Modelling the European Energy System to Fulfil the Paris Agreement Targets: The Role of Informatics

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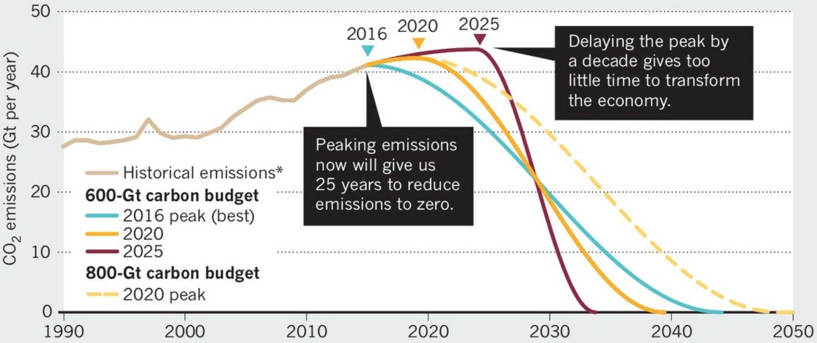
Agenda

The Global Carbon Dioxide Challenge

600 Gt budget gives 33% chance of 1.5°C
(Paris: 'pursue efforts to limit [warming] to 1.5°C')

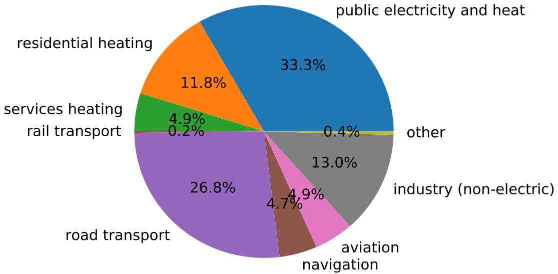
800 Gt budget gives 66% chance of 2°C
(Paris: hold 'the increase...to well below 2°C')



Source: 'Three years to safeguard our climate,' Nature, 2017

It's not just about electricity demand. . .

EU28 CO_2 emissions in 2015 (total 3.2 Gt CO_2, 8% of global):



. . . but electrification of other sectors is critical for decarbonisation!

Wind and solar dominate the expandable potentials for low-carbon energy provision, so electrification is essential to decarbonise other sectors.

Source: Brown, data from EEA

Energy System Design: Research Questions

1. What **infrastructure** (wind, solar, hydro generators, heating/cooling units, storage and networks) does a highly renewable energy system require, **where** should it go, and **when** should it be built?
2. Given a desired CO_2 emissions reduction (e.g. 95% compared to 1990), what is the **cost-optimal** combination of infrastructure?
3. How do we deal with the **variablility** of wind and solar?

Assess the multitude of trade-offs in the energy system!

Approaches to Dealing with Variable Renewables

1. smoothing renewable feed-in **in space** with transmission networks,
2. smoothing the variability **in time** with storage, and
3. demand-side management with coupling to other energy **sectors** like heating, transport and industrial demand.

Problem 1: Spatial resolution and scope

Need high **spatial resolution** to represent renewables variations and transmission constraints, as well as **continental** scope to capture energy markets and large-scale smoothing.

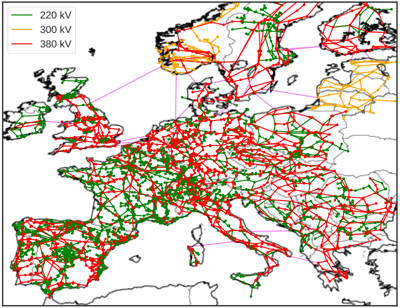


Figure: Power grid of PyPSA-EUR

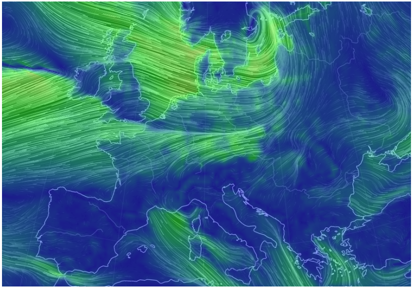


Figure: Snapshot of wind speeds in EU

Problem 2: Temporal resolution and scope

Need high **temporal resolution** and **multi-year time series** to represent load and VRE resource variability, correlations and extreme events, and the use of storage.

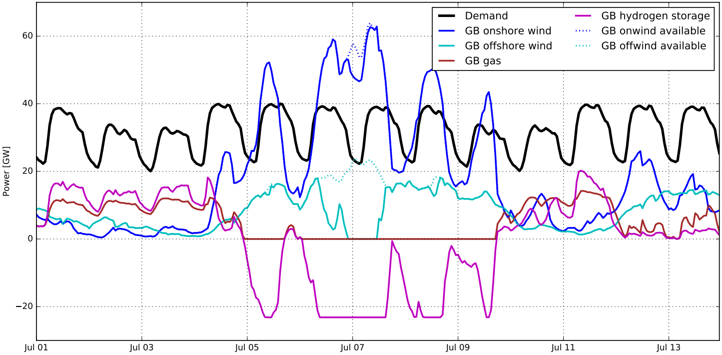
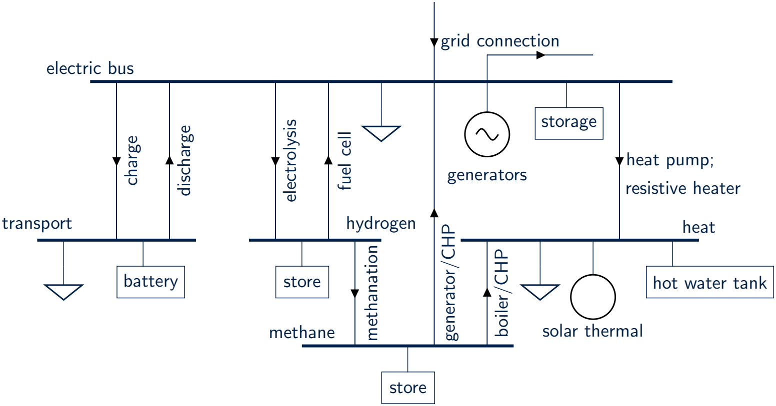


Figure: An exemplary energy system time profile for Great Britain in July 2013

Problem 3: Model Complexity of Sector Coupling

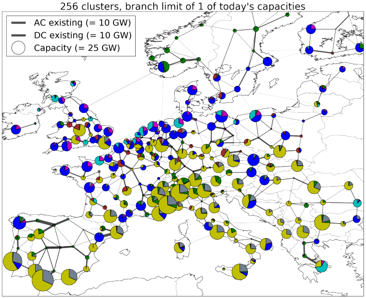
Large number of interacting **interdependencies**.
What can we **simplify** while retaining accuracy?
What should we **co-optimise** and what can be treated separately?



Contribution of Informatics

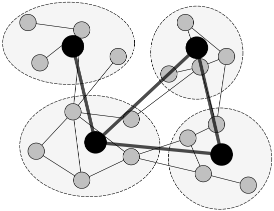
Data side:

- Processing big weather datasets
- Geographical potential analysis
- Merging open data sources
- Visualization of results



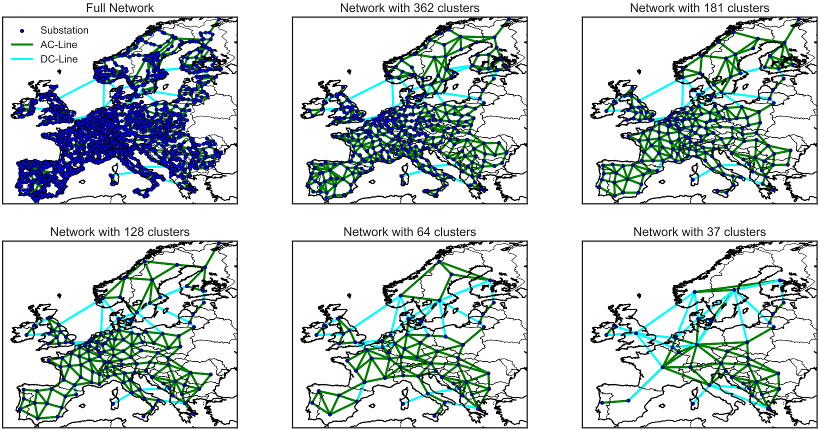
Algorithmic side:

- Data reduction techniques such as network clustering and PCA
- New optimisation routines for more speed and accuracy
- Information theory to trace interdependencies
- Understanding the solution space



Example 1: Network Clustering

There are many **algorithms** for clustering/aggregating networks, but likewise many ways to determine the **nodal weights** for clustering.

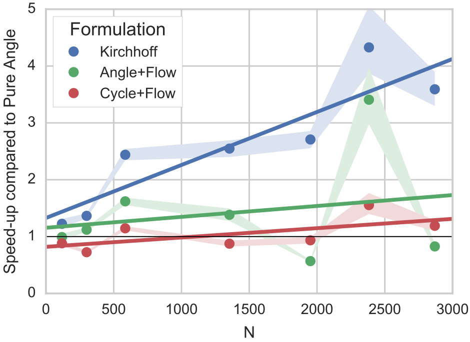


Example 2: LOPF speedup with cycle flows

We can use dual graph theory to decompose the flows in the network into two parts:

1. A flow on a spanning tree of a network, uniquely determined by nodal balance (KCL).
2. Cycle flows, which don't affect KCL and whose strength is fixed by enforcing KVL.

Up next: Explore performance boosts of non-linear power flow approximations/ relaxations.

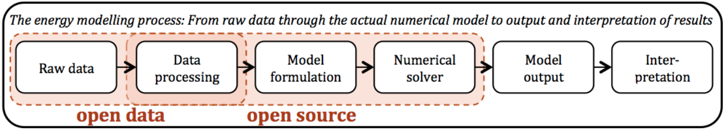


- speed-up of up to **200 times**
- average speed-up of **factor 12**
- speed-up is highest for large networks with lots of renewables

Source: J. Hrsch, H. Ronellenfitsch, D. Witthaut, T. Brown, Linear Optimal Power Flow Using Cycle Flows, `https://arxiv.org/abs/1704.01881`, 2017

The Idea of Open Energy Modelling

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



Why is openness important?

- Transparency
- Quality
- Credibility
- Avoiding double-work
- Encouraging cooperation
- Reproducibility
- Visibility
- Education
- Public funding
- Public engagement
- Unknown benefits and synergies

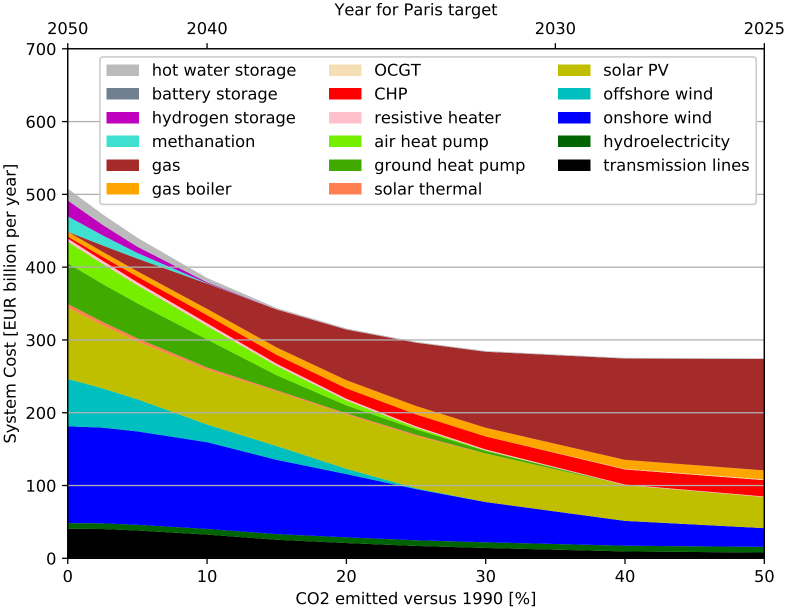
Open Energy Modelling Initiative

The **Open Energy Modelling Initiative** is a grass roots community of open energy modellers from universities, research institutions and the interested public that promotes open code, open data and open publishing in energy modelling.

openmod open energy modelling initiative

Our free software **PyPSA** is online at `pypsa.org` and on GitHub.

- It can do **total energy system investment optimisation** with linear optimal power flow including generation expansion, transmission expansion, storage expansion, sector coupling, unit commitment, and security-constraints)
- It has **data and models** for power plants, storage, meshed AC grids, meshed DC grids, hydro plants, variable renewables and sector coupling at European scale.



Source: PyPSA-EUR, 2017

The takeaway messages...

- The Energy Transition is an **urgent challenge** for science, society and industry.
- Studies show that the Energy Transition is **feasible**, but due to **complexity**, researchers have to **simplify** crucial modelling aspects.
- Our research group aims at leveraging **new algorithms and methodologies** from across informatics, physics, mathematics, economics and engineering to **tackle this complexity**.
- Taking account of European interactions, spatial & temporal detail, and sector coupling are **all crucial** for reducing CO_2 emissions.
- The energy system is complex and contains short- and long-term uncertainties (e.g. cost developments, scaleability of storage, social acceptance, consumer behaviour), so **openness is critical**.

What next?

Find the slides:
`fneum.github.io/assets/energyinformatics.pdf`

Send an email:
`fabian.neumann@kit.edu`

Get involved with the Open Energy Modelling Initiative:
`openmod-initiative.org/`

Find our models:
`github.com/pypsa/PyPSA`
`github.com/pypsa/pypsa-eur`

Of course, there is much more to find on my supervisor's website:
`nworbmot.org`