scales!

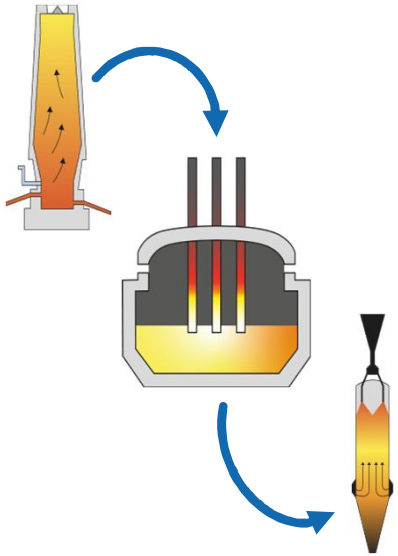
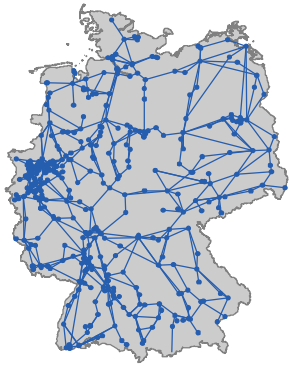
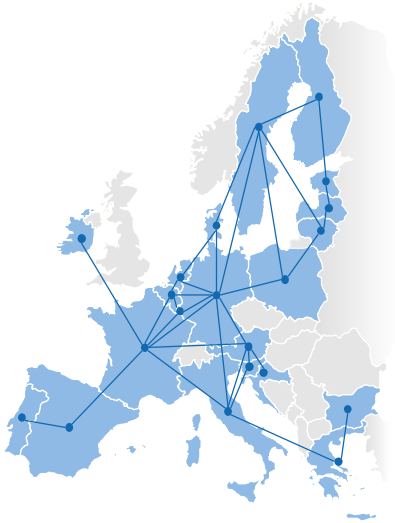
ETH zürich

Reinert et al., *Front. Energy Res.*, 2022
https://doi.org/10.3389/fenrg.2022.884525

SecMOD: Workflow



Multi-scale applications of SecMOD: examples at flexible resolution

Site level	National level	International level
		
optimal production routes in steel plants[1]	optimal transition path & LCA of national energy systems[2]	transition of the European electricity system[3]

Energy transition: from tech to the environment to people

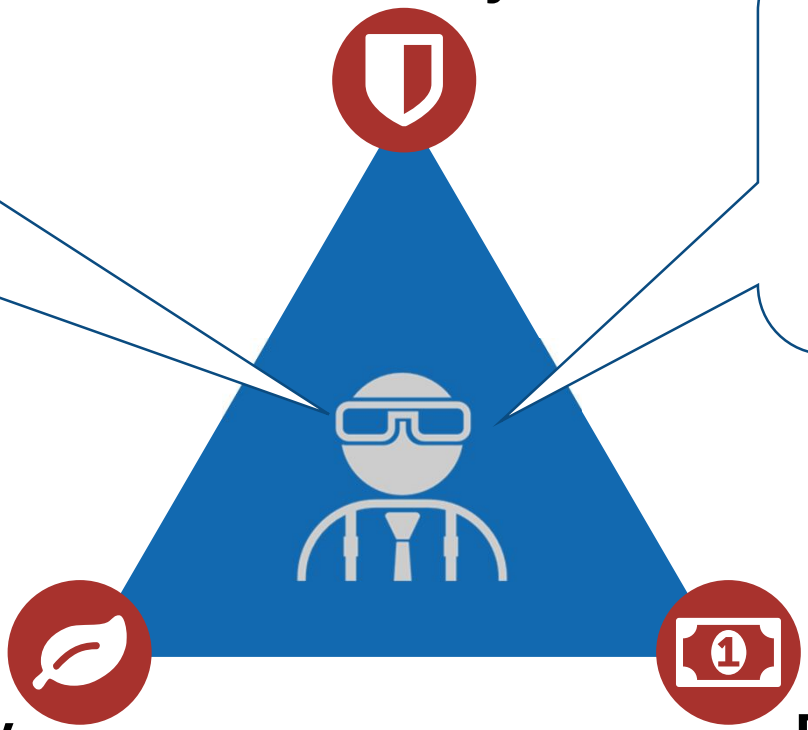
availability of sources
ensuring transport of energy

Security

Yes, I want

the energy transition…

… but not in my backyard !



Sustainability

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life cycle

Equity

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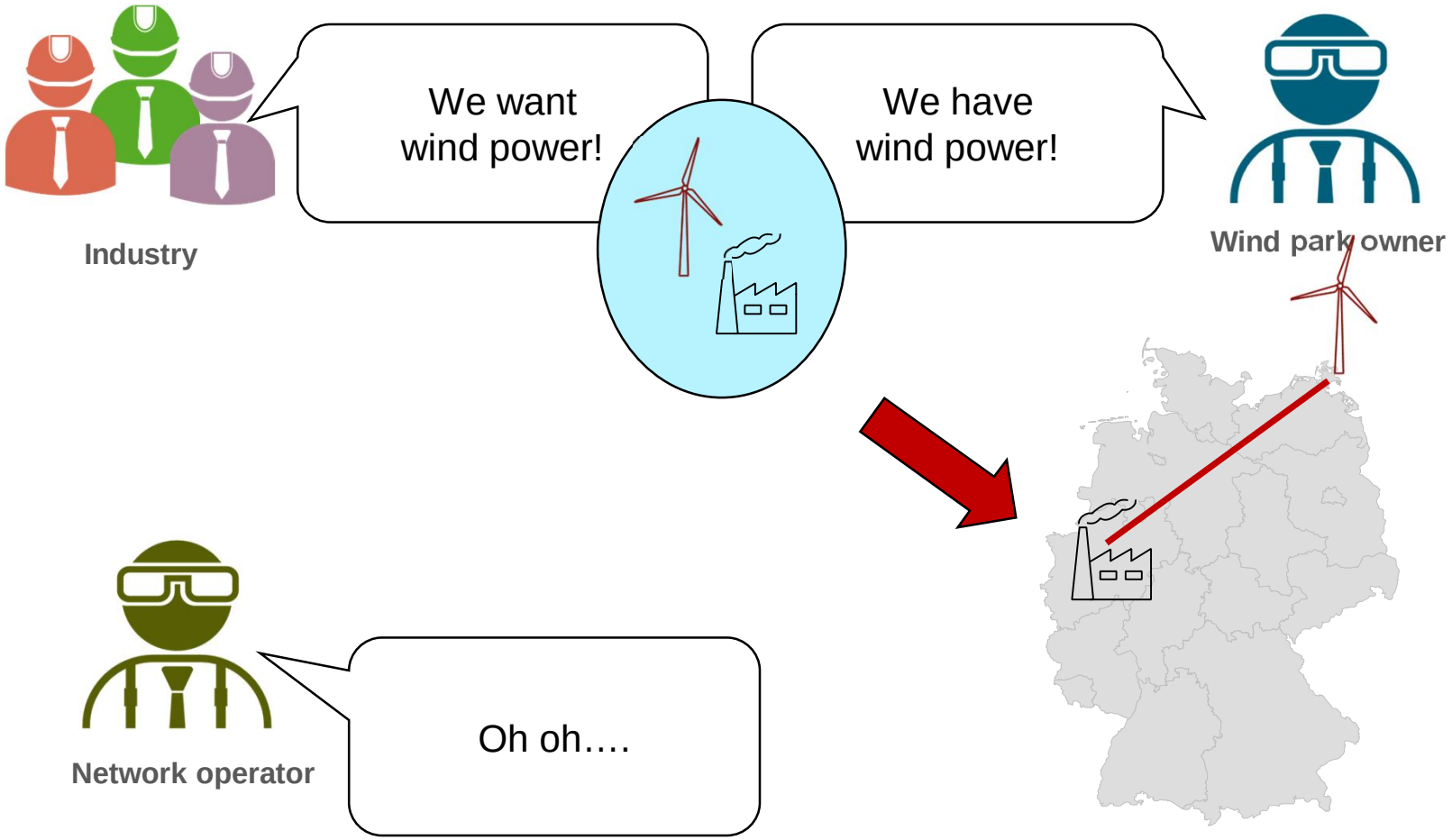
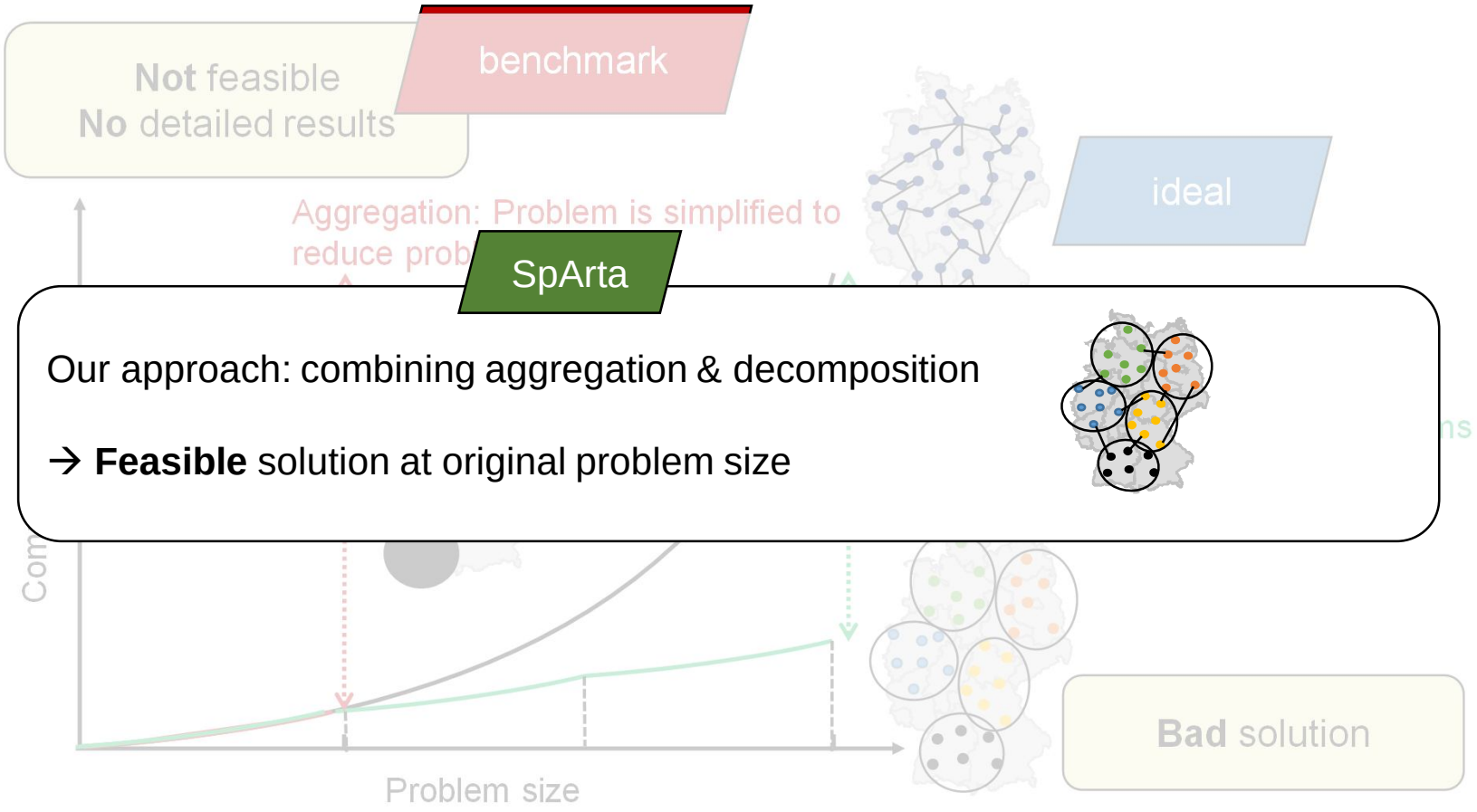
Why the copperplate approach isn‘t enough

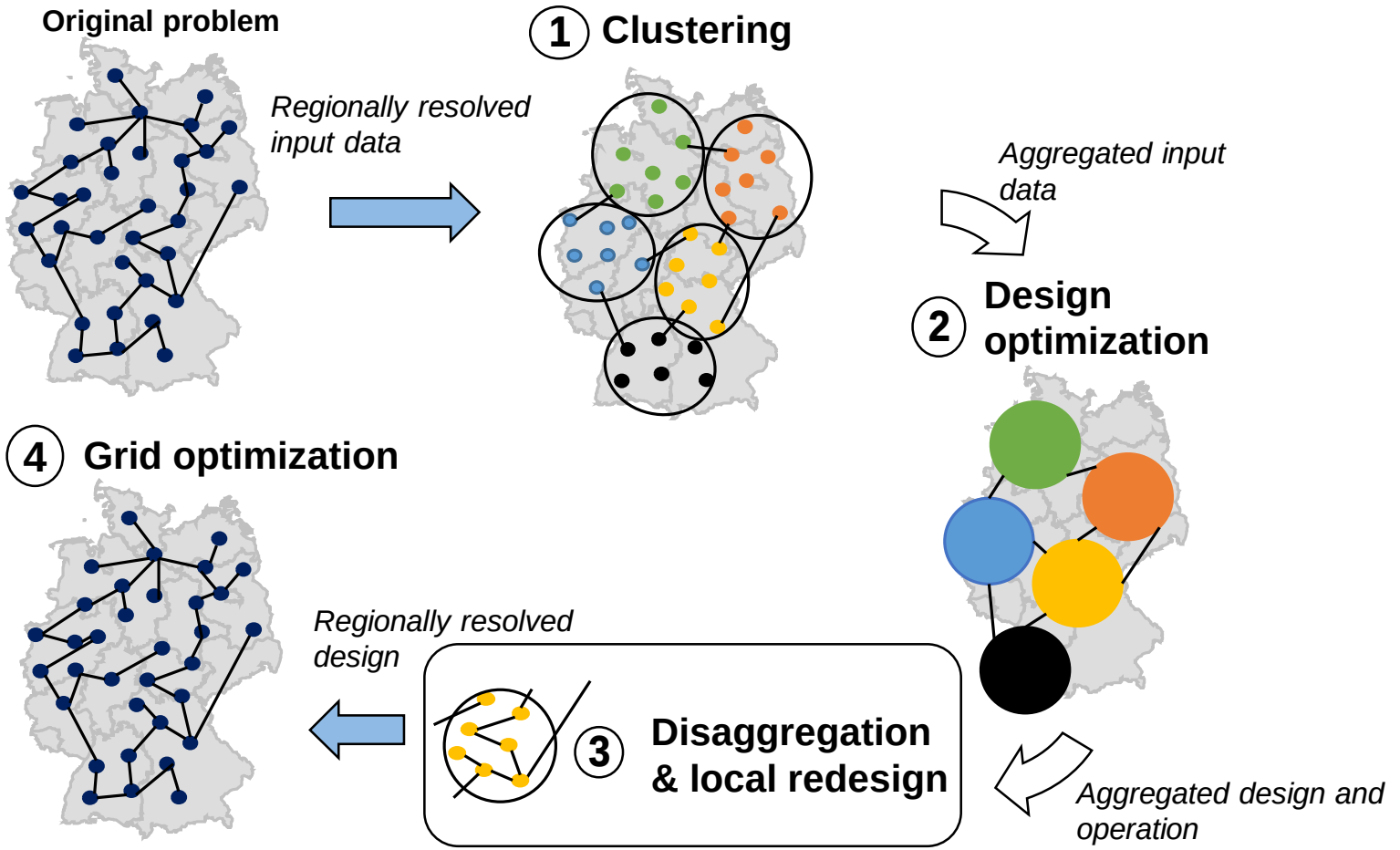
Christiane Reinert



The challenge: computational time

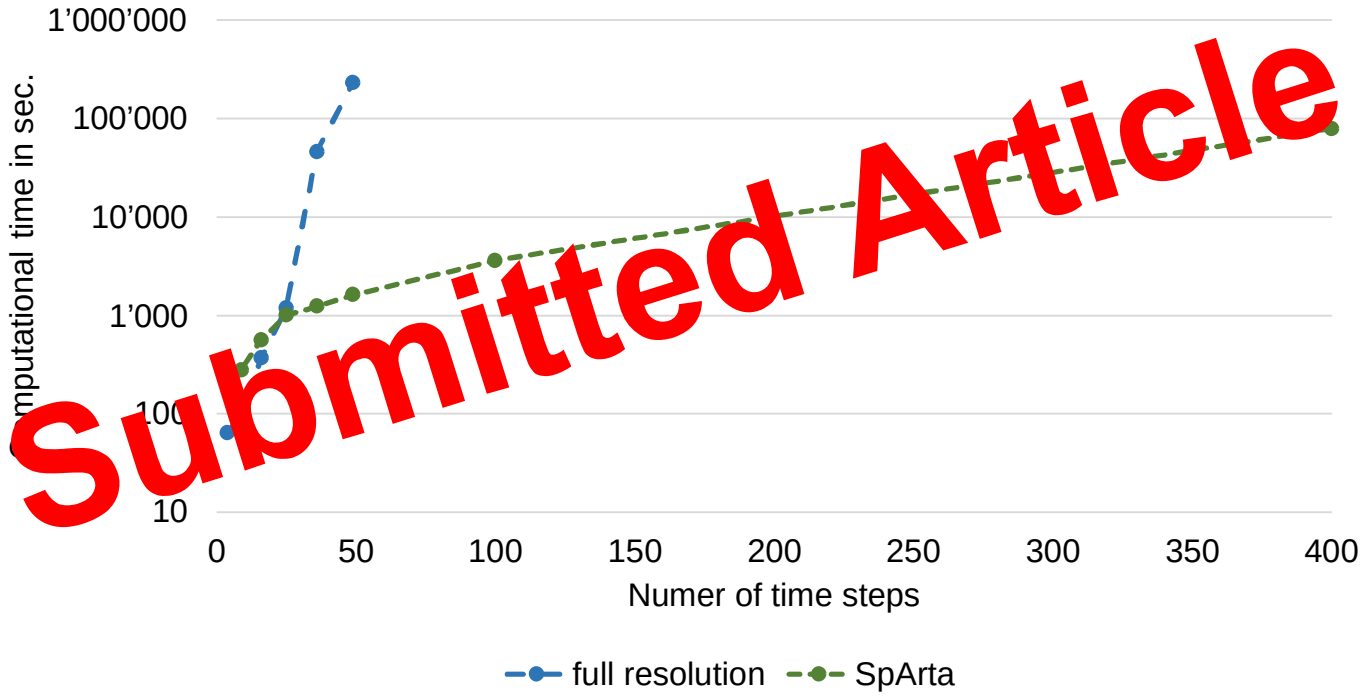


The SpArta method: Spatial Aggregation and decomposition



Results: computational time of SpArta compared to full-scale

- Comparison of computational time with SpArta and fully resolved system (416 nodes)



Increase in tractable problem size by almost a factor of 10!

Energy transition: from tech to the environment to people

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Let’s save the climate…

… by killing all the fish ?

Sustainability

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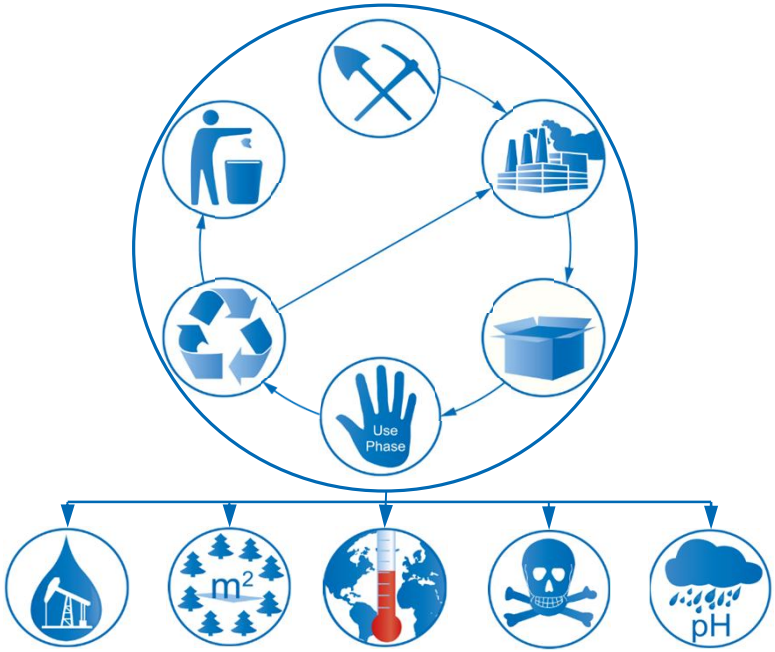
Life-cycle assessment (LCA): Quantifying environmental burdens



Standardized methodology

- Quantify environmental impacts over the whole life cycle
- Numerous environmental impacts
- ISO 14040 + ISO 14044
- Allows quantitative comparison between processes or systems of the same function

Matrix notation of SecMOD = energy hubs = LCA

Matrix notation allows direct interface between energy system optimization and LCA

LCA notation

$$\underbrace{A}\ s \quad = \underbrace{f}$$

technology matrix — functional unit

$$\underbrace{Q}\ \underbrace{B}\ s = \underbrace{h}$$

specific cost — environmental & economic cost

Flexible extensibility

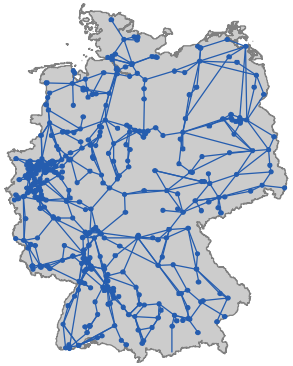
Process A

$$\begin{pmatrix} \cdots & -1 \\ \cdots & -0.5 \\ \ddots & \vdots \\ \cdots & 1.5 \end{pmatrix} s = \begin{pmatrix} 0 \\ 0 \\ \vdots \\ 1 \end{pmatrix}$$

Product 1
Product 2
Product 3

$$A \qquad s = f$$

Multi-scale applications: LCA of the German electricity system

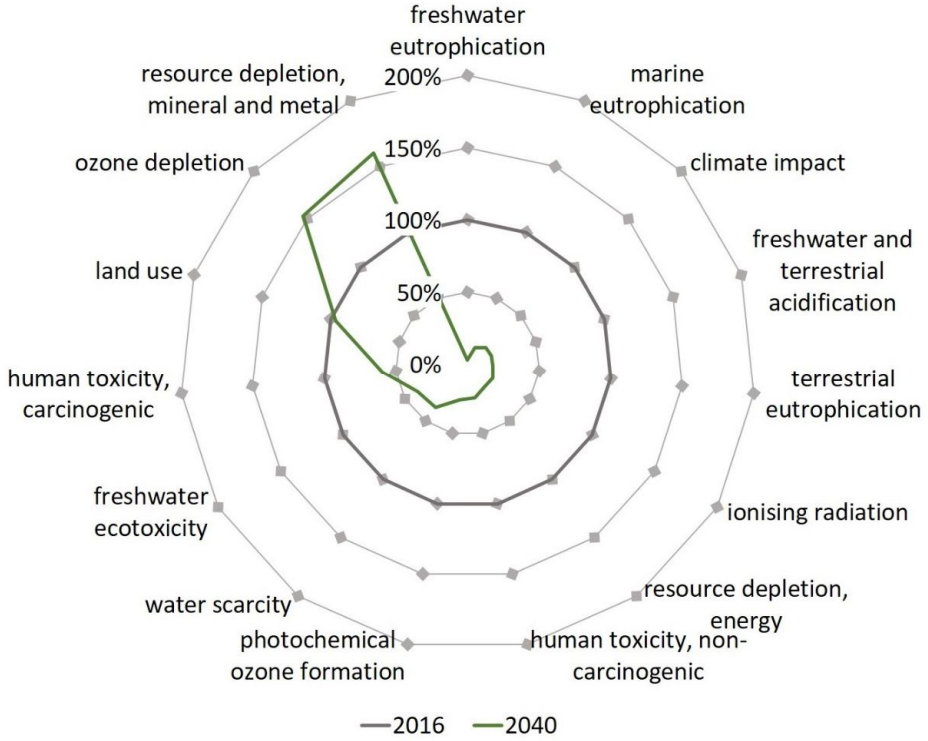


aggregated to 10 days with 24 typical time steps

- 18 nodes connected by transmission grid
- 8760 time steps
- island system

based on ecoinvent 3.5, impact categories based on ILCD 2.0

operational GHG emission reduced to -88% by 2040

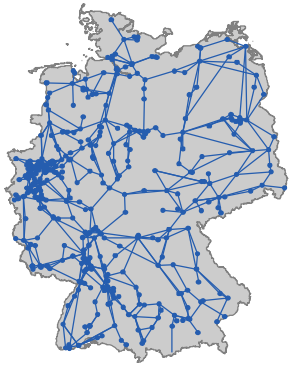


Sarah Deutz

Nils Baumgärtner

Baumgärtner, Deutz et al. *Front. Energy Res.*, 2022

Multi-scale applications: LCA of the German electricity system



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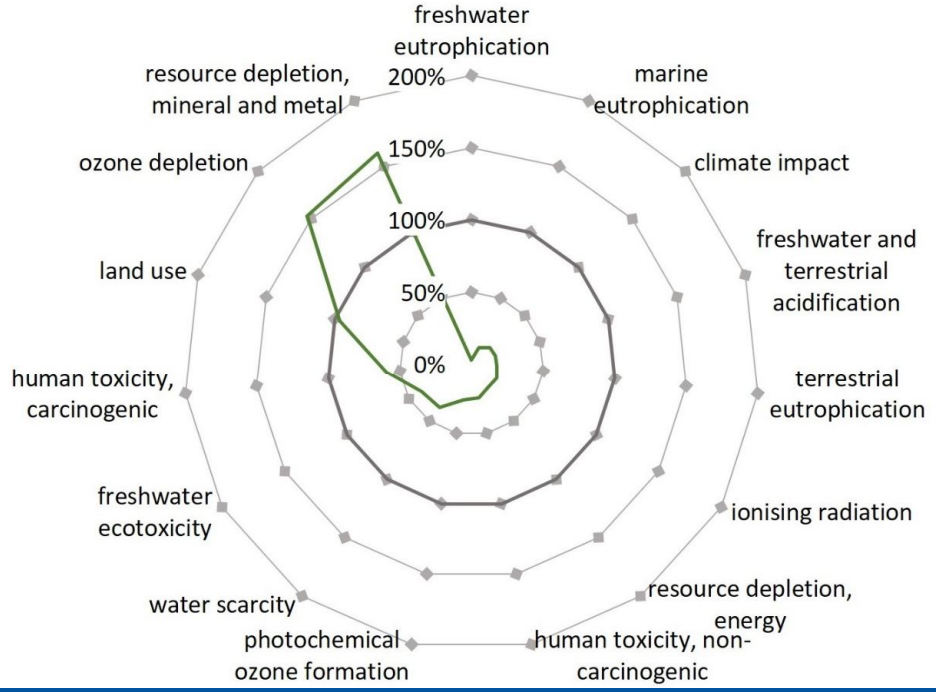


Sarah Deutz

Nils Baumgärtner

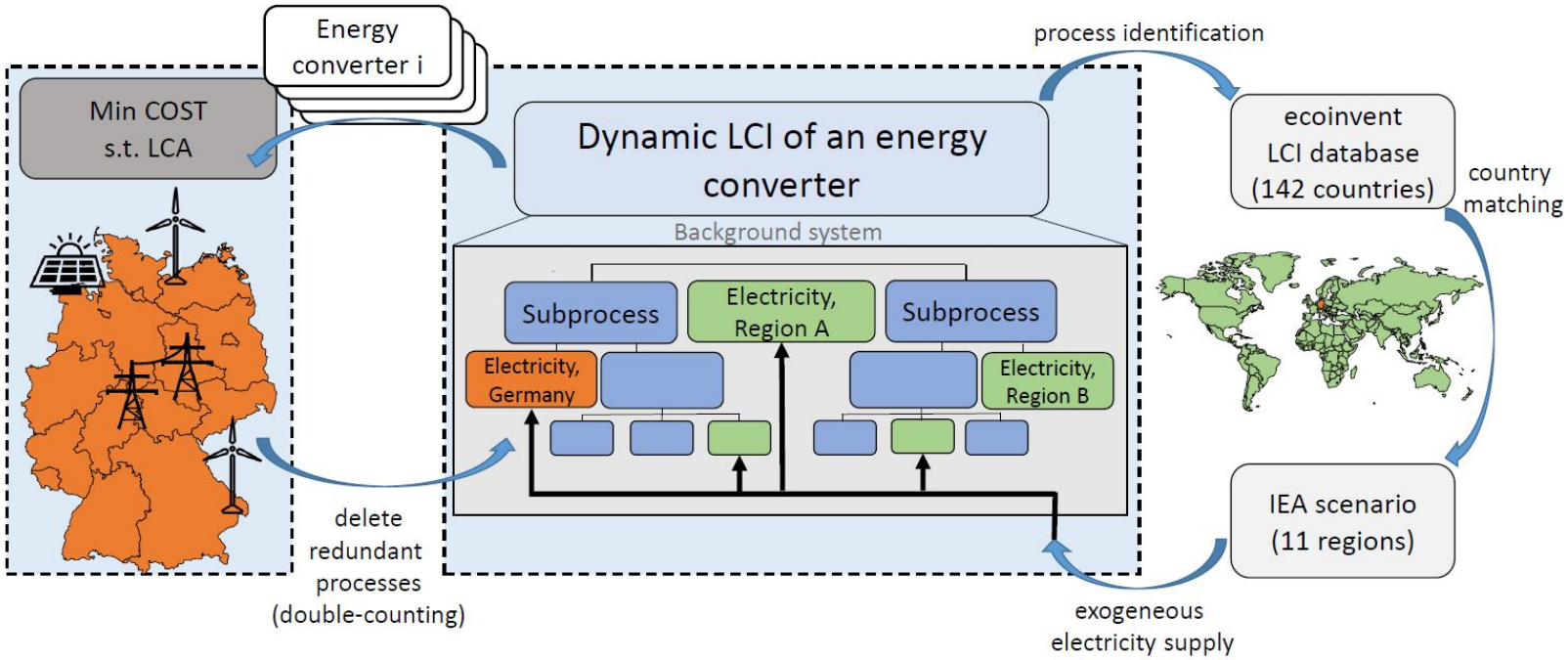
- The energy transition has many environmental co-benefits
- But also unwanted side-effects we need to take care of

Baumgärtner, Deutz et al. *Front. Energy Res.*, 2022

Dynamic LCA: Is it important that the rest of the world employs clean energy, too?

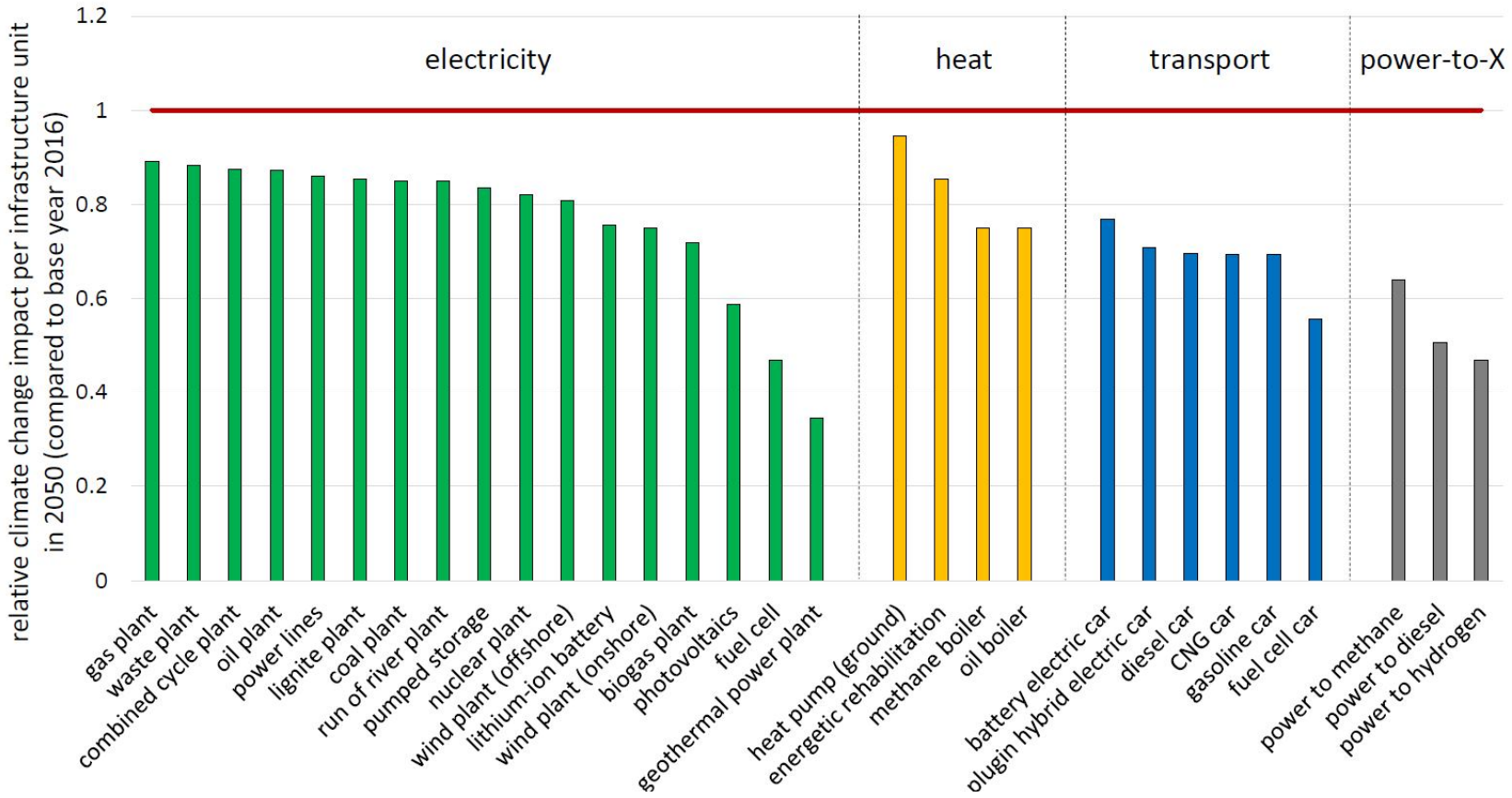
- LCA is based on static data, does not consider long-term changes in supply chains

→ No consideration of energy transitions beyond our system boundary!



Reinert et al. *Comput. Chem. Eng.*, 2021

Infrastructure impacts



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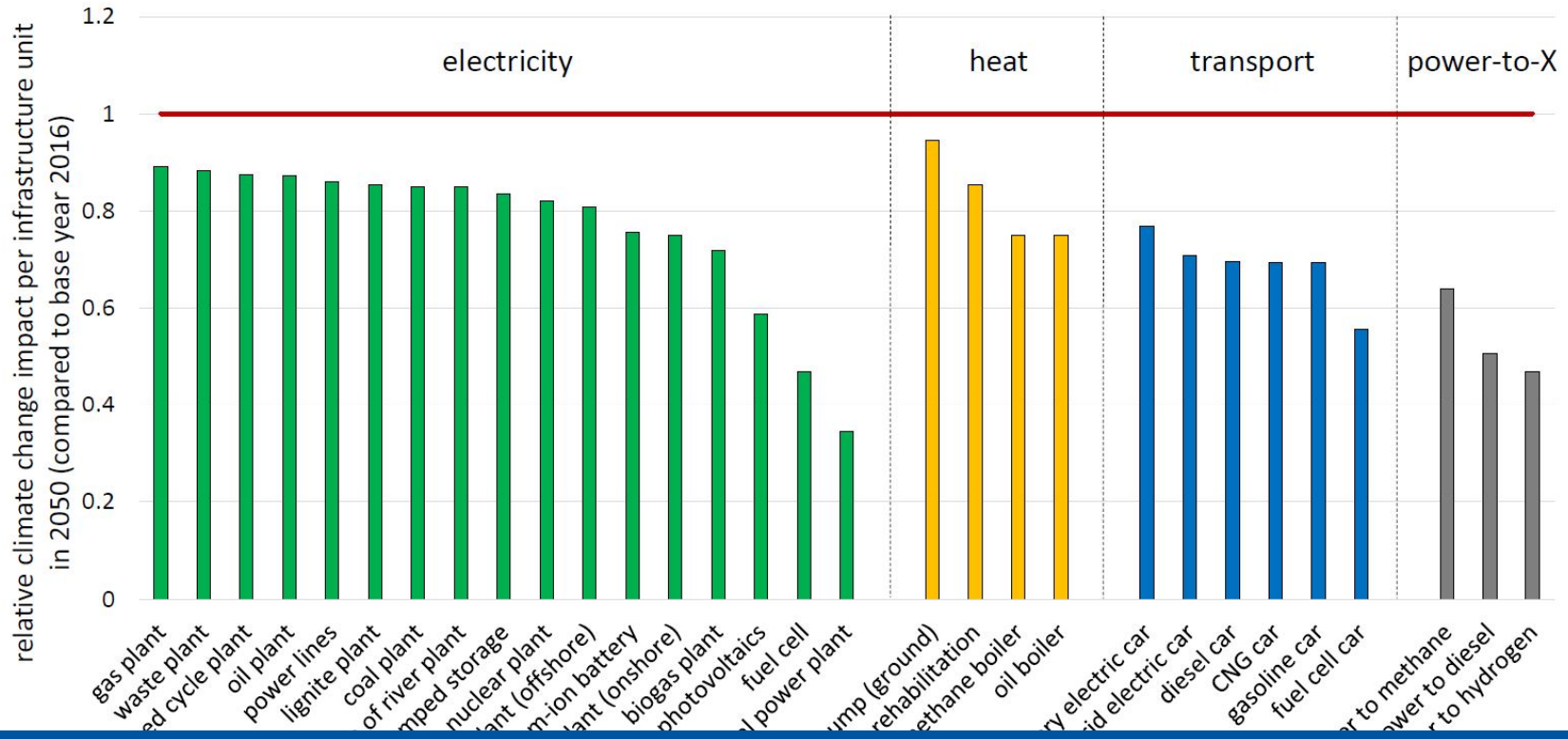


- Impacts shift from operation to infrastructure
- Dynamic LCA allows to consider the energy transition in LCA

Reinert et al. *Comput. Chem. Eng.*, 2021

Energy transition: from tech to the environment to people

availability of sources
ensuring transport of energy

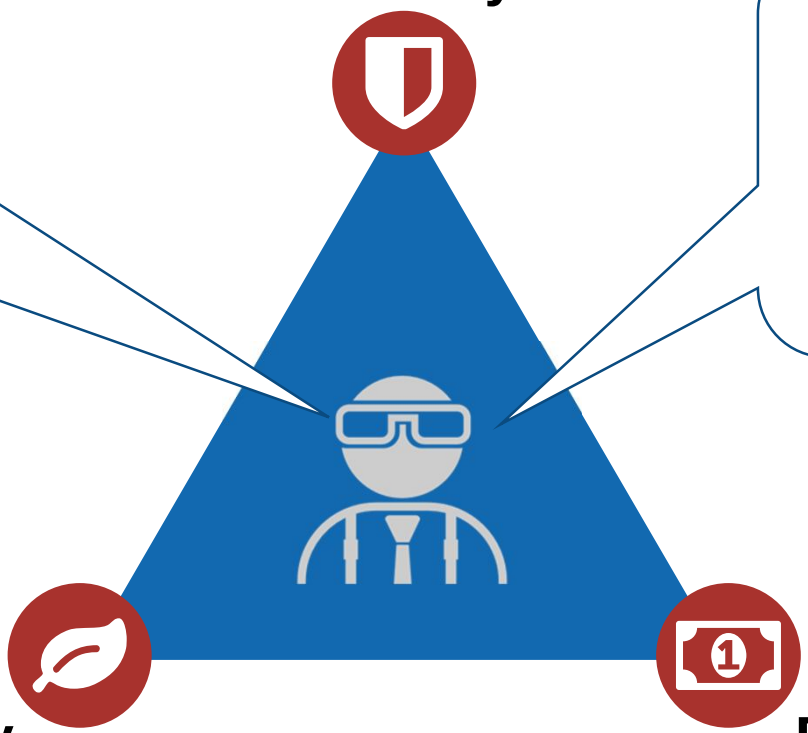
Security

Yes, I want

the energy transition…

… but not

using CO_2 storage !



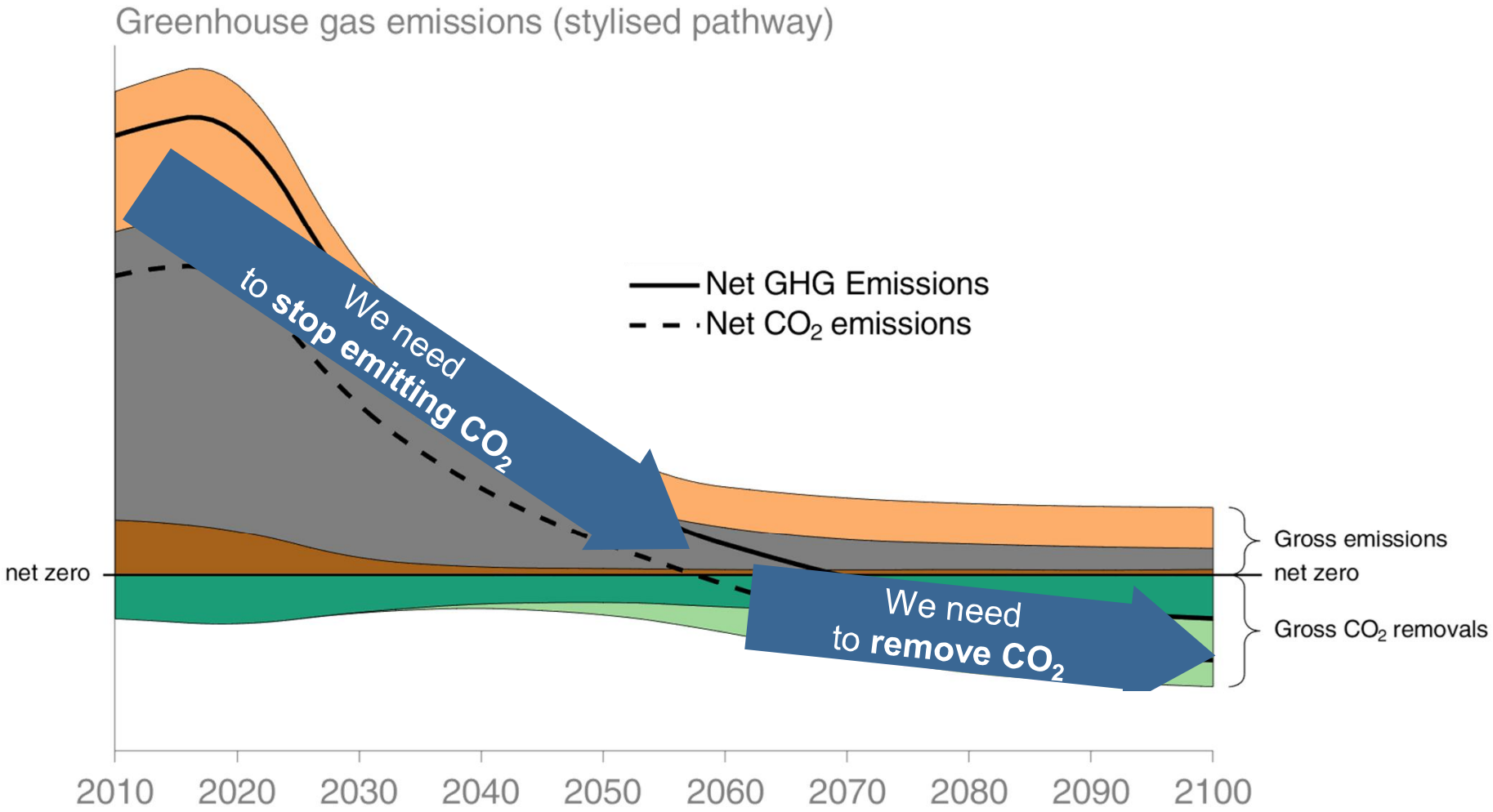
Sustainability

climate protection
life cycle

Equity

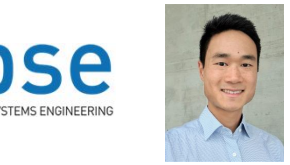
price development
competition

The need for CO_2 storage

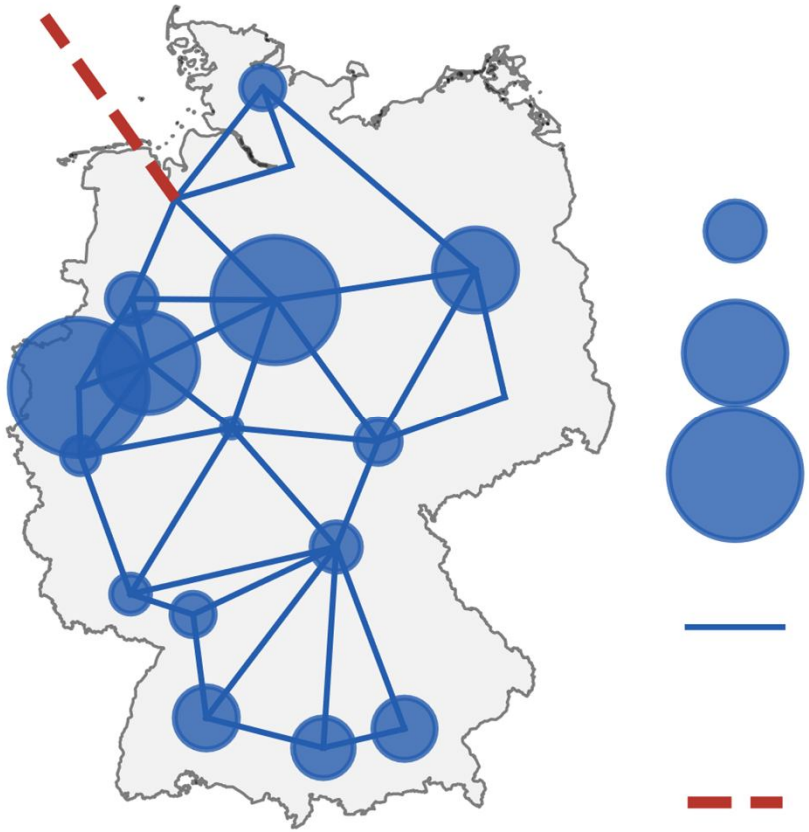


https://www.ipcc.ch/

The cost of not storing CO_2

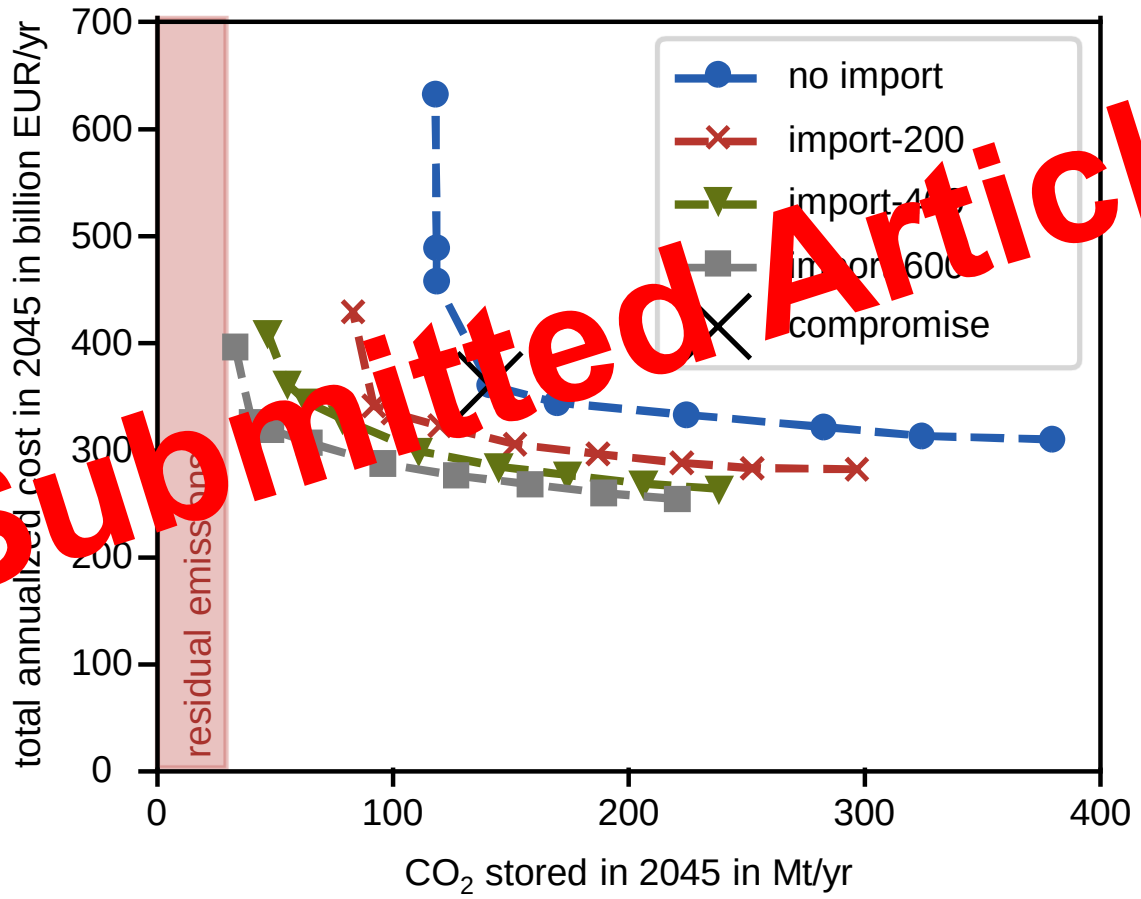


David Shu

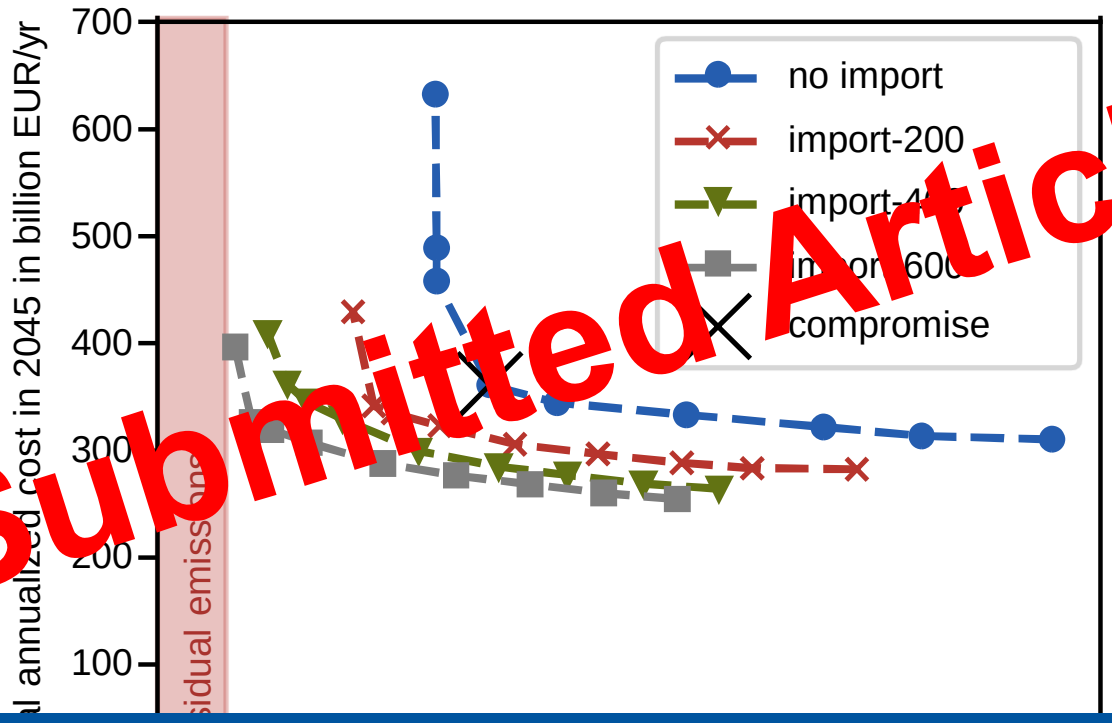


- CO_2 point sources
- Direct Air Capture
- Transportation network
- Offshore storage in Norway

Trade-offs towards net-zero: To CCS or not to CCS ?

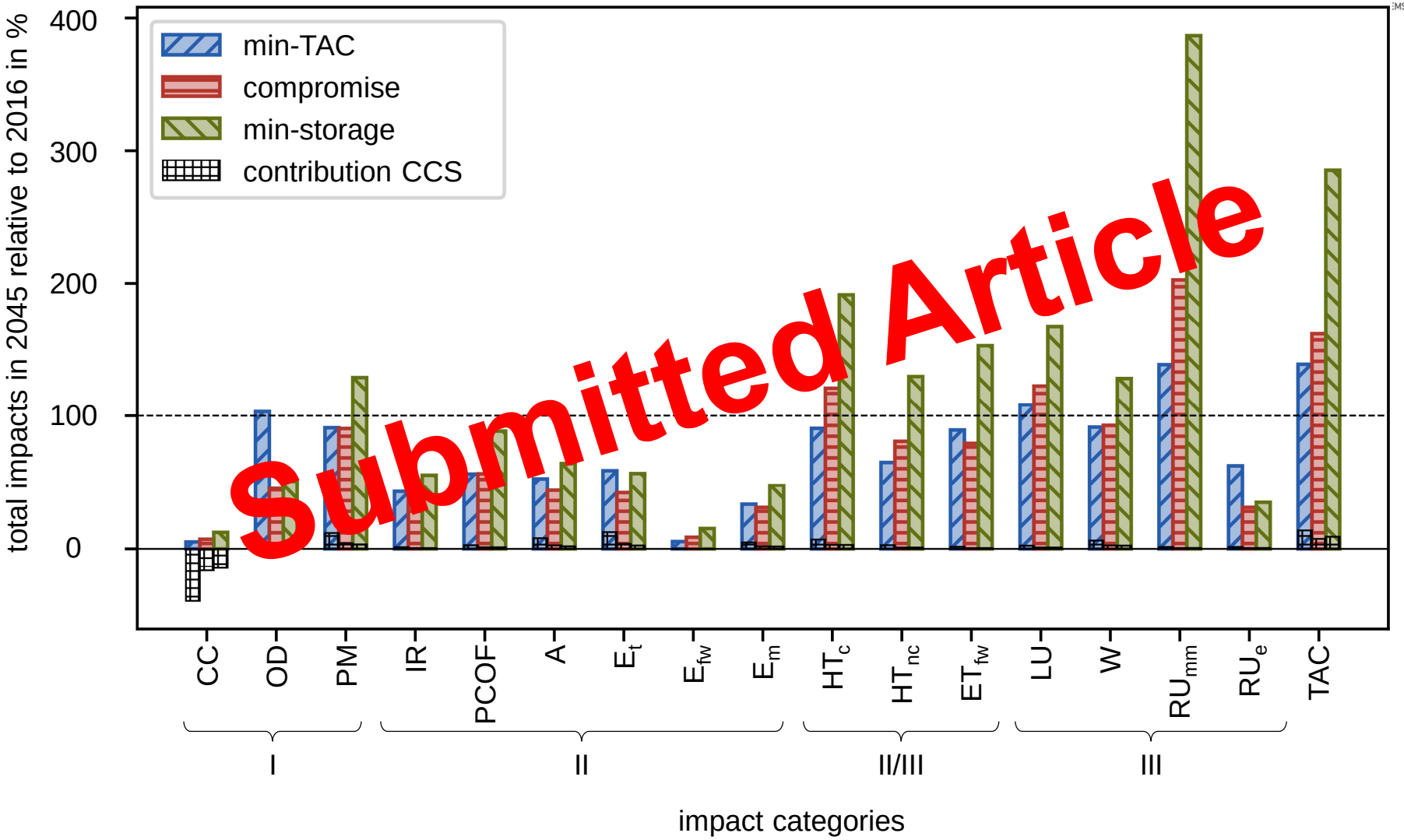


Trade-offs towards net-zero: To CCS or not to CCS ?



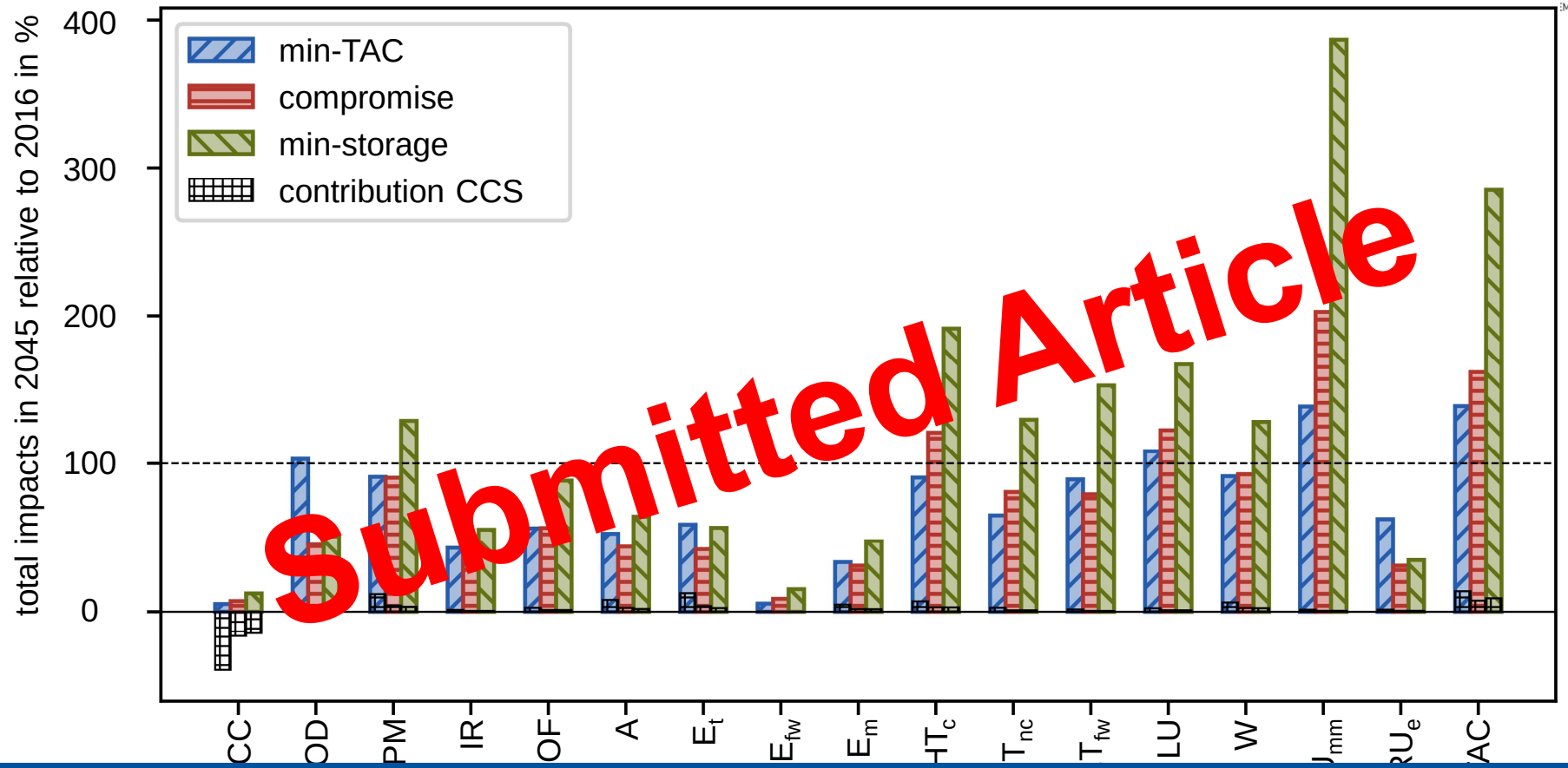
- Avoiding CO_2 storage has strong cost trade-off
- Imports reduce cost and trade-off – but still substantial

The environmental cost of not storing CO_2



Shu et al. *submitted*

The environmental cost of not storing CO_2



Avoiding CO_2 storage increases most environmental impacts

Shu et al. *submitted*

Energy transition: from tech to the environment to people

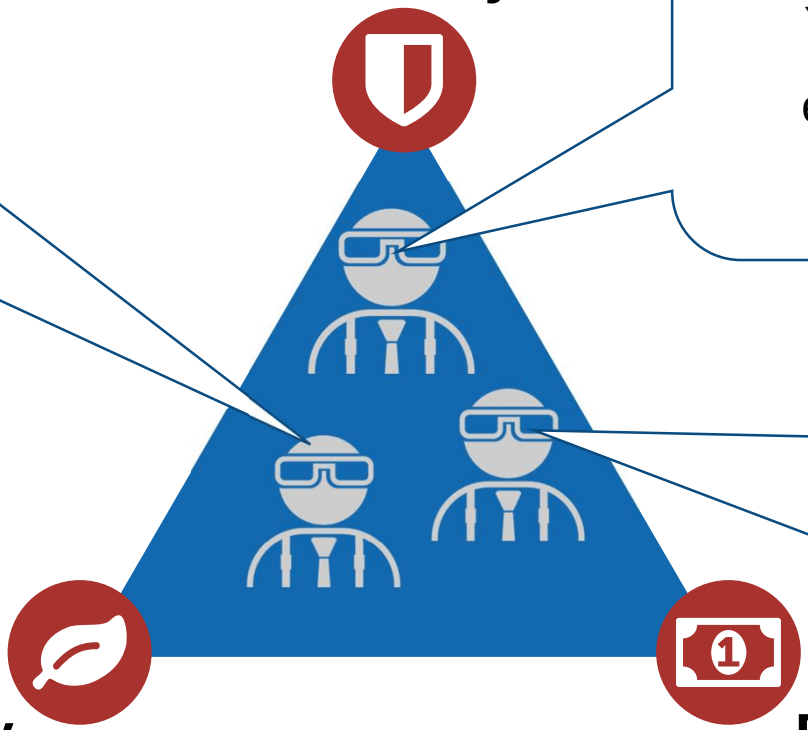
availability of sources
ensuring transport of energy

Security

Yes, I know how to energy transition…

Yes, I know how to energy transition…

Yes, I know how to energy transition…



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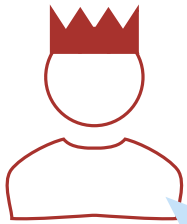
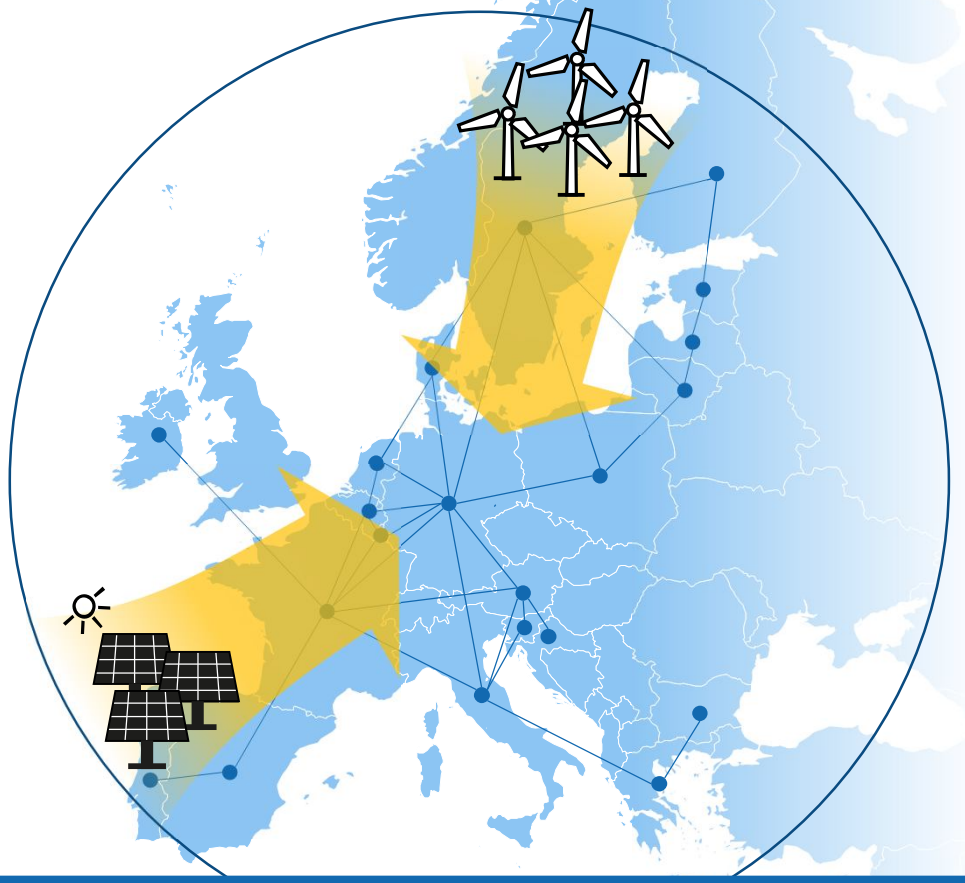
Transition to net-zero requires a system perspective accounting for sector-coupling

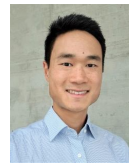


central
decision maker

- electricity mix
- mobility options
- heating options



Christiane Reinert



David Shu

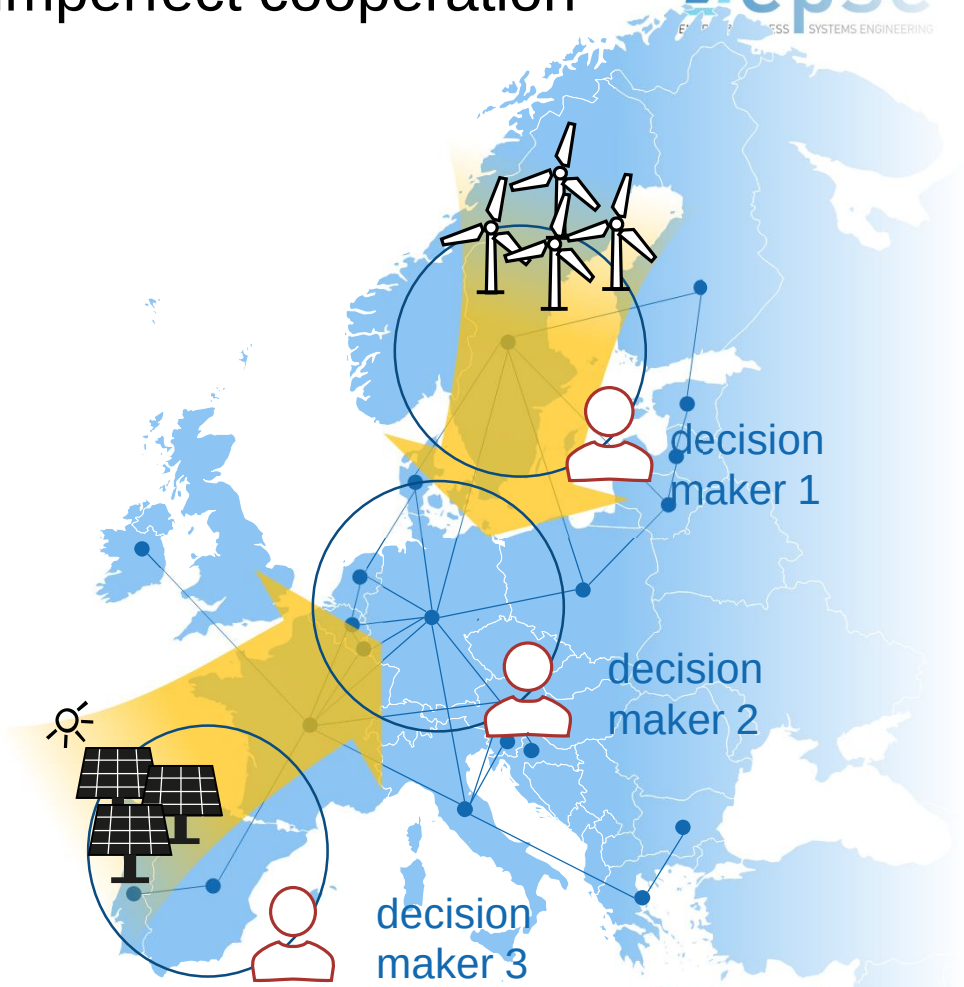
The central planner paradigm assumes perfect cooperation determines to determine transition pathways.

Decentral decision-making leads to imperfect cooperation

multiple decision makers
- individual objectives
- national capacity expansion strategies

coupling by electricity market
- locational market clearing
- costs of electricity trade

emission reduction via EU emission trading system
- costs of emission certificates



The central planner paradigm misrepresents decision maker interactions on the electricity market and ETS.

Shu, Reinert, et al. *in preparation*

Slides with unpublished material removed

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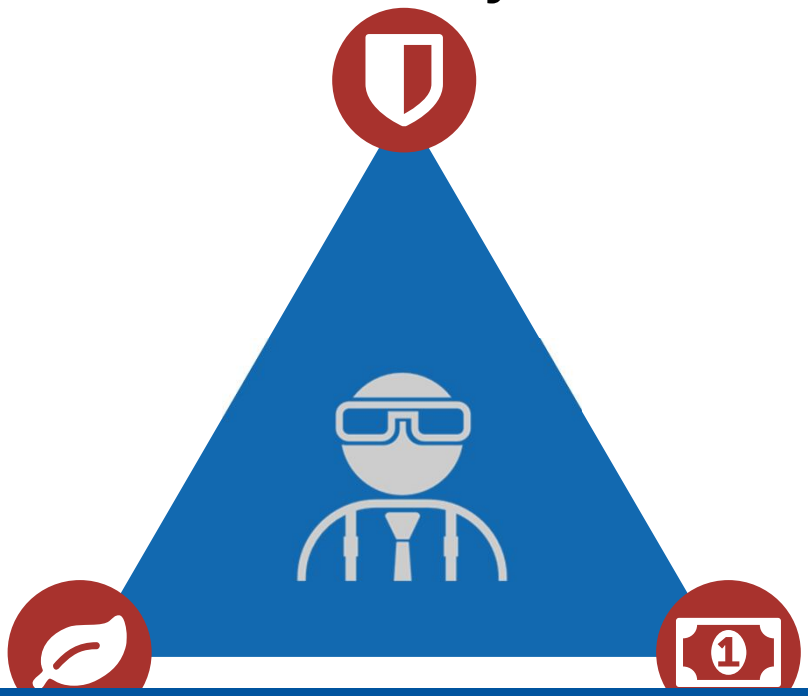
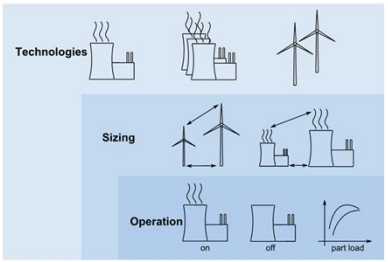


Navigating the energy transition needs a holistic perspective

Navigation tools for the energy transition vs. number 42

Energy systems



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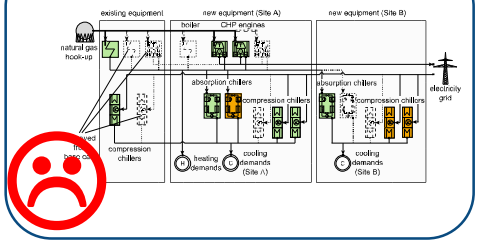
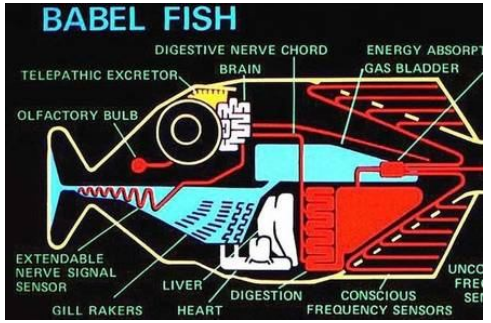


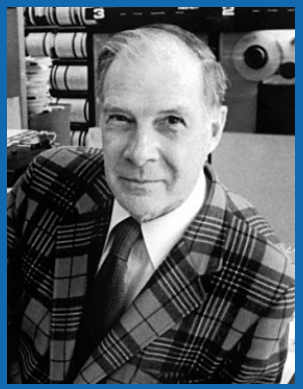
The answer

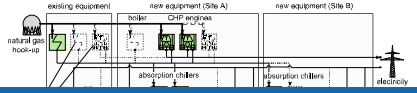


Navigation tools for the energy transition vs. number 42

The purpose of computing is insight, not numbers.

R.W. Hamming
Numerical Methods for Scientists and Engineers (1962)





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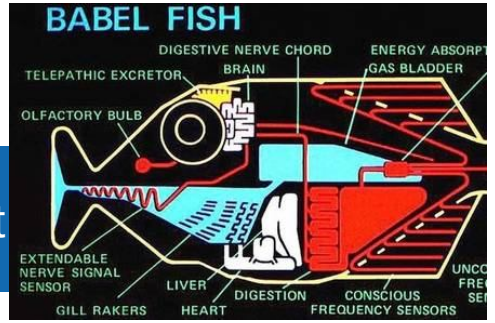

⇒ Need to translate optimization results into insight

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