Can energy system models save the world? A cautionary tale

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PowerWeb Lunch Lecture TU Delft 22. September 2022





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EUROPEAN CLIMATE + ENERGY MODELLING FORUM



The ECEMF project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101022622.

Sveet swiss energy research for the energy transition

PATHFNDR

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The mission: Design a feasible climate-neutral energy system

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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." – <u>https://www.bbc.com/news/election-2017-40120184</u>





Continental or regional scale electricity supply

Continental supply: Wind and PV at best locations



relative to demand

● ≥ 10 Regional supply: Regions self-supply on average over the year

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

497 regions

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?



Less integrated systems are possible, but cost more



Continental

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







Underlying model: Euro-Calliope, power system only



Tim Tröndle

Spatial resolution



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

497 first-level administrative units

Objective function	Temp	
Minimise total system cost	4 hou	
	2007-	
Tröndle et al. (2020). <i>Joule</i> . <u>https://doi.org/gg8zk2</u>		

Technologies

term storage

oral resolution

urs, single year, -2016

Sensitivity analysis

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

Fully open + reproducible

github.com/calliope-project/ euro-calliope





TI

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



TI

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

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

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





100 150 200

Time-varying (hourly) supply and demand





European energy supply without imported fuels or electricity



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



SPORES: an algorithm for near-optimal results



Francesco Lombardi

Costoptimal solution

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



Preference 1 low biofuel use

1











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

Multi-dimensional option space



Preference 2 low storage use



Overlap of preferences







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



Storage capacity needed



Electricity production	Fuel autarky	EV as flexibility	Heat	Transpor
Gini coefficient	Gini coefficient	(0.52 - 0.92)	electrification	electrificati
(0.54 - 0.74)	(0.64 - 0.99)		(4 - 100) %	(53 - 100)



+

Biofuel utilisation









Heat electrification





Low biofuels

Result number 17

Total grid expansion + 1.5 TW

Low storage

Result number 158

Total grid expansion + 1.3 TW



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

Result number 110







Explore results yourself: <u>https://explore.callio.pe/</u>



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: $R^2 = 0.95$



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?







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



• integrating human behavior and social risks and opportunities + environmental factors



Challenges: social, environmental, and other limits



S S

- 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), <u>https://doi.org/10.1007/978-3-030-99177-7_7</u>

'We don't have enough' lithium globally to meet EV targets, mining CEO says

-------- Anchor/Reporter

1 October 2019

EUROPE

New distance rule could rule out new onshore wind farms









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



"Loading dock" approach

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



Co-production approach



SEEDS: Building a "human-computer loop"

æQ

Energy Production Technology ⁽⁾

		(Live
SEEDS Optimal Solution	^	\$ ⑦
Priority on X	0	
Priority on Y	۲	
Photovoltaic	~	
Roof-mounted Solar	~	6
Open-field Solar	^	
0 V alue: 65%	100	
Wind	~	
Hydropower	^	ADDITIONAL RE
Pumped Hydro	~	
Hydro reservoir	^	Lorem ipsum dol
0 O Value: 65%	100	elit.
	 SEEDS Optimal Solution Priority on X Priority on Y Photovoltaic Roof-mounted Solar Open-field Solar Value: 65% Wind Hydropower Pumped Hydro Hydro reservoir Hydro reservoir Value: 65% 	SEEDS Optimal Solution Priority on X Priority on Y Priority on

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?

Renewable and Sustainable Energy Reviews 60 (2016) 1634-1653

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rse

Smart Energy Europe: The technical and economic impact of one potential 100% renewable energy scenario for the European Union

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Keywords: 100% renewable energy Jobs Europe EnergyPLAN WESTERN WIND AND SOLAR INTEGRATION STUDY:

This study presents one scenario for a 100% renewable energy system in Europe by the this study presents one scenario for a 100% renewable energy system in Europe by internation from a business-as-usual situation in 2050, to a 100% renewable energy Europe series of steps. Each step reflects one major technological change. For each step, the international series of steps of the series of steps of the series of steps of the series of t in terms of energy (primary energy supply), environment (carbon dioxide emissions), 7 annual socio-economic cost). The steps are ordered in terms of their scientific and p follows: decommissioning nuclear power, implementing a large amount of heat say private car fleet to electricity, providing heat in rural areas with heat pumps, pro areas with district heating, converting fuel in heavy-duty vehicles to a renew meloring network growth methans. The result indicate that heating the Smort F. replacing natural gas with methane. The results indicate that by using the Smart E a 100% renewable energy system in Europe is technically possible without consi a noom renewable energy system in Europe is reclinically possible without const amount of bioenergy. This is due to the additional flexibility that is created by co heating, cooling, and transport sectors together, which enables an intermittent over 80% in the electricity sector. The cost of the *Smart Energy Europe* scenario over 80% in the electricity sector. The cost of the *smart Energy Europe* scenario higher than a business-as-usual scenario, but since the final scenario is b instead of imported fuels, it will create approximately 10 million additional

EXECUTIVE SUMMARY

The National Renewable Energy Labora A national laboratory of the U.S. Department of Er

2010

PREPARED BY: **GE Energy**

MAY 2010

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1.	Infroduction	
2	Methodology	
2.	21 Key Principles	
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3	Results and discussion	
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	3.4 Renewable electrolation the final scenario	
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2016

Synergies of sector coupling and transmission reinforcement in a costoptimised, highly renewable European energy system T. Brown ^{a, b, *}, D. Schlachtberger ^b, A. Kies ^b, S. Schramm ^b, M. Greiner ^c

ARTICLE INFO

ABSTRACT

2018

2020

Mark Z. Jacobson



So: can energy system modelling save the world?

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

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

Scaleindepedent, e.g.:





Transforming ENERGY





MILANO 1863





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

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

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Indian Institute of Technology, Delhi

> Major updates in October

ILE INDITEONERY FLAGE to work with us on

energy system modelling



