"BEYOND COST REDUCTION: A NEW METHOD TO IMPROVE THE VALUE OF TECHNOLOGIES IN ENERGY SYSTEMS"

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Based on:

M. Parzen, F. Neumann, A.H. Van der Weijde, D. Friedrich, A. Kiprakis, Beyond cost reduction: Improving the Value of Energy Storage in the Electricity System (2021), URL: https://arxiv.org/abs/2101.10092

IAEE Conference

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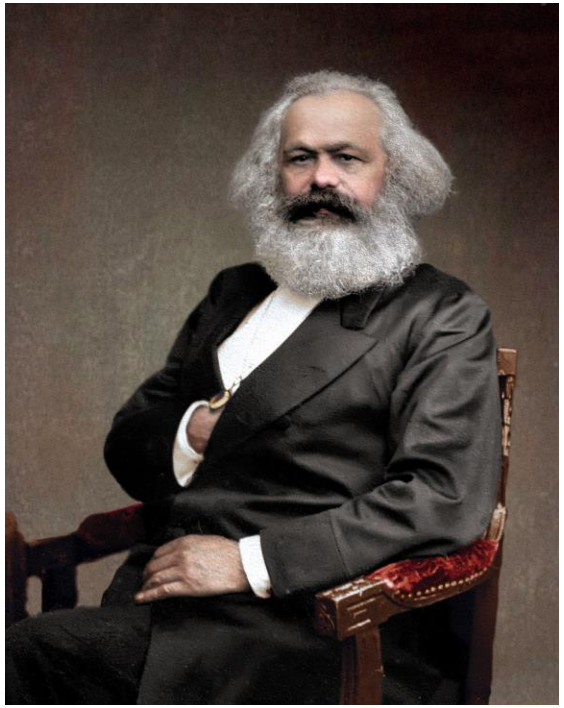
COSTS AND WORK RELATION



Generally speaking:

Something **COSTS** because someone needs to **WORK** for it

AIR	OIL	PV
0 costs	little costs	high costs

WHAT IS LIFE?

LIFE IS A MULTI-OBJECTIVE FUNCTION

IMPORTANT

Min(Total costs)

Future generations should work less/ have more time

Max(health)

Future generations should live longer and healthier

Max(happiness)

Future generations should be more happy

Max(nature)

Future generations have a planet worth to life on

VALUE DEFINITION – DO YOU AGREE?

AN ENERGY TECHNOLOGY

IS VALUABLE IF IT

LOWERS TOTAL SYSTEM COSTS

TECHNOLOGY ASSESSMENT – WHY?

We need to assess which technology is valuable!

Gives answers on:

What technology to invest?

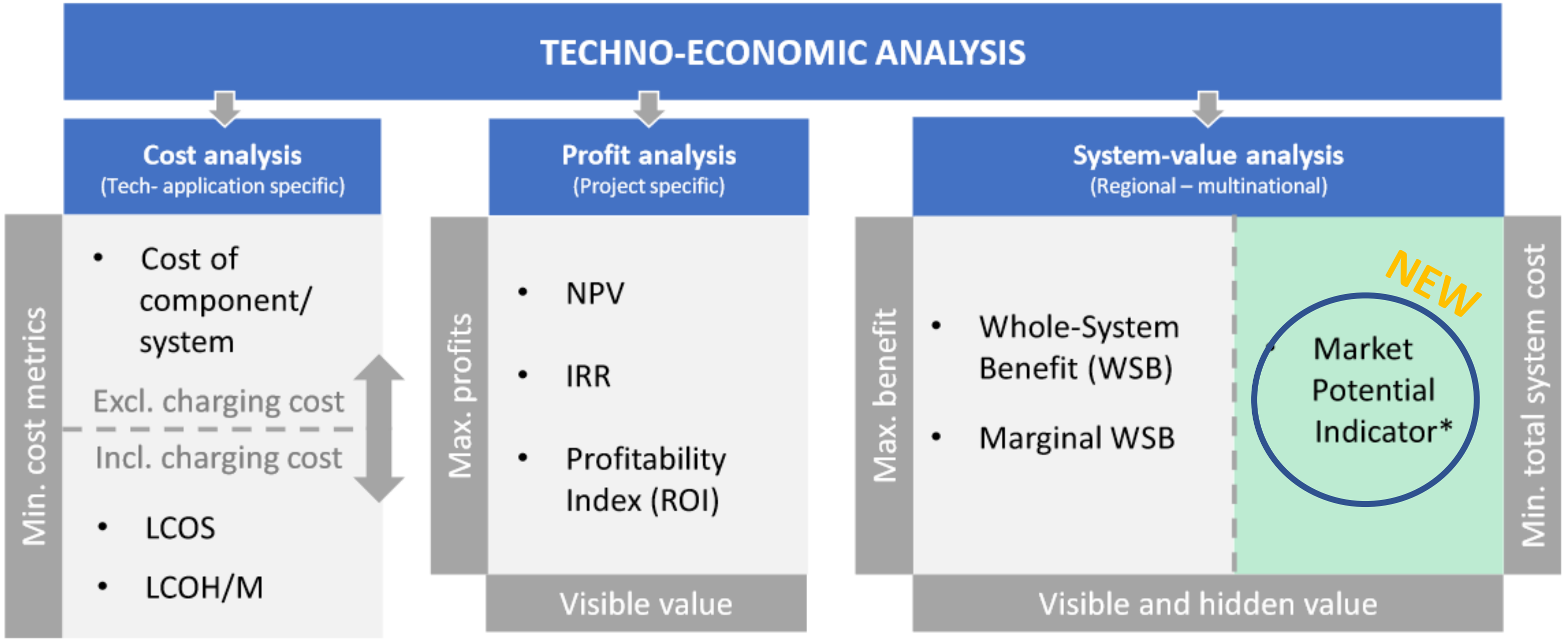
- Research
- Manufacturing capabilities - 'Gigafactory'
- Subsidy/support

Users:

- Manufacturer (Siemens Energy, GE, …)
- Regulators (ACER in EU, FERC in US, …)
- System operators (TSO in EU, …)
- Policy makers (Governments, Consultants, …)
- …

TECHNOLOGY ASSESSMENT – WHAT METHODS?

How we are assessing energy technology at the moment?



NONE method worked properly to suggest technology that reduces the total system cost

METRICS WERE USED TO JUDGE ABOUT COMPETITIVENESS

"…**[LCOS study]** insights increase transparency around the **future competitiveness of electricity storage** technologies and can help guide research, policy, and investment activities to ensure cost-efficient deployment"

Schmidt et al. **(2019),** Projecting the Future Levelized Cost of Electricity Storage Technologies, **Joule**

More sophisticated LCOS study …"We find that lithium-ion batteries are likely to **outcompete** alternative ESTs by 2030 across applications and largely independent of selected scenarios"

Beuse et al. **(2020),** Projecting the Competition between Energy-Storage Technologies in the Electricity Sector, **Joule**

ENERGY STORAGE CASE STUDY

ACCOUNTING VALUES FROM:
ENERGY ARBITRAGE AND
SEASONAL RESERVE PROVISION

How does an energy system modelling work?

Find the long-term cost-optimal energy system, including investments and short-term costs:

$$\text{Minimise}\left(\begin{array}{c}\textbf{Yearly}\\ \textbf{system costs}\end{array}\right) = \sum_{n}\left(\begin{array}{c}\textbf{Annualised}\\ \textbf{capital costs}\end{array}\right) + \sum_{n,t}\left(\begin{array}{c}\textbf{Marginal}\\ \textbf{costs}\end{array}\right)$$

subject to constraints… adding PHYSICS

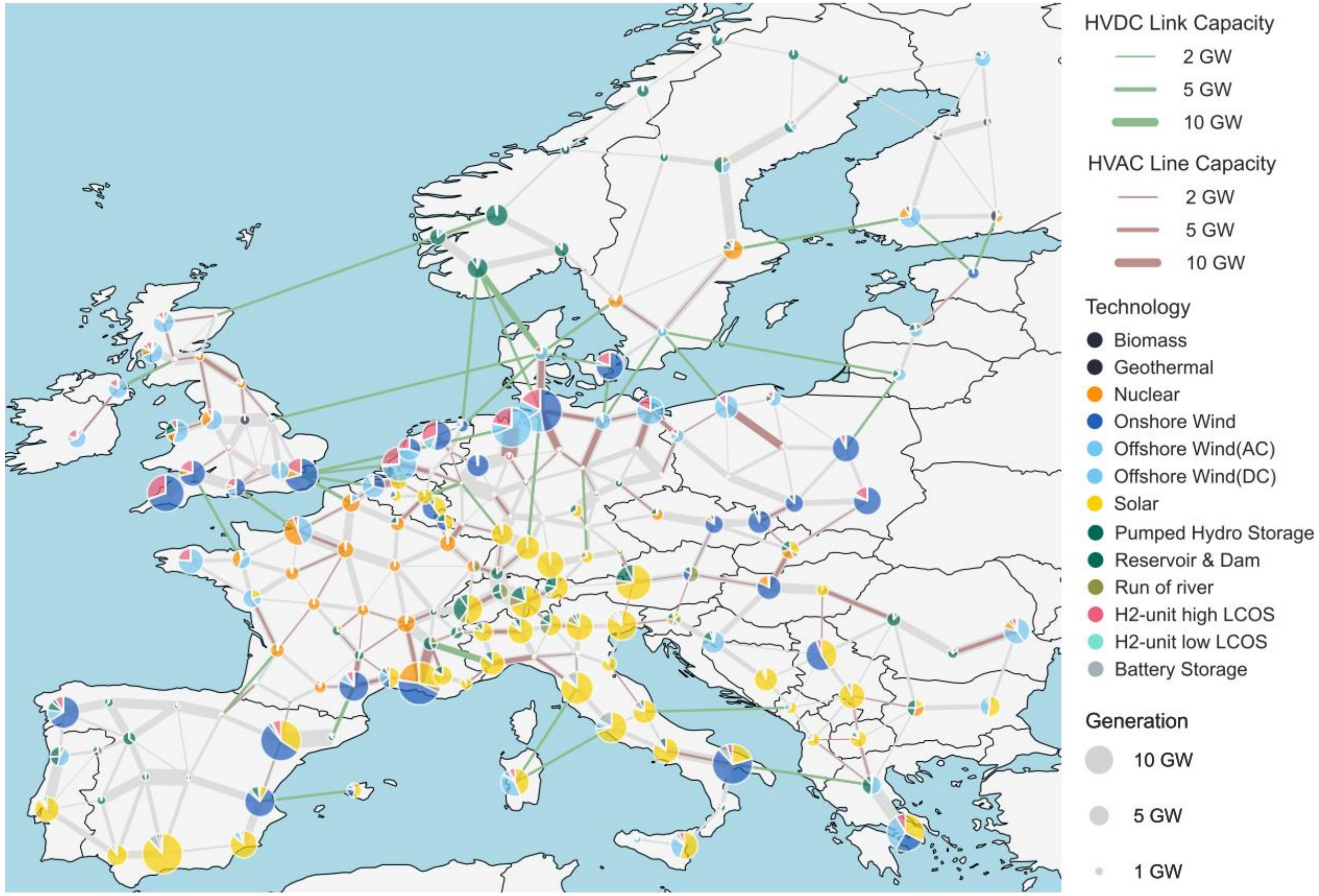
- meeting **energy demand** at each node n (e.g. region) and time t (e.g. hour of year)
- **transmission constraints** between nodes and (linearised) power flow
- wind, solar, hydro (variable renewables) **availability time series** $\forall\ n, t$
- (installed capacity) $\leq$ (**geographical potentials** for renewables)
- **CO_2 constraint** (e.g. 30 Mt/a CO_2-Cap)
- **Dispatchability** from gas plants, battery storage, hydrogen storage, HVDC links

Physics are one thing. Realistic data another thing.

PyPSA-Eur is a workflow to build a model from open data.

Cover the ENSTSOE-E area and contains:

- All **AC lines** at and above 2020 kV, substations and **HVDC links**
- Database of conventional **power plants**
- Time series for **electrical demand**
- Time series for renewable generator **availability**
- Geographic **potentials** for wind and solar expansion



Storage Inputs:

Power related components:

Table 1: Power related energy storage model inputs representing 2030 data

Energy storage components	Electrolysor		Fuel cell		Battery Inverter
LCOS Scenario	[Low]	[High]	[Low]	[High]	[-]
Investment [EUR/kW_{el}]	339	677	339	423[a]	209[c]
FOM[a] [$\%/year$]	2	3	2	3	3
Lifetime [a]	25	15	20	20	10
Efficiency [%]	68	79	47	58	90
Discount Rate [%]	7	7	7	7	7
Based on Ref.	[12] Alkaline	[12] SOEC[d]	[70] PEM[e]	[70, 71] SOFC[f]	[71, 72] Li-Ion Battery[g]

[a] Fixed operation and maintenance cost
[b] Includes fuel cell stack replacement after 10 years which cost 30% of initial cost
[c] Includes 80 EUR/kW balance of plant, mainly assigned to wiring and connection [72]
[d] Solid-Oxide Electrolyser
[e] Proton Exchange Membrane or Polymer Electrolyte Membrane
[f] Solid-Oxide Fuel Cell
[g] Lithium-Ion Battery

Energy related components:

Table 2: Energy related energy storage model inputs representing 2030 data

Energy storage components	H_2 storage		Battery storage
LCOS Scenario	[High]	[Low]	[-]
Investment [EUR/kWh_{el}]	8.4	8.4	188[b]
FOM[a] [$\%/year$]	-	-	-
Lifetime [a]	20	20	10
Efficiency [%]	-	-	-
Based on Ref.	[71] H_2 steel tanks	[71]	[72] Li-Ion Battery

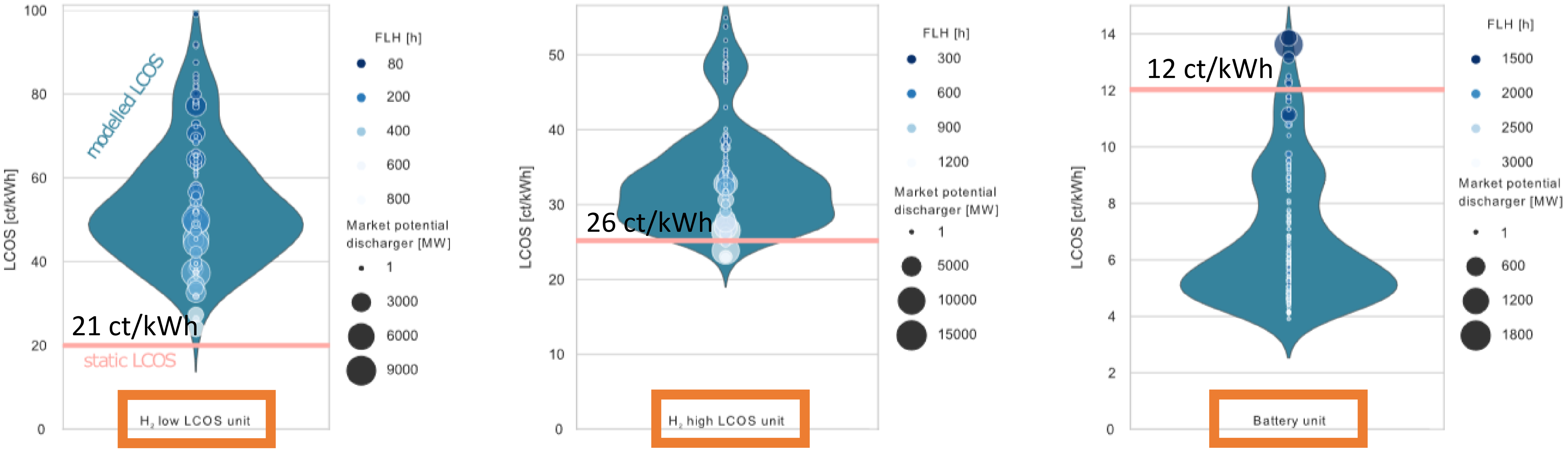
[a] Fixed operation and maintenance cost
[b] Includes 81 EUR/kW for engineering, procurement and construction costs [72]

Classical static LCOS results

H2- low LCOS unit	H2- high LCOS unit	Battery benchmark
21 ct/kWh	**26 ct/kWh**	**10 ct/kWh**
Alkaline electrolyser + PEM fuel cell	Solid-oxide electrolyser + Solid-Oxid fuel cell	Li-Ion Battery

Static Vs. Modelled LCOS **in 4D**

- Talking about one single LCOS is misleading -> wide range of LCOS exist
- Assuming constant Full load hours (FLH) is dangerous as well.
- **Market potential exist for both**, high and low LCOS cost version **– Why we assess the LCOS?**



NEW MARKET POTENTIAL METHOD – TO GUIDE INNOVATION

Market Potential Method

Metric/ Approach	**Market Potential Indicator**	**Market Potential Criteria**
Type	*Probable scenario*	*Subjective decision*
Result (exemplary)	*10 GW for technology A in scenario 1*	*Technology selection*

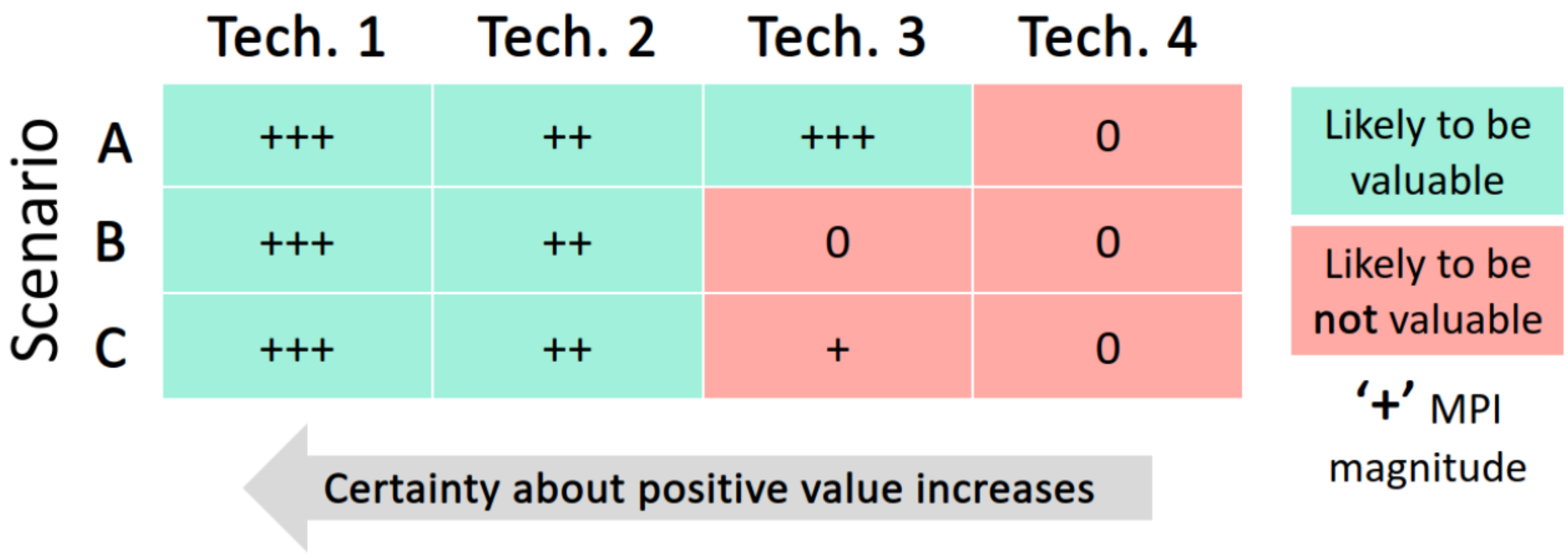
MARKET POTENTIAL CRITERIA

General rules:

- MPI = 0, tech. is **unlikely to be valuable**
- MPI > 0, tech. is **likely to be valuable**
- MPI > 0 in multiple scenarios **reduces uncertainty**

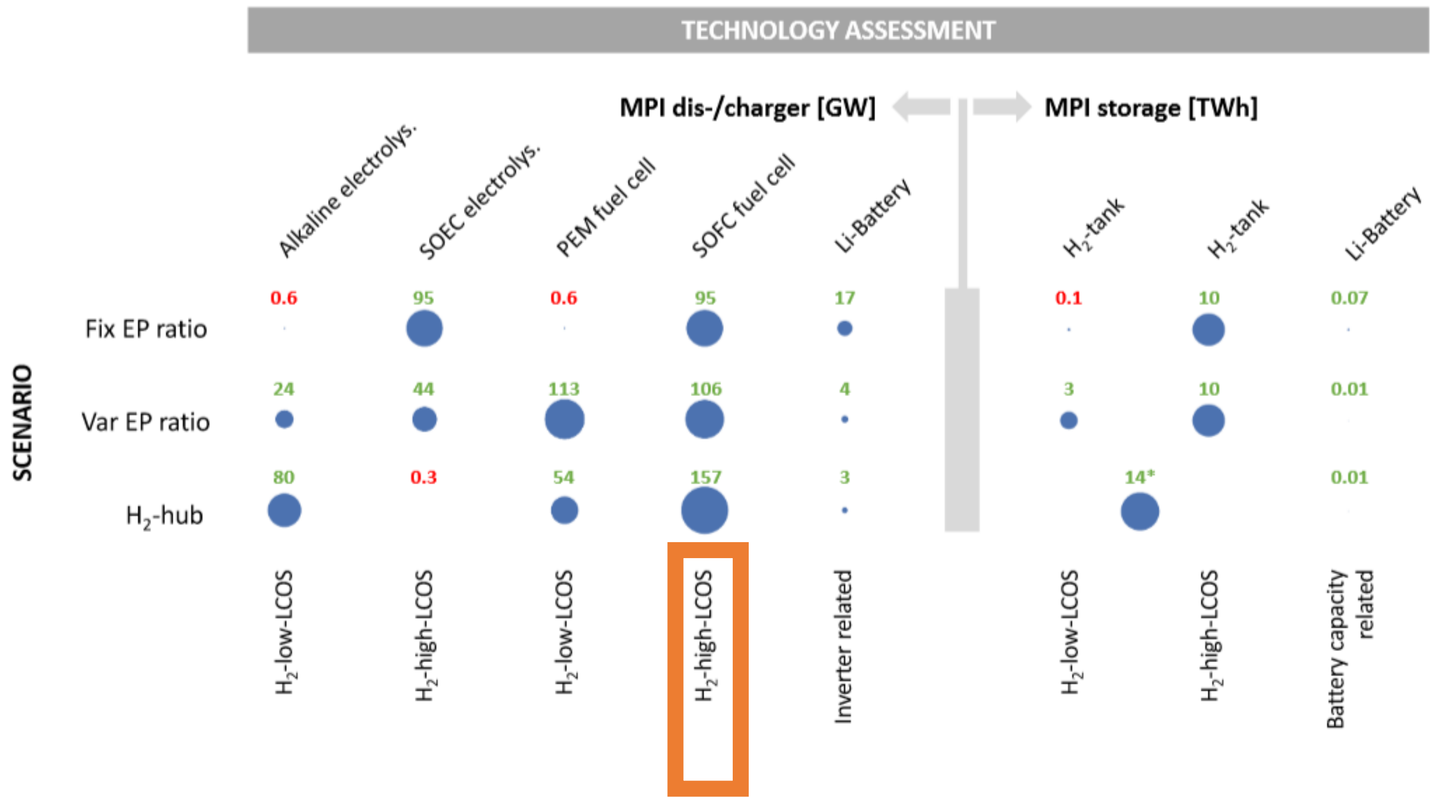
Additional 'subjective' rules:

- MPI > X or 'threshold rule'
- $MPI_A > MPI_B$ or 'bigger is better' rule



Scenario	Tech. 1	Tech. 2	Tech. 3	Tech. 4
A	+++	++	+++	0
B	+++	++	0	0
C	+++	++	+	0

Market Potential Method = Systematic Deployment Assessment



Some results:

- SOFC fuel cell and Li-Ion batteries are ‘safe bets’
- Alkaline electrolyser seems to prefer to work with SOFC fuel cell
- Results suggest that **high cost technology can be equally or more valuable**

-> LCOS is incomplete

Modelling and improvements

YES. Modelling can always improve:

- Including other 'values' by additional system services (i.e. new constraints)
- Including more sectors (i.e. PyPSA-Eur-Sec)
- Adding more technologies/components
- Improving data situation (i.e. load distribution, existing VRE)
- Expanding to new regions (i.e. Africa VS. Europe)
- Adding non-linear effects
- Improving energy market representation (i.e. Game-theory elements)
- …

BUT at least it can improve …

KEY MESSAGE

In regard to energy technology:

“LOWER COST **IS NOT EQUAL TO** HIGHER VALUE”

- Even if they have the same function

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"wind turbines" by Mycatkins is licensed under CC BY 2.0

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APPLICATIONS OF MPM AND FUTURE WORK

General applications for MPM:

- Giving technology design recommendations (**Storage**, **generators**, **DSR**)
- Evaluating energy technology market potentials (**= system-value**)

KEY FOR BUSINESS DECISION

Future work. Supporting open source tool improvements:

- Adding new regions to the model (**i.e PyPSA-Africa**) https://max-parzen.github.io/Project_PyPSA_Africa.html
- Adding new technologies concentrated solar power, marine technologies
- Reduce structural and parameter uncertainty & find approaches to deal with uncertainty

Future work. Performing MPM with probable scenarios:

- Adding data and approaches for probable scenario
- Perform technology assessment

NEXT EARTH MISSION:

Open Energy System Modelling Expansion for regions that benefit the most…

DO YOU WANT TO JOIN?

PROJECT START: 01. MAI.2021
Duration: 6-8 month
Current team size: +13 mostly PhD students
Advisors: +10 leaders, professionals, experts
More details: https://max-parzen.github.io/

Source: NASA

Contact Details

PyPSA meets Africa

openmod open energy modelling initiative

openmod-initiative.org

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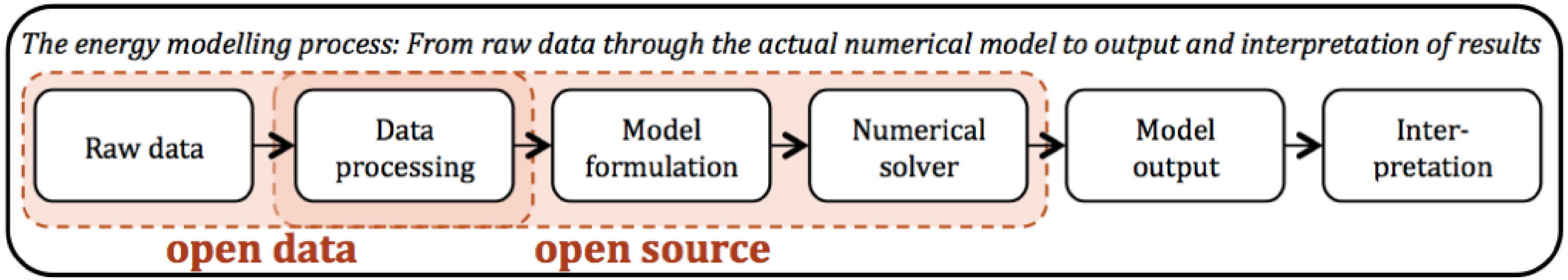
AWESOME OPENMOD COMMUNITY

The whole chain from raw data to modelling results should be open:



Open data + free software ⇒ Transparency + Reproducibility

There's an initiative for that! Sign up for the mailing list / come to the next workshop:

openmod open energy modelling initiative

openmod-initiative.org

BACK UP

Is “Levelized Cost of Storage” (LCOS) a good metric?

$$LCOS\left[\frac{\$}{MWh}\right] = \frac{\text{Investment cost} + \sum_n^N \frac{\text{O\&M cost}}{(1+r)^n} + \sum_n^N \frac{\text{Charging cost}}{(1+r)^n} + \frac{\text{End-of-life cost}}{(1+r)^{N+1}}}{\sum_n^N \frac{Elec_{Discharged}}{(1+r)^n}}.$$

$$\frac{\textbf{COST}}{\textbf{USE}}$$

Schmidt et al. 2019, “Projecting the Future Levelized Cost of Electricity Storage Technologies”, Joule 3, 81–100, https://doi.org/10.1016/j.joule.2018.12.008

Typical assumptions:

- **Storage design** fixed (Energy to power (EP) ratio is constant)
- **Charging price** fixed or included by “representative” timeseries
- **Full-load-hours** fixed (FLH = measure of usage)

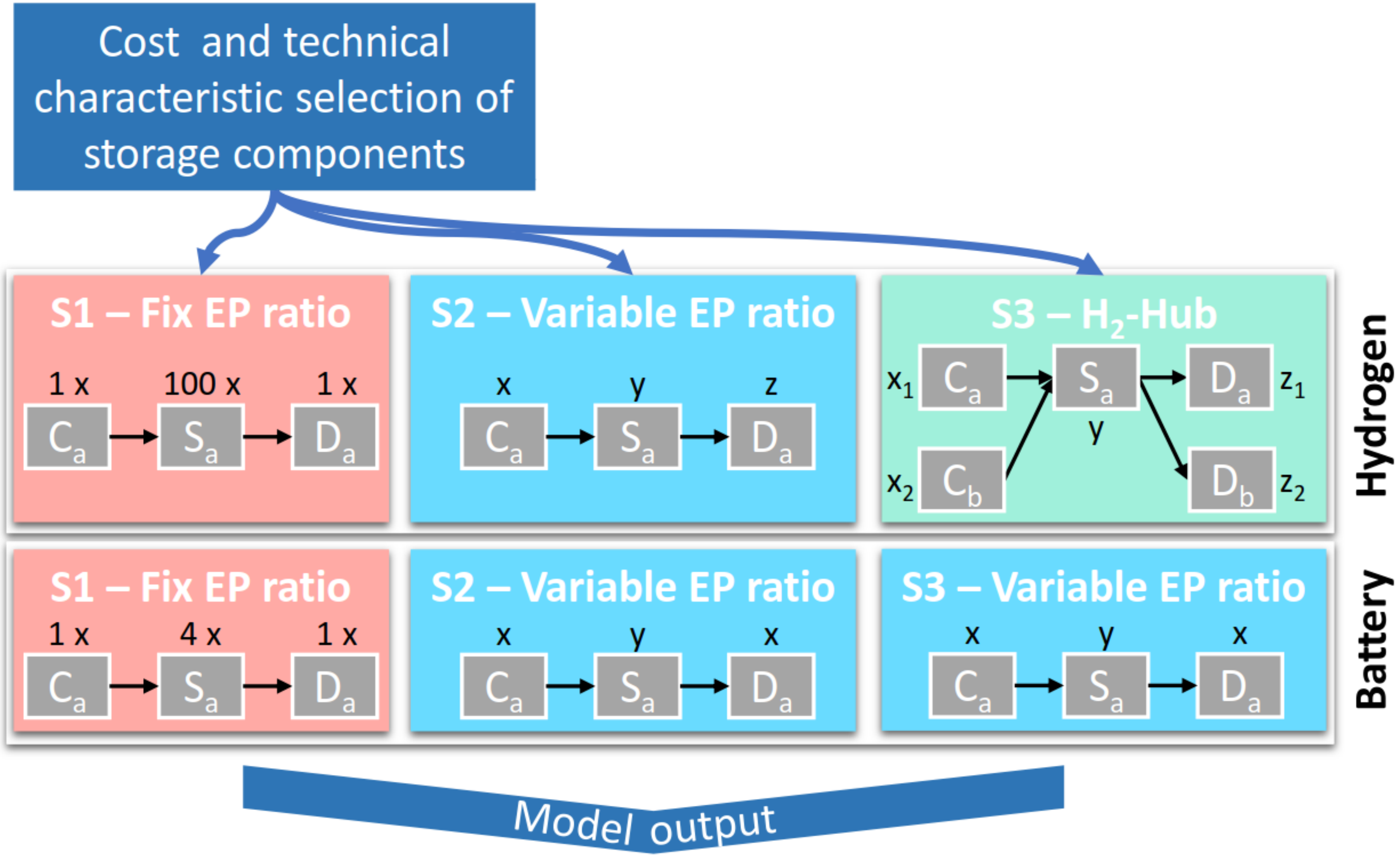
Why high cost is not equal high value?

SOME REASONS

Difference in:

- spatial-temporal energy system characteristics (network structure, demand profiles, resource potential)
- power profile (i.e. generators)
- design flexibility of components (i.e. energy storage systems)
- efficiency of components
- invest and O&M cost of components

Three Storage Scenarios with different Technology-Constraints

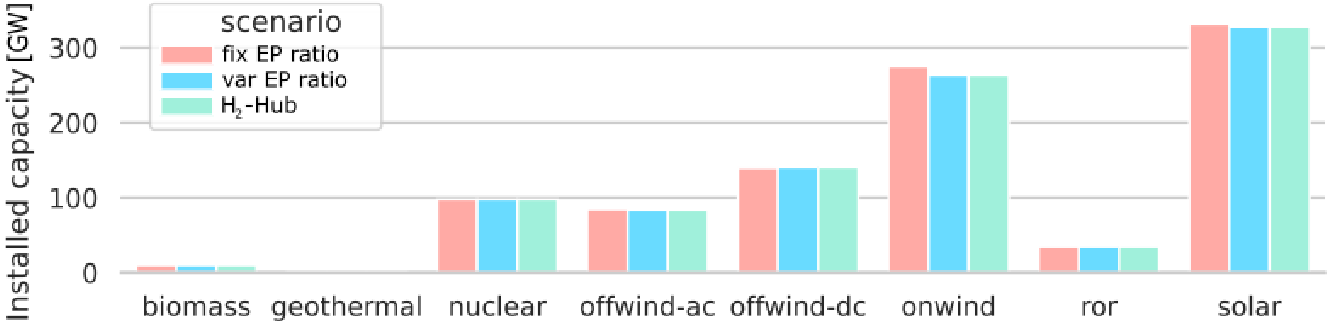


LCOS ranges + market potential indicator

Is Increasing the Design Freedom worth it?

Scenario	Total system cost	Relative investment[a]	Curtailment [% of annual demand]
Fix EP ratio	152.9 B€	4.874 ct/kWh	0.61%
Var EP ratio	139.9 B€	4.460 ct/kWh	0.73%
H2-hub	139.7 B€	4.453 ct/kWh	0.37%

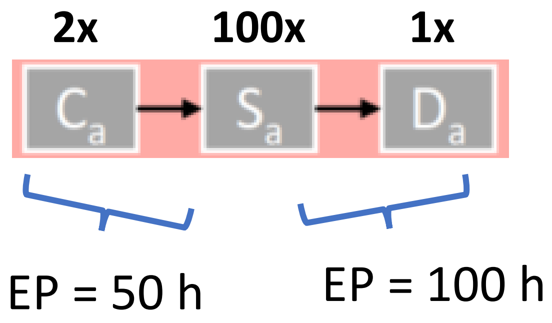
[a] Total system cost per annual demand

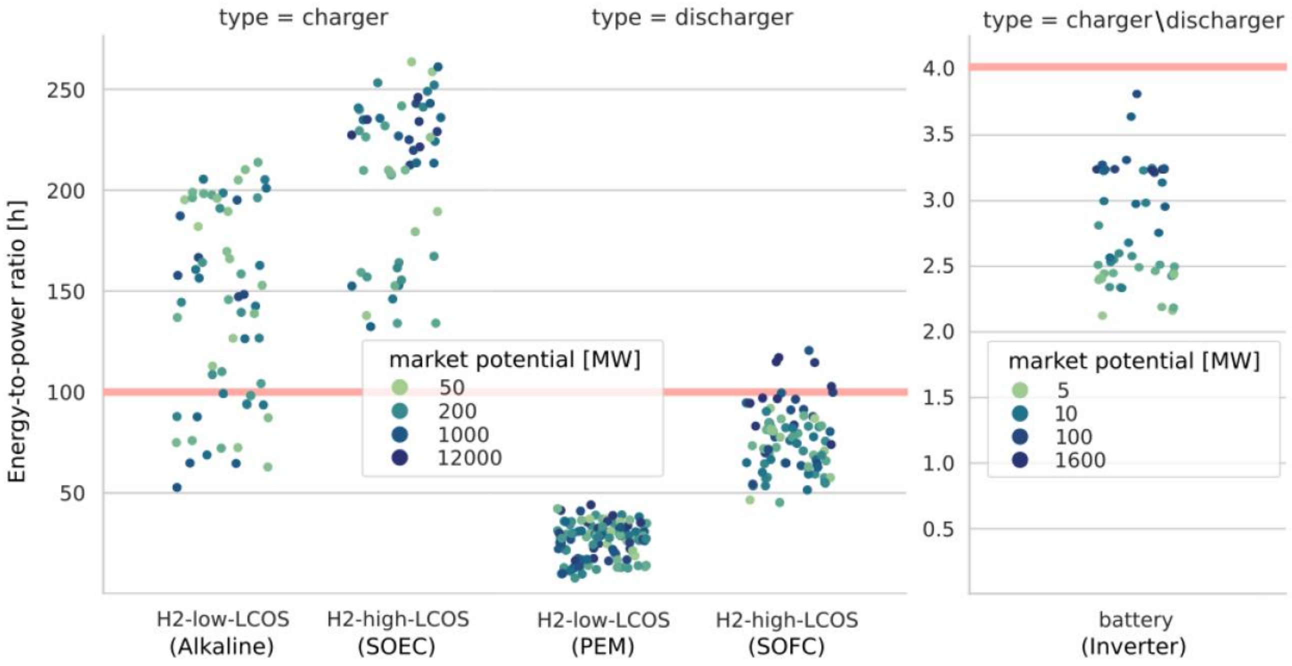


- Relaxing design constraints
- Reduces **10%** of system cost
- While the system **doesn't** change much

How are Storage Components **Sized** for Optimality?

EP-ratio Example:





- The red lines refers to typically built energy-to-power ratio
- **EU-system desires** slow charge & quick discharge

Back-up – LCOS components and our study

	LCOS components	Zakeri et al.[7]	Jülch et al.[30]	Lazard[31,32]	Lai et al.[33]	Pawel[34]	Battk et al.[35]	This study	Our study
Economic	Investment cost	x	x	x	x	x	x	x	x
	Replacement cost	x	x	x				x	x
	Operating cost	x	x	x	x	x	x	x	x
	Power cost	x	x	x	x	x	x	x	x
	End-of-life cost	x	x			x		x	
	Discount rate	x	x	x	x	x	x	x	x
	Taxes			x					
Technical	Nominal capacity	x	x	x	x	x	x	x	x
	Depth of discharge	x	x	x		x	x	x	
	Round-trip efficiency	x	x	x	x	x	x	x	x
	Cycle life	x	x				x	x	
	Shelf life	x	x		x	x	x	x	x
	Construction time							x	
	Degradation rate				x	x		x	
	Self-discharge		x					x	

Schmidt et al. 2019, “Projecting the Future Levelized Cost of Electricity Storage Technologies”, Joule 3, 81–100, https://doi.org/10.1016/j.joule.2018.12.008

Back-up – Energy storage distribution

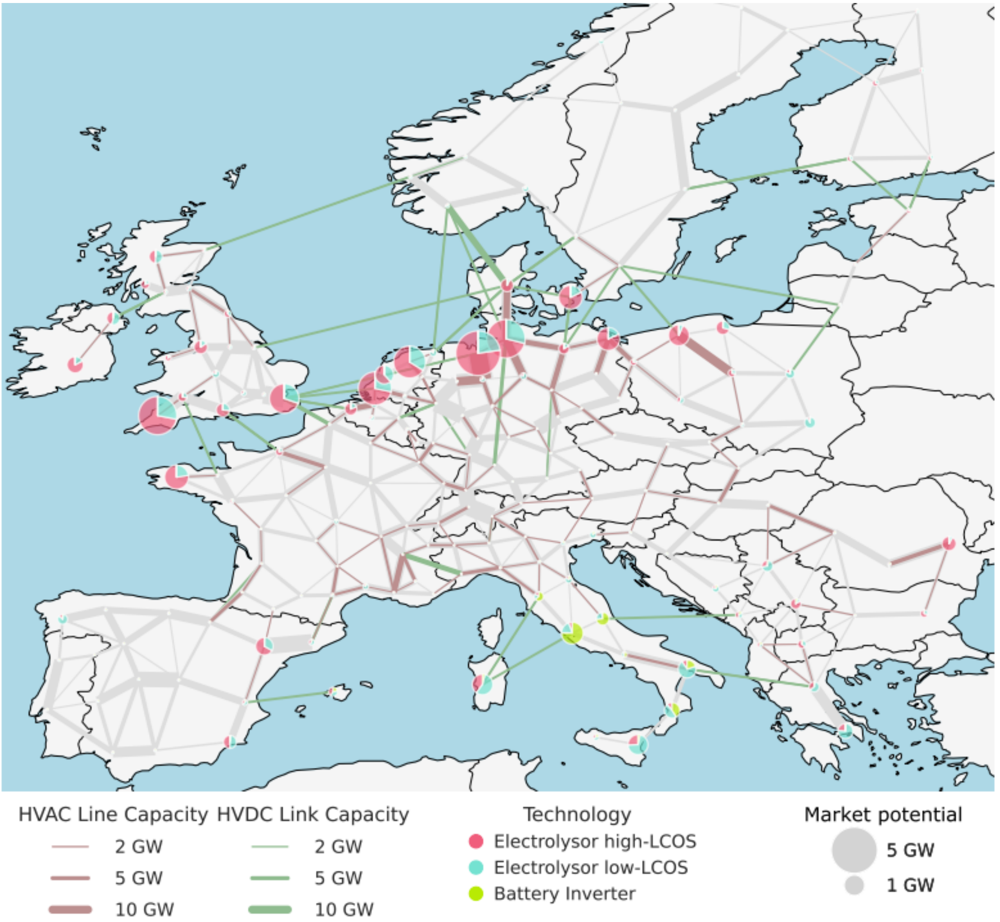


Figure 10: Optimal energy storage charger distribution in the variable energy to power sizing scenario. Showing the location of market potential in a 100% emission reduction scenario. Comparing to Figure 4, most hydrogen units are co-located with wind plants while batteries gravitate towards solar plant optimised areas.

Back-up – Applying the Fourier Transform to analyse the operational behaviour

- Operational charging behaviour at 1 nodes analysed with Fast-Fourier Transform