What are open energy models and what can they contribute?

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Karlsruhe Institute of Technology

HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

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What are energy models?

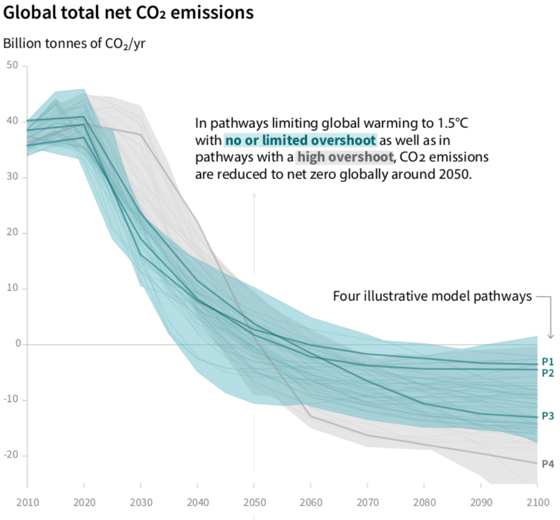
Energy models are computer models used to simulate the past, current and future energy system.

They are used to examine the effect on the energy system of new technologies, new policies and other changes.

They typically consist of **data** describing the energy system and its components, and **computer code** for running simulations.

They are used to study the energy system on a **variety of scales and levels of detail**, covering different spatial scales, temporal scales, energy sectors and technological details that vary depending on the application.

Integrated Assessment Models (IAM): Global, long-term, but details rough

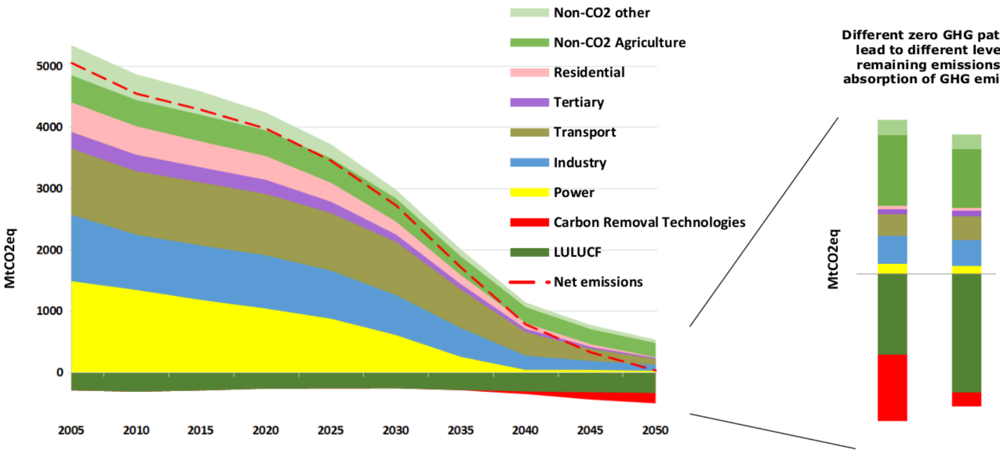


- IPCC scenarios for global CO_2 emissions that limit warming to 1.5°C above industrial levels (**Paris accord**)
- Level of use of negative emission technologies (NET) depends on rate of progress
- 2°C target without NET also needs rapid fall by 2050
- Common theme: **net-zero by 2050**

Source: IPCC SR15 on 1.5C, 2018

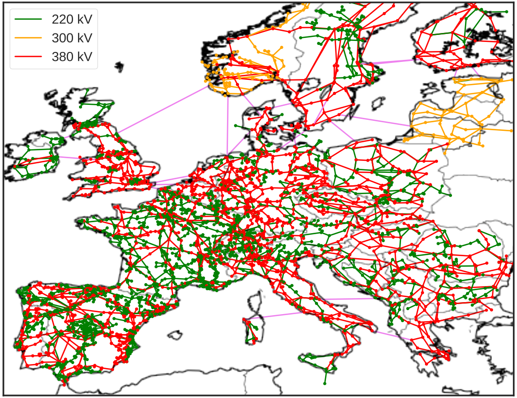
PRIMES: European countries, multi-decade, more technological detail

Paris-compliant 1.5° C scenarios from European Commission - **net-zero GHG in EU by 2050**



Source: European Commission 'Clean Planet for All', 2018

PyPSA-Eur: Network model at substation level, hourly resolution



Basic **validation** of grid model in Hörsch et al (Energy Strategy Reviews (ESR), 2018), github.com/PyPSA/pypsa-eur

- Grid data based on **GridKit** extraction of ENTSO-E interactive map
- **powerplantmatching** tool combines open databases using matching algorithm DUKE
- Renewable energy time series from open **atlite**, which processes terabytes of weather data from e.g. new ERA5 global reanalysis
- Geographic **potentials** for RE from land use GIS availability
- All energy demand and supply options (power, transport, heating and industry)

What kind of questions are they used to answer?

- Is net-zero greenhouse gas emissions for the energy system technically feasible?
- What will it cost? What technologies will be required?
- How do we integrate variable wind and solar generation?
- What is the role for nuclear and carbon capture and usage/sequestration?
- Transport: battery or fuel cell electric vehicles? In which segments?
- Heating: heat pumps, solar thermal, biomass or power-to-gas? In which segments?
- Can we accelerate the coal exit?
- Is there a long-term role for natural gas?
- Can we maintain affordability while avoiding unpopular infrastructure (e.g. onshore wind, overhead transmission)?
- Should the energy system be decentralised or centralised?

What are open energy models?

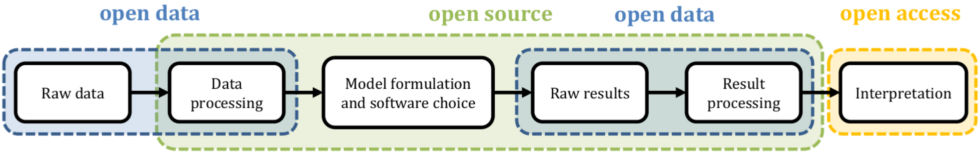
What is open modelling?

Open energy modelling means modelling with open software, open data and open publishing.

Open means that anybody is free to download the software/data/publications, inspect it, machine process it, share it with others, modify it, and redistribute the changes.

This is typically done by uploading the model to an online platform with an **open licence** telling users what their reuse rights are.

The **whole pipeline** should be open:



Why open modelling?

openness . . .

- increases **transparency**, **reproducibility** and **credibility**, which lead to better research and policy advice (no more 'black boxes' determining hundreds of billions of energy spending)
- reduces **duplication of effort** and frees time/money to develop **new ideas**
- *can* improve research **quality** through feedback and correction
- allows easier **collaboration** (no need for contracts, NDAs, etc.)
- is a **moral imperative** given that much of the work is publicly funded
- puts pressure on **official data holders** to open up
- is essential given the increasing **complexity** of the energy system - we all need data from different domains (grids, buildings, transport, industry) and cannot collect it alone
- can increase **public acceptance** of difficult infrastructure trade-offs

See also S. Pfenninger et al, 'The importance of open data and software: Is energy research lagging behind?,' Energy Policy, V101, p211, 2017 and S. Pfenninger, 'Energy scientists

Examples where modelling assumptions are very important

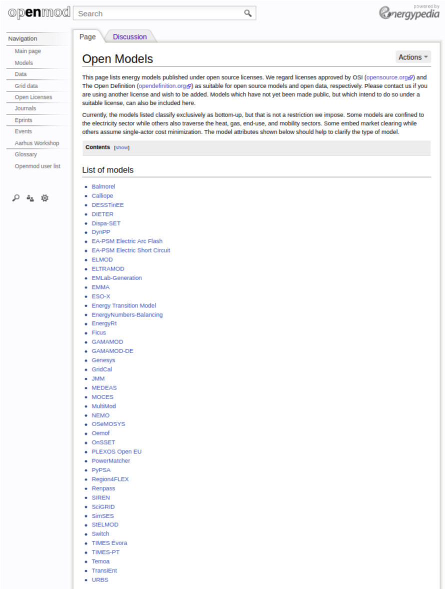
- **Modelgate**: In 2014 the European Commission was using discount rates of 17.5% for building efficiency measures in their 2030 framework package, leading to a weak efficiency reduction target of 27% by 2030. 3-5% would be recommended for efficiency; 17.5% is more in line with risky oil & gas projects. The target has since been raised to 32.5%. link
- **Wind and solar in IAMs**: Intransparent, high costs; learning rates too slow; exaggerated backup requirements; and in one case "limiting total share of wind and solar to below 30% of the overall electricity production" because of potential 'instability'. link
- **Uranium in IAMs**: Undocumented limits on uranium reserves and resources, that have to be reverse-engineered. link
- **Biomass in IAMs**: Similar to uranium.
- **Fuel switching in IAMs**: In some models demand is defined as final energy rather than energy services, making it impossible to e.g. switch from liquid fuels to electricity in transport.

Common objections from modellers

- **It's too much work to prepare/support**: You don't have to do either of these things. Publishing undocumented data may also help somebody.
- **There's no benefit to me**: Your work describing the dataset will be highly cited. The two `https://renewables.ninja` papers have 325 citations since 2016, PyPSA paper has 45 citations since 2018.
- **But we've put in 10,000 person-hours!**: Let's avoid more duplicated effort in future by pooling our efforts.
- **There are mistakes in open datasets**: Thank you for your feedback, please tell us where, and we'll fix it. Mistakes in closed models never come to light.

See also the openmod FAQ for a complete list.

What open models are out there?



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Open Models Actions

This page lists energy models published under open source licenses. We regard licenses approved by OSI (opensource.org) and The Open Definition (opendefinition.org) as suitable for open source models and open data, respectively. Please contact us if you are using another license and wish to be added. Models which have not yet been made public, but which intend to do so under a suitable license, can also be included here.

Currently, the models listed classify exclusively as bottom-up, but that is not a restriction we impose. Some models are confined to the electricity sector while others also traverse the heat, gas, end-use, and mobility sectors. Some embed market clearing while others assume single-actor cost minimization. The model attributes shown below should help to clarify the type of model.

Contents [show]

List of models

- Balmorel
- Calliope
- DESSTinEE
- DIETER
- Dispa-SET
- DynPP
- EA-PSM Electric Arc Flash
- EA-PSM Electric Short Circuit
- ELMOD
- ELTRAMOD
- EMLab-Generation
- EMMA
- ESO-X
- Energy Transition Model
- EnergyNumbers-Balancing
- EnergyRt
- Ficus
- GAMAMOD
- GAMAMOD-DE
- Genesys
- GridCal
- JMM
- MEDEAS
- MOCES
- MultiMod
- NEMO
- OSeMOSYS
- Oemof
- OnSSET
- PLEXOS Open EU
- PowerMatcher
- PyPSA
- Region4FLEX
- Renpass
- SIREN
- SciGRID
- SimSES
- StELMOD
- Switch
- TIMES Évora
- TIMES-PT
- Temoa
- TransiEnt
- URBS

- The first three appeared before 2010
- Since then there has been a flood, with **over 40 models** listed on the openmod wiki pages: `https://wiki.openmod-initiative.org/wiki/Open_Models`
- Why the boom? Interest in GHG reduction, renewables integration, new generation of modellers raised on free software, funding bodies demanding openness
- They are used in academia, research institutes, government bodies and private companies

The killer app: open data

Personal opinion: anybody can build a modelling framework. The real killer app of openness is **high quality, validated datasets**.

It's very important to open the framework for transparency and reproduceability, but there are hundreds out there already and they all "cook with water".

Collecting data on the other hand is **hard work**, and validating it is **even harder**.

Examples of datasets we need:

- Spatially and temporally resolved demand for electricity, transport, heating and industry
- Spatially and temporally resolved renewable availability
- Biomass by type and usage pathway
- Detailed knowledge of industrial processes
- Detailed knowledge of existing network infrastructure

The Open Energy Modelling Initiative

There's an initiative for that!

We are a **grass roots community** of 575+ open energy modellers from universities, research institutions and the interested public.

We promote **open code**, **open data** and **open science** in energy modelling.

Join the **mailing list**, participate in the online **forum**, contribute to the **wiki** and come to the next **biannual workshop**.

openmod open energy modelling initiative

openmod-initiative.org

Source: openmod initiative

What can the openmod community offer NGOs?

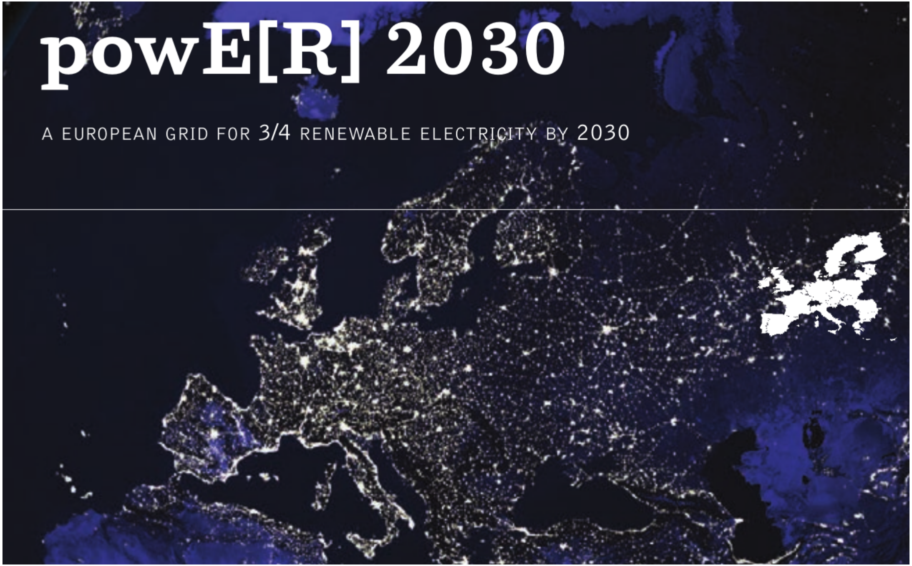
Guidelines for procuring and funding future studies

If you are procuring modelling studies, insist that the model used is open!

You will gain multiple benefits:

- full **transparency for you** - no need to rely on consultants who may choose not to reveal critical details
- full **transparency for the public** - increases credibility
- **lower costs** if existing open models are used
- **reuseability** - you can reuse the model yourself and avoid **lock-in** with a particular consultant
- combine open data with open source **presentation and visualisation** tools - e.g. create a dashboard for the public to explore different assumptions

Case Study: 2014 Greenpeace powE[R] 2030 European grid study

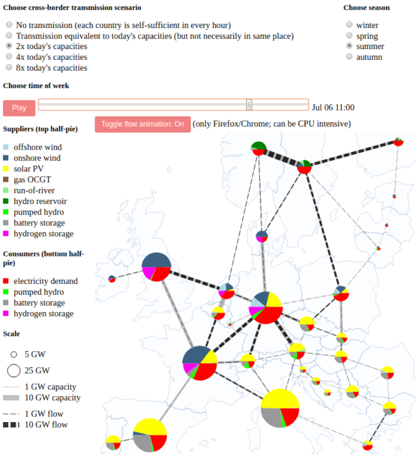


Source: Greenpeace 2014

Online Visualisations and Interactive ‘Live’ Models

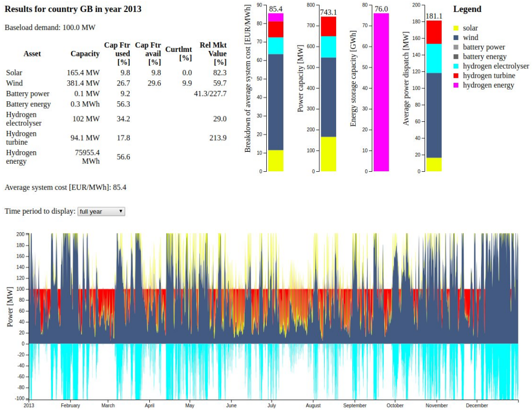
Online animated simulation results:

`pypsa.org/animations/`



Live user-driven energy optimisation:

`model.energy`



Long-term utopic vision

A **set of open models** recognised by industry, academia, government and NGOs.

- TSO X uses the model to show that network expansion is required under assumptions Y
- Academic Z shows changing regulation A would require less grid expansion
- Regulator C adapts regulation correspondingly
- NGO D shows in the model that stronger efficiency measures at reasonable cost could avoid E% of onshore wind in an area of high bird and bat biodiversity
- Government F takes note, increases incentives for efficiency measures
- Public confidence in Energy Transition rises

This is **not** possible in the current fragmented, closed model landscape, since there is neither **comparability** nor **common sets of assumptions**.

Conclusions

Conclusions

- Energy modelling is critical for understanding the future energy system, but **most energy models are closed and intransparent**
- Energy modelling results depend strongly on assumptions and approach - therefore **openness and transparency are critical**, guaranteed by open licences for data and code
- There are **many high quality open models** available, tendency strongly increasing
- Openness offers **multiple benefits** to academics, private actors, governments, NGOs and the public

Example: Recent results from PyPSA-Eur

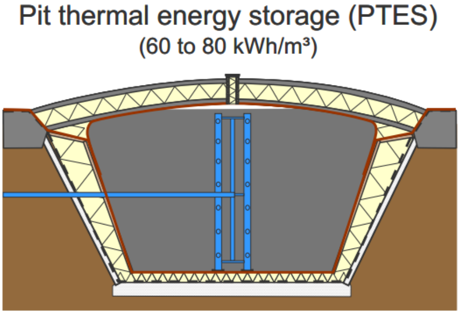
Must take account of social & political constraints

Sustainability doesn't just mean taking account of environmental constraints.

There are also **social and political constraints**, particularly for transmission grid and onshore wind development.

Fortunately other sectors offer flexibility back to grid

Other sectors offer **flexibility** (e.g. battery electric vehicles, power-to-gas, thermal storage), enabling energy to be **stored cheaply** and **transported easily** (e.g. using natural gas network).



Sectoral coupling with spatial resolution, European scope

The Issue: Most cross-sectoral studies are at country level, but don't have the resolution to resolve transmission bottlenecks or the variability of renewables

Our Goal: Model full energy system over Europe with enough resolution to understand the effects of congestion and the cost-benefits of transmission reinforcement

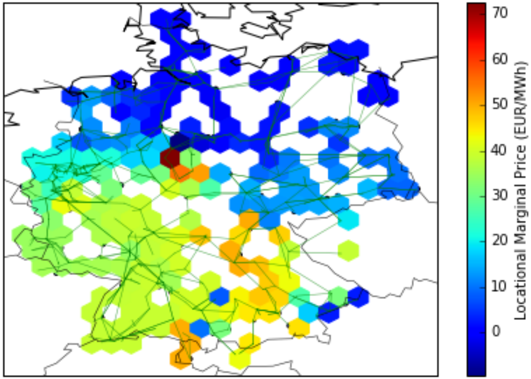
The Challenge: Enormous datasets, computability, complexity

Today: Some preliminary results from my group and our cooperation partners

Python for Power System Analysis (PyPSA)

Our free software PyPSA is available online at `https://pypsa.org/` and on github. It can do:

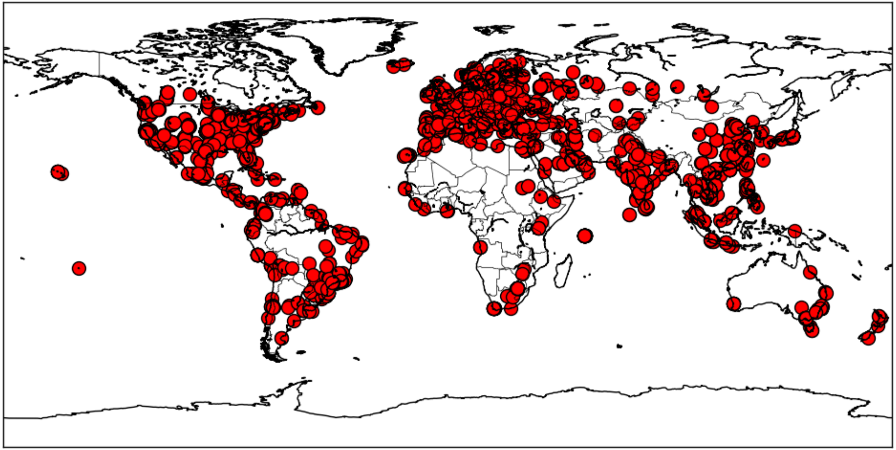
- Static **power flow**
- **Linear optimal power flow** (LOPF) (multiple periods, unit commitment, storage, coupling to other sectors)
- **Security-constrained LOPF**
- Total electricity system **investment optimisation**



It has models for storage, meshed AC grids, meshed DC grids, hydro plants, variable renewables and sector coupling.

Python for Power System Analysis: Worldwide Usage

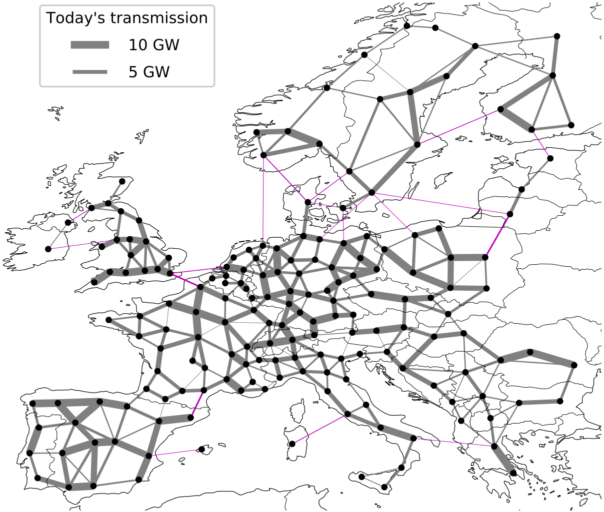
PyPSA is used worldwide by **dozens of research institutes and companies** (Fraunhofer ISE, DLR Oldenburg, FZJ, TU Berlin, RLI, a European TSO, Saudi Aramco, Edison Energy, spire and many others). There have been visitors to the website from most countries in the world:



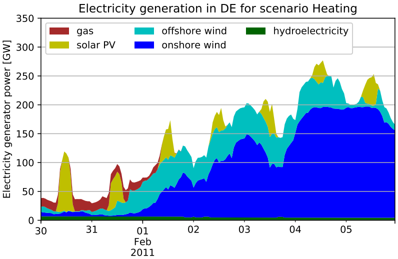
181-node model of European energy system

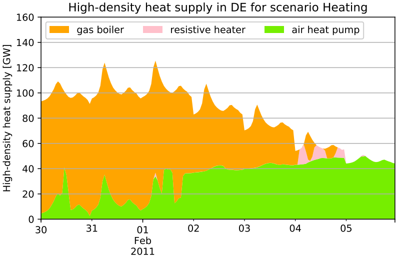
Some brief, preliminary results from our sector-coupled, 181-node model of the European energy system.

- Couple **all energy sectors** (power, heat, transport industry)
- Reduce CO_2 emissions **to zero**
- Assume **smaller bidding zones** and **widespread dynamic pricing**
- **Conservative** technology assumptions
- Examine effect of **acceptance** for **grid expansion** and **onshore wind**



Example problem with balancing: Cold week in winter





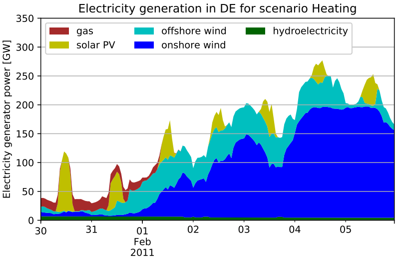
There are difficult periods in winter with:

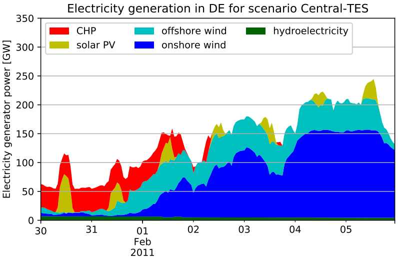
- **Low** wind and solar generation
- **High** space heating demand
- **Low** air temperatures, which are bad for air-sourced heat pump performance

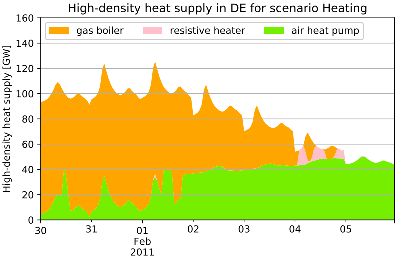
Less-smart solution: **backup gas boilers** burning either natural gas, or synthetic methane.

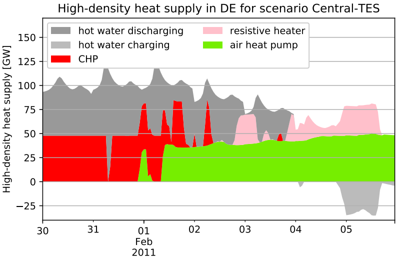
Smart solution: **long-term thermal energy storage** in **district heating networks** and efficient **combined-heat-and-power plants**.

Cold week in winter: inflexible (left); smart (right)

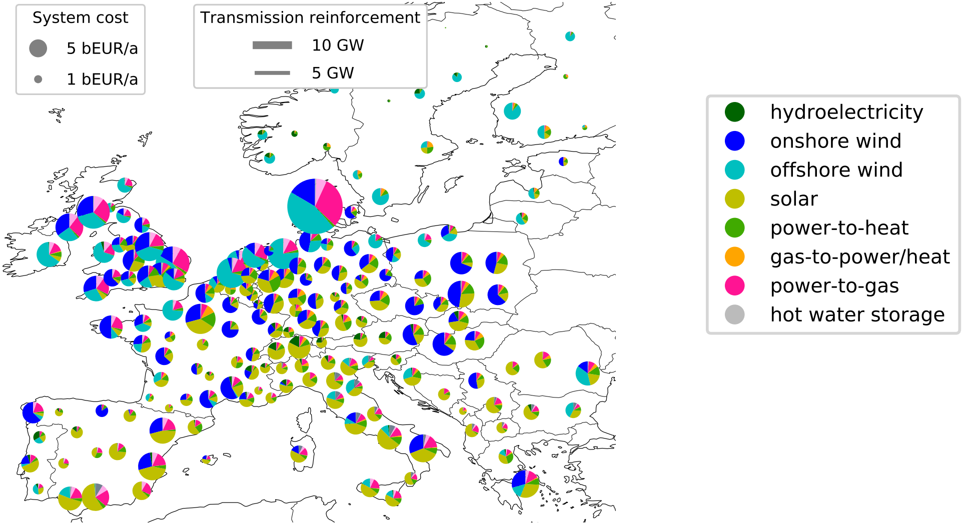




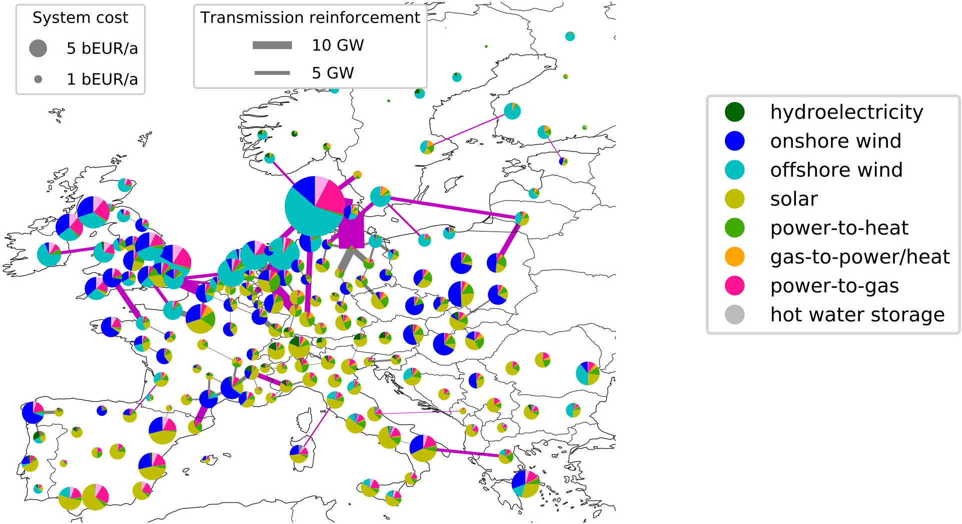




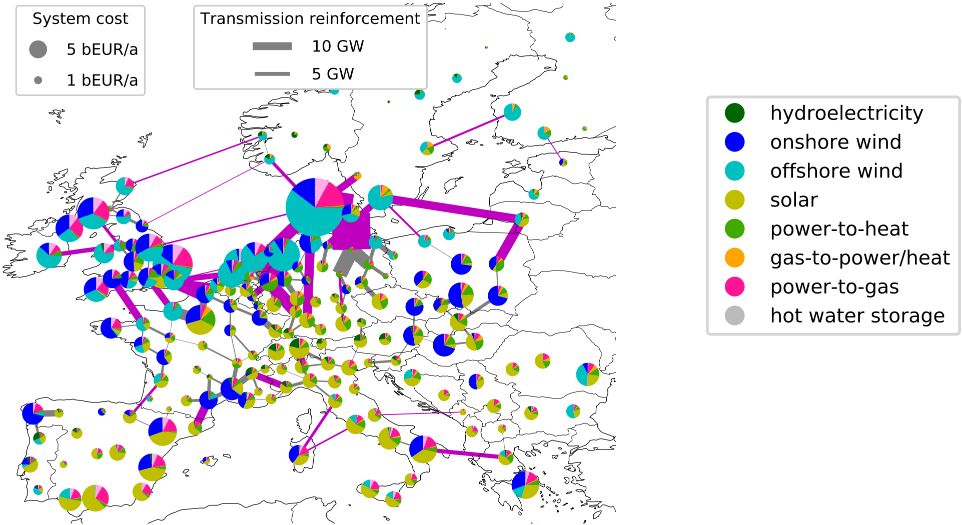
Distribution of technologies: No grid expansion



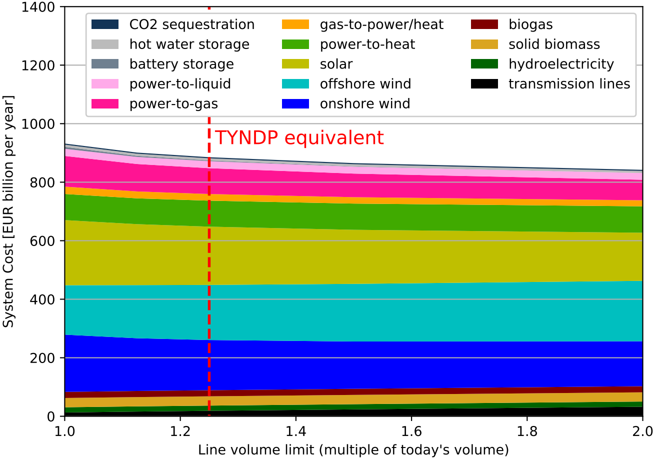
Distribution of technologies: 25% more grid volume - similar to TYNDP



Distribution of technologies: 50% more grid volume - double the TYNDP

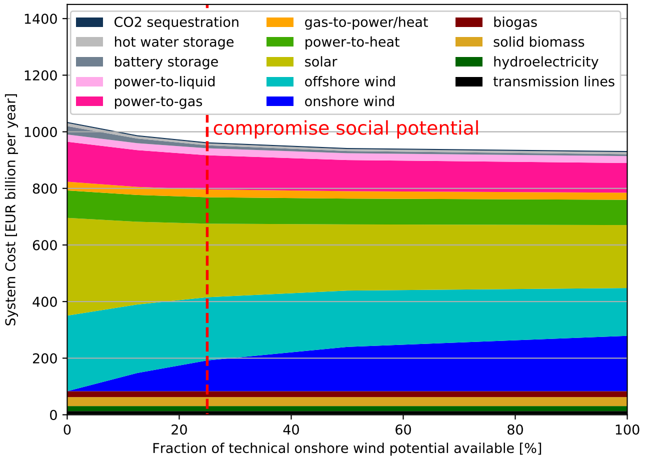


Benefit of grid expansion for sector-coupled system



- Direct system costs **higher than today's system** (€ 700 billion per year with same assumptions)
- Systems **without grid expansion** are feasible, but more costly
- As grid is expanded, **costs reduce** from solar and power-to-gas; more offshore wind
- Total cost benefit of extra grid: ∼ € 90 billion per year
- **Over half of benefit available at 25% expansion** (like TYNDP)

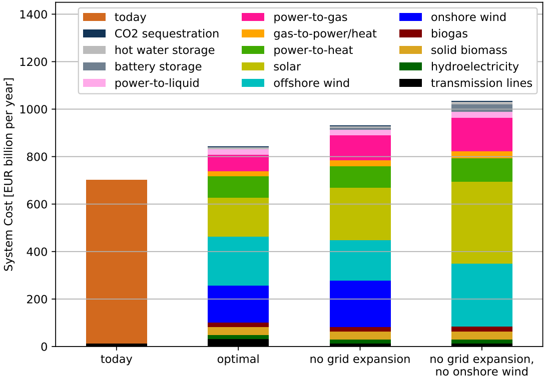
Benefit of full onshore wind potentials



- **Technical potentials** for onshore wind respect land usage
- However, they do not represent the **socially-acceptable potentials**
- Technical potential of ~ 400 GW in Germany is **unlikely to be built**
- Costs rise by ~ € 100 billion per year as we **eliminate onshore wind** (with no grid expansion)
- Rise is only ~ € 30 billion per year if we **allow a quarter of technical potential** (~ 100 GW for Germany)

Should also consider indirect costs, which change the picture

Costs increase as we reduce emissions and accommodate public acceptance. . .



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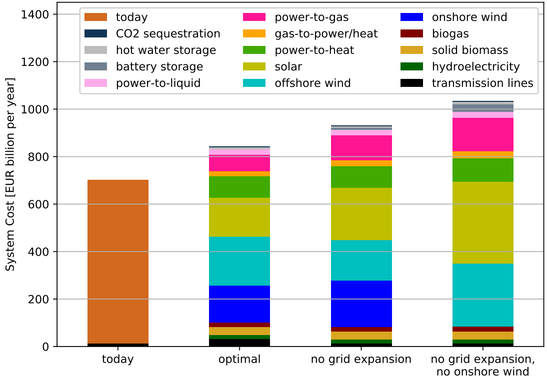
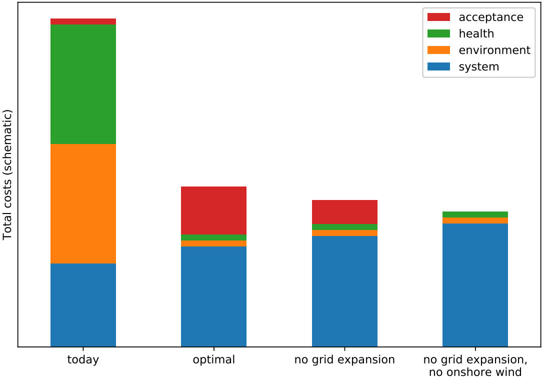
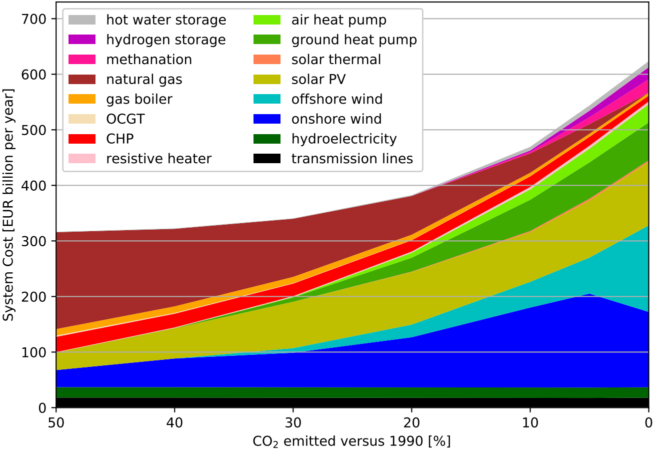
Costs increase as we reduce emissions and accommodate public acceptance. . .



but not if we include indirect environmental, health and social costs (schematic example)



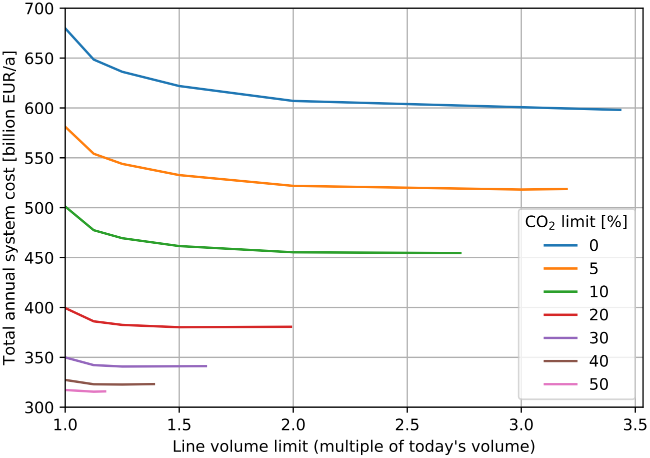
Pathway down to zero emissions in electricity, heating and transport



If we look at investments to eradicate CO_2 emissions in electricity, heating and transport we see:

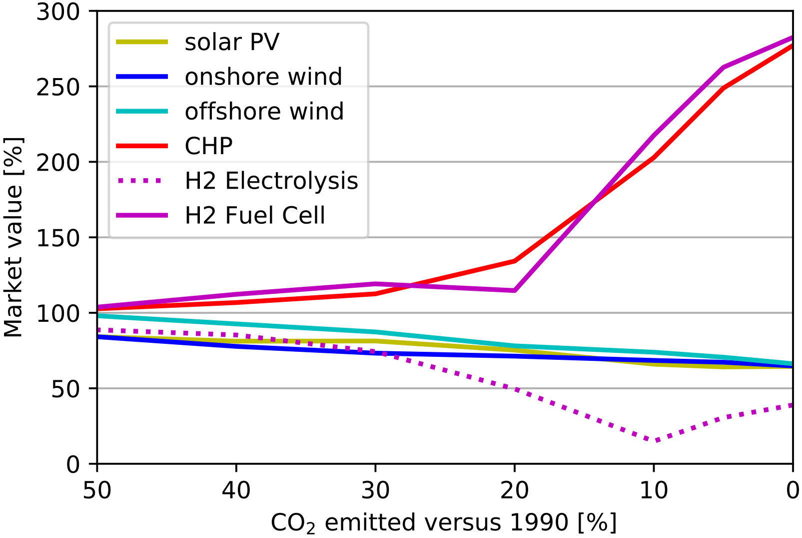
- Electricity and transport are decarbonised first
- Heating comes next with expansion of heat pumps below 30%
- Below 10%, power-to-gas solutions replace natural gas

Benefit of grid depends on level of carbon dioxide reduction



- Optimal grid (rightmost point of each curve) grows successively larger
- Benefit of grid expansion grows with depth of CO_2 reduction
- Can still get away with no transmission reinforcement (if the system is operated flexibly)

Relative market values drop, but not drastically



More details?

For more details, see publications, code and data listed at:

`https://www.nworbmot.org`

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