# Open Energy Modelling: Situation in Europe; Case Studies

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Karlsruhe Institute of Technology

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RESEARCH FOR GRAND CHALLENGES

# Table of Contents

# Situation in Europe

# Why Energy Modelling in Particular Need to be Open

What makes energy modelling special?

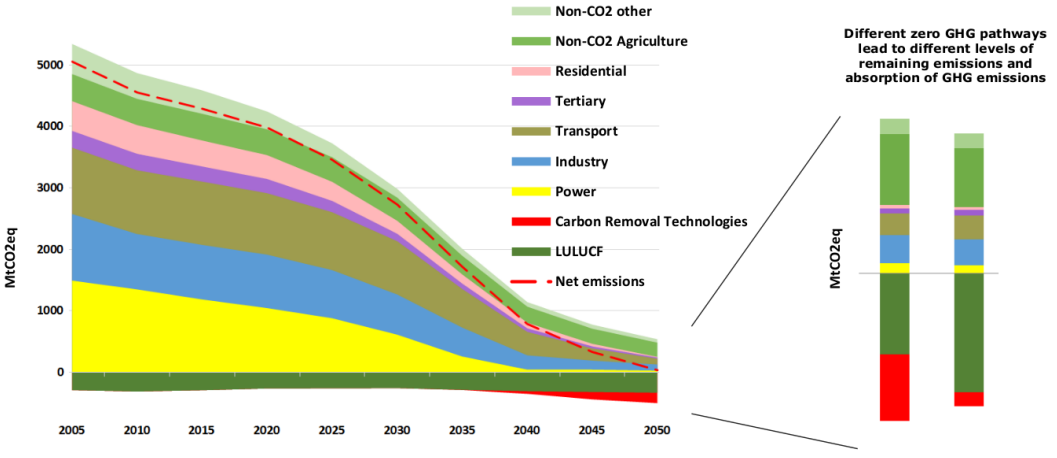
- Energy has **high social, political and economic relevance** (large positive role in economy, but also negative role in climate change, air pollution, resource conflicts)
- Large role of **business interests** in energy (hundreds of billions of euros spent each year in Europe on energy, much of it imported)
- Large **uncertainties about future** (renewables v nuclear v fossil carbon sequestration, public acceptance (nuclear, power lines, wind), fast-moving costs (a 2005 report projected cost of solar panels in 2050 at € 5500/kWp, today it's € 500/kWp))
- Need for **computer modelling** to avoid bad investment decisions, discuss trade-offs

# Situation in Europe

- Push from **researchers** in last 10 years for open models, newer focus on **open data**
- Most policy at European and national level still done with **legacy closed models**
- Large companies are using open models as they **gain credibility**, now also NGOs
- Fora like EMP-E bring together researchers and policy-makers, openness **high on agenda**
- Lots of headroom to improve openness in policy-making
- Many model frameworks from Europe being used **outside Europe** for energy policy

# PRIMES-based closed modelling for European Commission

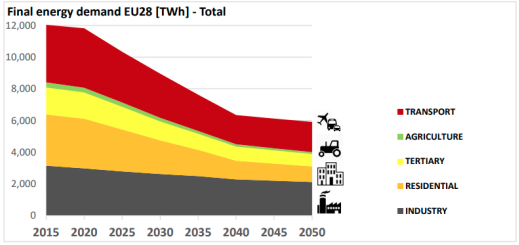
Paris-compliant 1.5° C scenarios from European Commission - **net-zero GHG in EU by 2050**

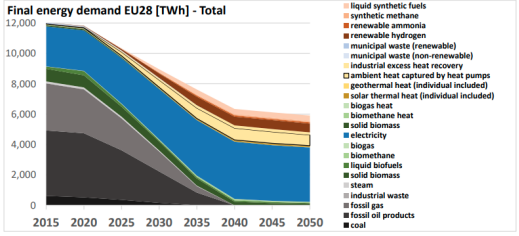



Source: European Commission 'Clean Planet for All', 2018

# Paris Agreement Compatible (PAC) Scenarios (open) from CAN and EEB

Climate Action Network (CAN) Europe and the European Environmental Bureau (EEB) drew on **150 stakeholders** from NGOs, science and industry to agree **open scenario** for Europe.





Source: PAC Scenarios

# Benefits of open models for policy-makers and NGOs

If procuring modelling studies, insist that the model used is open! **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 consultant
- combine open data with open source **presentation and visualisation** tools - e.g. create a dashboard for the public to explore different assumptions
- unleash **community** to **remix** your scenarios in ways you never imagined

# 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**.

# Case Study: OSeMOSYS


- open modelling framework **OSeMOSYS** widely used in academia and for policy
- UNDESA and UNDP has provided **modelling support** using OSeMOSYS on request from countries at left
- Ethiopia, Tunisia, Cyprus, Bolivia, Costa Rica **actively using** OSeMOSYS in policy
- Costa Rica setting up a **fully open source pipeline** for policy advice

**paper link**

Source: UN Modelling, Mark Howells

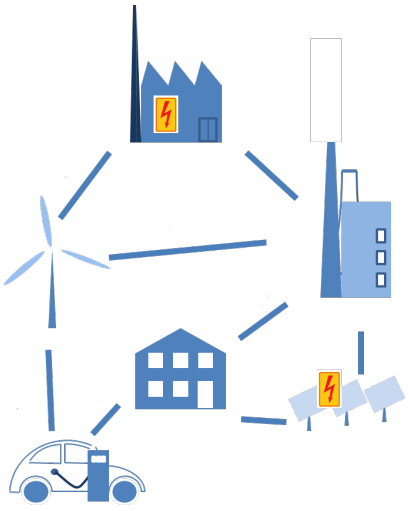
# What is Energy System Modelling?

**Energy System Modelling** is about the overall **design** and **operation** of the energy system.

- What are our **energy needs**?
- What **infrastructure** do they require?
- **Where** should it go?
- How much will it **cost**?

The answers to these questions affect **hundreds of billions** of euros of spending per year in Europe.

Researchers deal with these questions by **building computer models** of the energy system and then, for example, **optimizing** its design and operation.

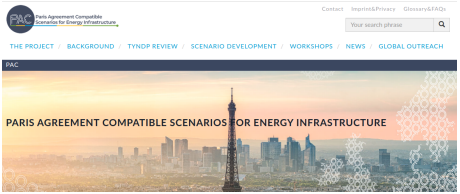


# Energy System Modelling: Who is it for?

Broadly speaking, we model energy systems to help **society** make decisions. Examples:

Government agencies commission studies to look at possible future scenarios:


But also companies and non-governmental organisations:

# Motivation: Controversial Studies Debunked


Sinn's study was **debunked** using an open model (he exaggerated storage requirements by 'up to **two orders of magnitude**')


Sinn's study was **debunked**, shown to use cherry-picked assumptions

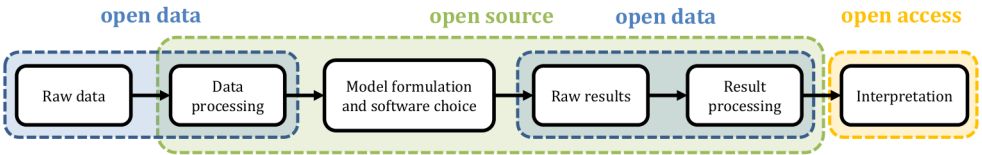
# What is open modelling?

**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:



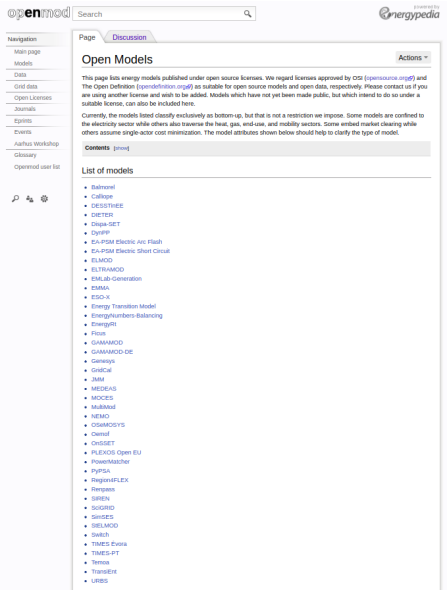
# Why open modelling?

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

# What other open models are out there?




- The first three appeared before 2010
- Since then there has been a flood, with **over 60 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

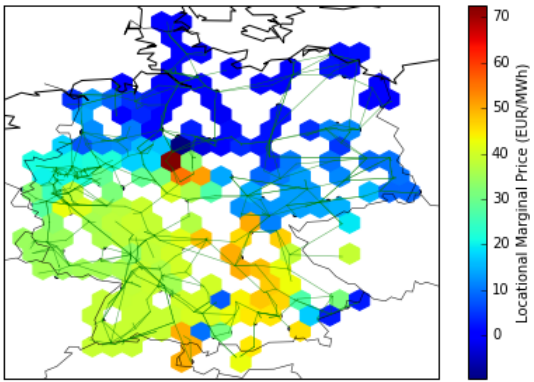
# openmod open energy modelling initiative

- **grass roots community** of open energy modellers from universities, research institutions and the interested public
- 700+ participants from all continents except Antarctica
- first meeting Berlin 18–19 September 2014
- promoting **open code**, **open data** and **open science** in energy modelling

# PyPSA for Energy System Optimization

# Python for Power System Analysis (PyPSA)

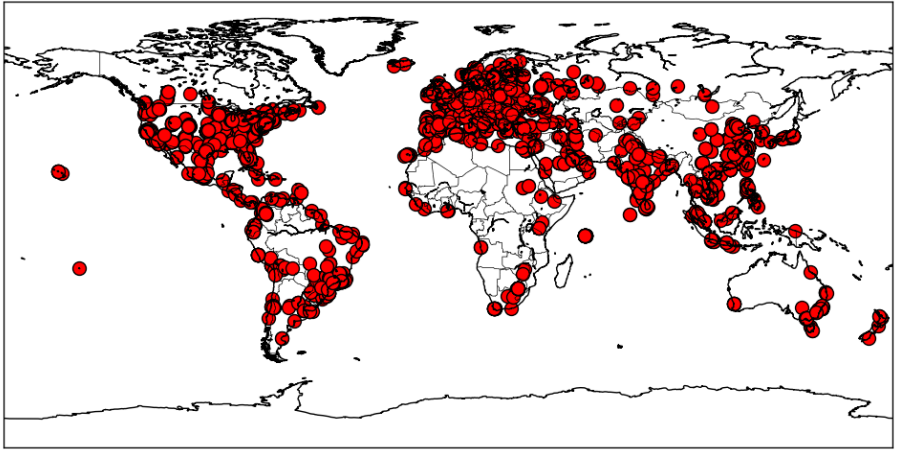
- **Open source** tool for modelling energy systems at **high resolution**.
- Fills missing gap between **load flow software** (e.g. PowerFactory, MATPOWER) and **energy system simulation software** (e.g. PLEXOS, TIMES,OSeMOSYS).
- Good grid modelling is increasingly important, for integration of **renewables** and **electrification** of transport, heating and industry.




PyPSA is available on **GitHub**.

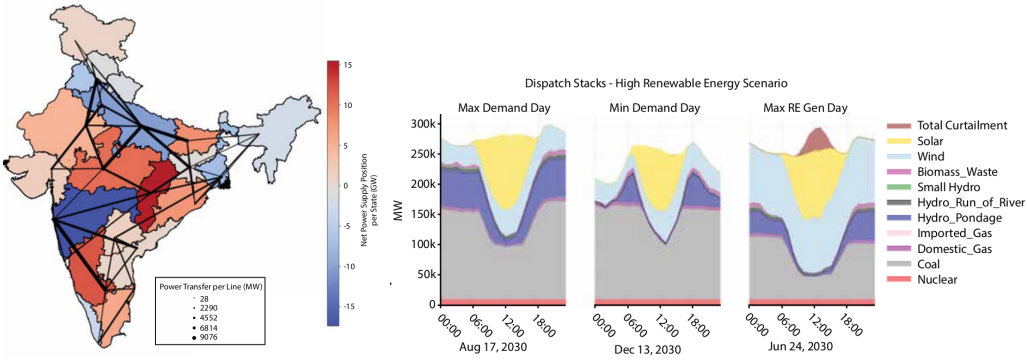
# Python for Power System Analysis: Worldwide Usage

PyPSA is used worldwide by **dozens of research institutes and companies** (TU Delft, Shell, TransnetBW, Fraunhofer ISE, DLR Oldenburg, FZJ, TU Berlin, RLI, TERI, Saudi Aramco, Edison Energy, spire and many others). Visitors to the website:



# Example User of PyPSA: TERI in India

For a government-backed study of India's power system in 2030, The Energy and Resources Institute (TERI) in New Delhi used PyPSA. Why? Easy to customize, lower cost than commercial alternatives, good for building up skills and reproducible by other stakeholders.

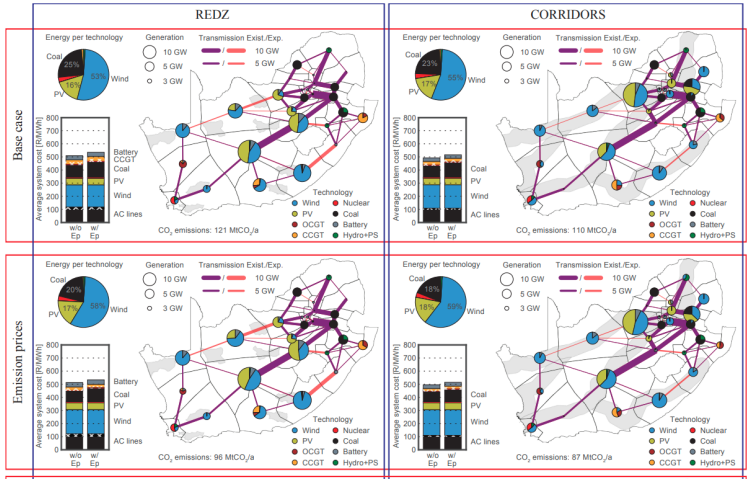





Source: TERI

# Example User of PyPSA: CSIR in South Africa

In a cooperation with the Council for Scientific and Industrial Research (CSIR) in South Africa, we examined decarbonization scenarios for the power system with a PyPSA-based model.






Source: Hörsch & Calitz

# Example User of PyPSA-Eur-Sec: TransnetBW in Germany

German Transmission System Operator (TSO) TransnetBW for South-West Germany used an open model (PyPSA-Eur-Sec) to model the energy system in 2050, because it was better and easier than building their own model from scratch.



Source: https://www.transnetbw.de/de/stromnetz2050/

# Our goal: understand effect of social & political constraints on net-zero

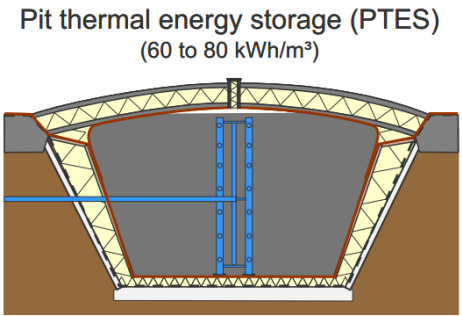

Sustainability doesn't just mean taking account of environmental constraints.

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

# Fortunately other energy sectors can offer flexibility back to grid

Other sectors offer **flexibility** (e.g. battery electric vehicles, thermal storage), enabling energy to be **moved in time cheaply** and **transported easily** (e.g. synthetic fuels in pipelines).

This allows us to **avoid unpopular infrastructure** using **smart coordination**.

# Goal: Sectoral coupling with high 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

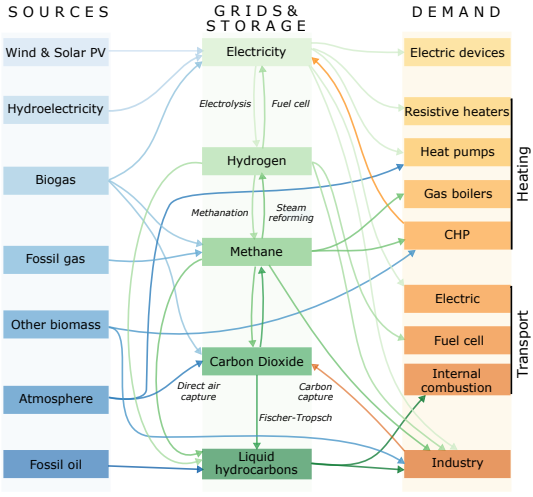
**Our Goal**: Model full energy system over Europe with enough resolution to understand congestion and the cost-benefits of transmission reinforcement & digitally-enabled flexibility

**The Challenge**: Enormous datasets, computability, complexity

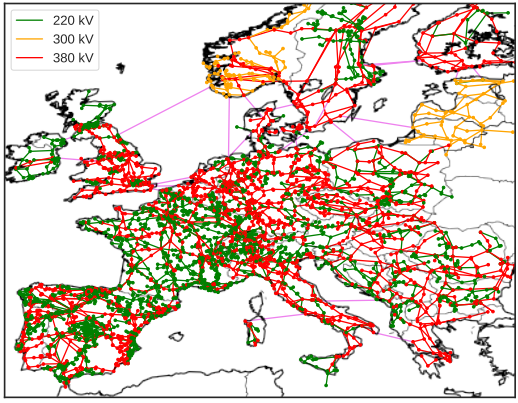
**Today**: Some preliminary results from my group and our cooperation partners

# What is PyPSA-Eur-Sec?

Represents all energy flows...



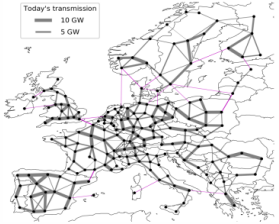

and bottlenecks in energy networks.

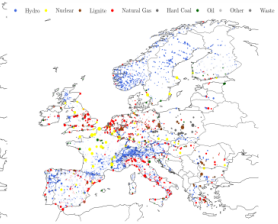


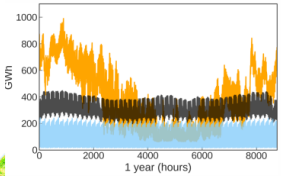
# Data-Driven Modelling

Lots of different types of data come together for the modelling...

- Clustered network model
- Power plants & technology assumptions
- Renewable potentials & decades of hourly time series for each point in space
- Demand forecasts & time series



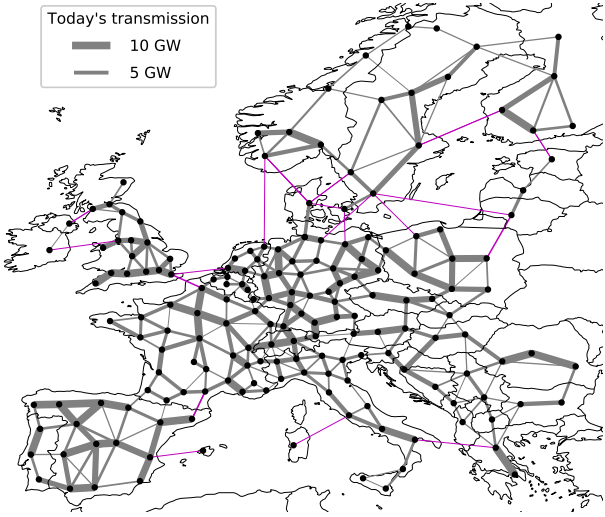




Analysis and optimisation

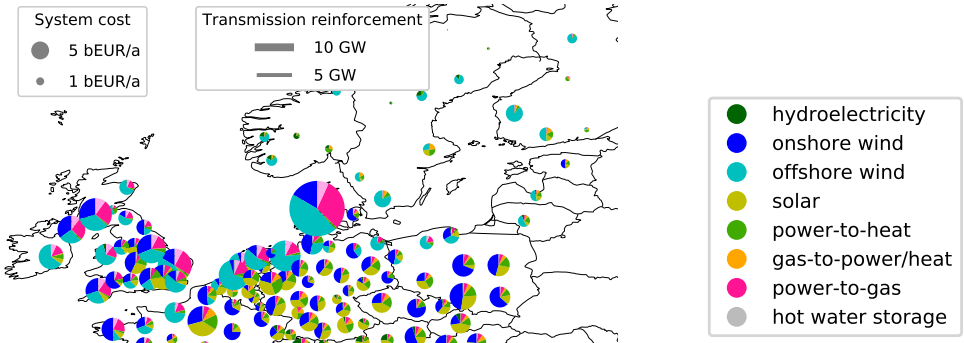
# Example results: 181-node model of European energy system

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

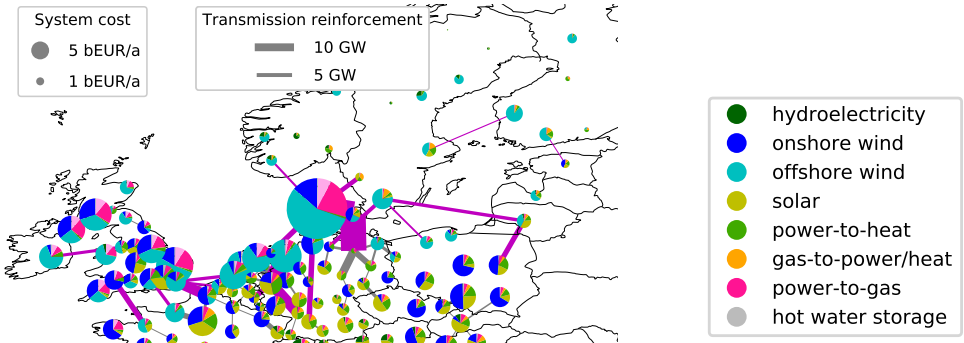
- Couple **all energy sectors** (power, heat, transport industry)
- Reduce $CO_2$ emissions **to zero**
- Assume **smaller bidding zones** and **widespread dynamic pricing**
- **Conservative** technology assumptions
- Examine effect of **acceptance** for **grid expansion** and **onshore wind**



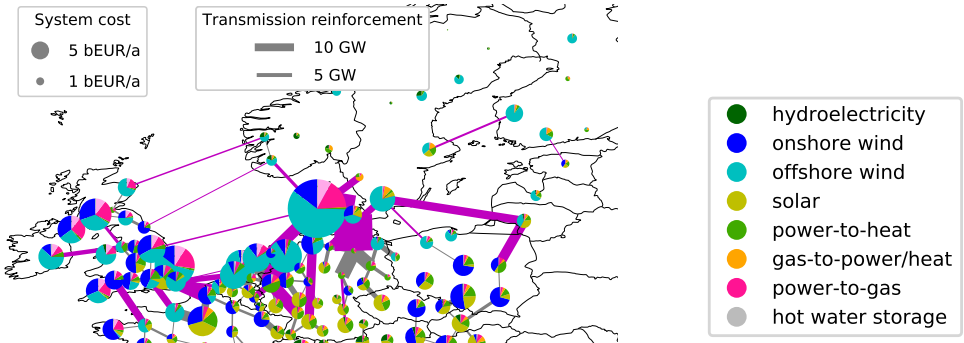
# Distribution of technologies: No grid expansion



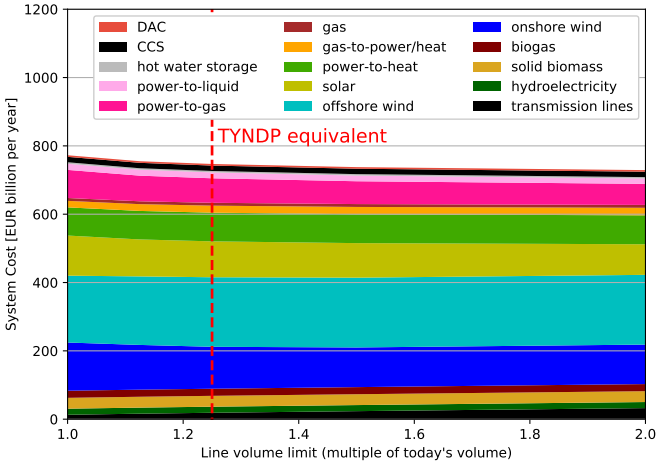
# Distribution of technologies: 25% more grid volume - similar to TYNDP



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

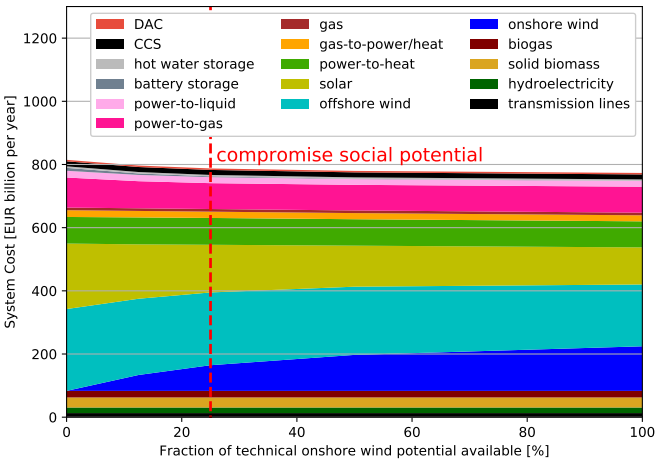


# Benefit of grid expansion for sector-coupled system



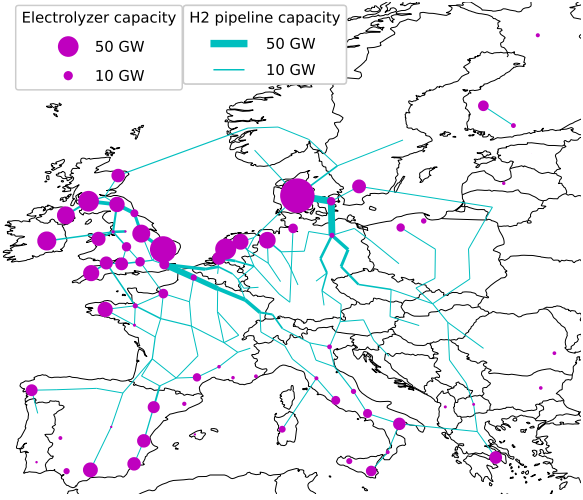

- Direct system costs **bit higher than today's system** (€ 700 billion per year with same assumptions)
- Systems **without grid expansion** are feasible, but more costly
- As grid is expanded, **costs reduce** from solar and power-to-gas; more offshore wind
- Total cost benefit of extra grid: $\sim$ € 47 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 $\sim$ 400 GW in Germany is **unlikely to be built**
- Costs rise by $\sim$ € 42 billion per year as we **eliminate onshore wind** (with no grid expansion)
- Rise is only $\sim$ € 14 billion per year if we **allow a quarter of technical potential** ($\sim$ 100 GW for Germany)

# Role of hydrogen network



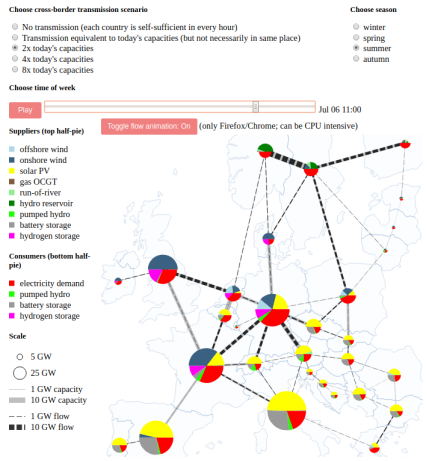

- New **hydrogen network** takes over role of transporting energy around Europe when no electricity grid expansion allowed
- Cost of network: € 8 billion per year
- Energy moved per hour (TWhkm/h):

| | |
|---|---|
| HVAC | 99 |
| HVDC | 3 |
| $H_2$ | 209 |

# Online Visualisations and Interactive 'Live' Models

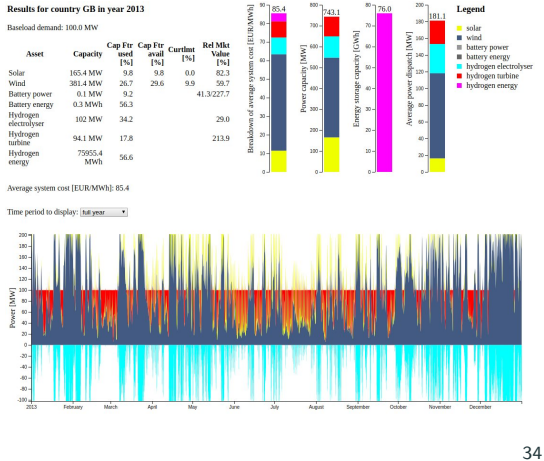
Online animated simulation results:

**pypsa.org/animations/**




Live user-driven energy optimisation:

**model.energy**



# Conclusions

# Conclusions

- Energy modelling is a field that strongly benefits from an open approach
- Transparency helps society to make decisions with difficult trade-offs
- The field has seen an explosion of open data and free software in the last 5 years, mostly driven by academia
- Adoption of open models is increasing outside academia in government, companies and NGOs

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