Multi-timescale challenges in sector-coupled energy systems

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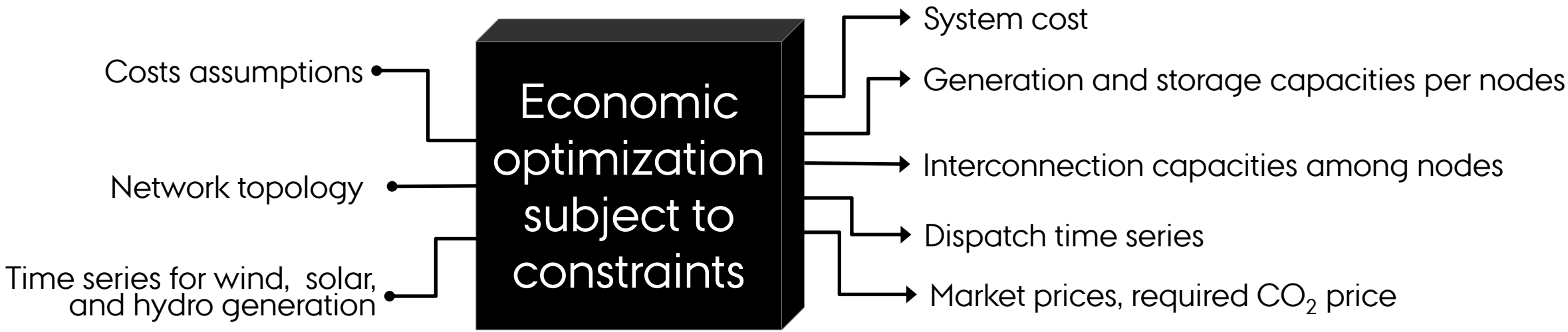
Outline

1. Methodology
2. Study: Early transformation pays-off
3. The need for balancing at different time scales
4. Time series representing wind, solar, and hydro generation

Methodology

Join capacity and dispatch optimization in a nutshell



26 tech. x 30 countries x 8760 hours = $7 \cdot 10^6$ variables, solved in ~2 hours in simulation cluster

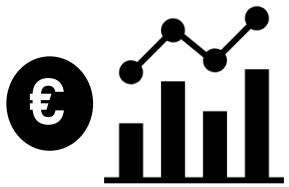
Methodology

Economic optimization subject to constraints

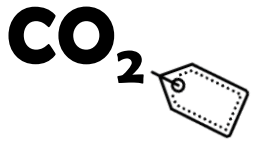
$$\min \left(\sum_{n} \underset{costs}{generation} + \underset{costs}{storage} + \underset{costs}{transmission} + \sum_{n,t} \underset{costs}{variable} \right)$$

Subject to constraints :

$$generation + balance = demand \quad \leftrightarrow \quad \lambda_{n,t} \qquad \forall\, n, t$$



$$\sum emissions \leq CAP_{CO2} \quad \leftrightarrow \quad \mu_{CO2}$$

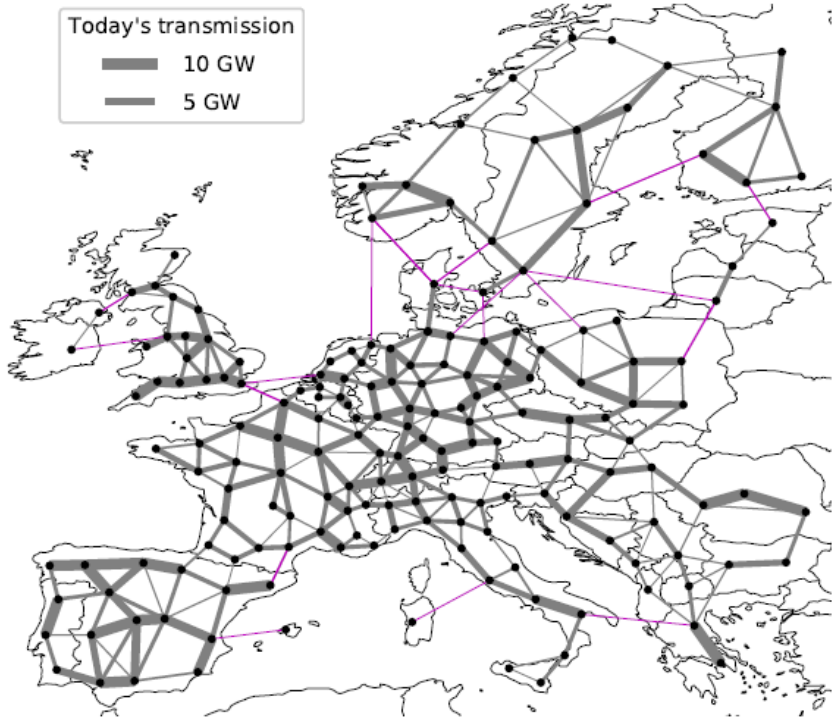


Perfect competition and foresight, long-term market equilibrium

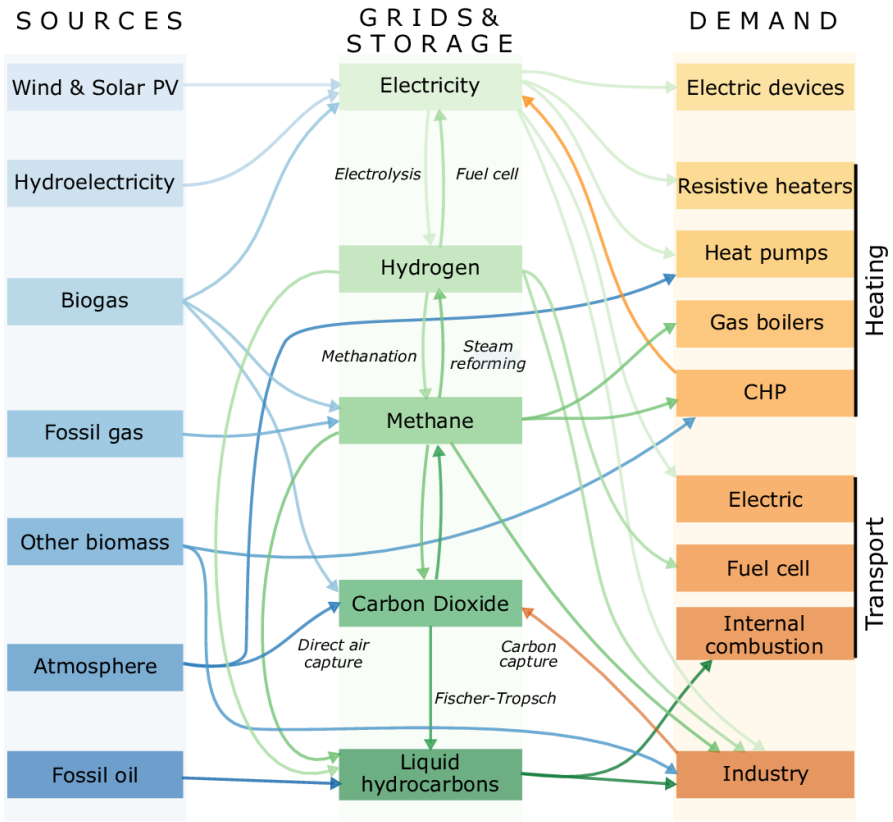
Implemented in PyPSA (Python for Power System Analysis)

Methodology: PyPSA-Eur-Sec

Networked model + Hourly resolution



Detailed sector coupling

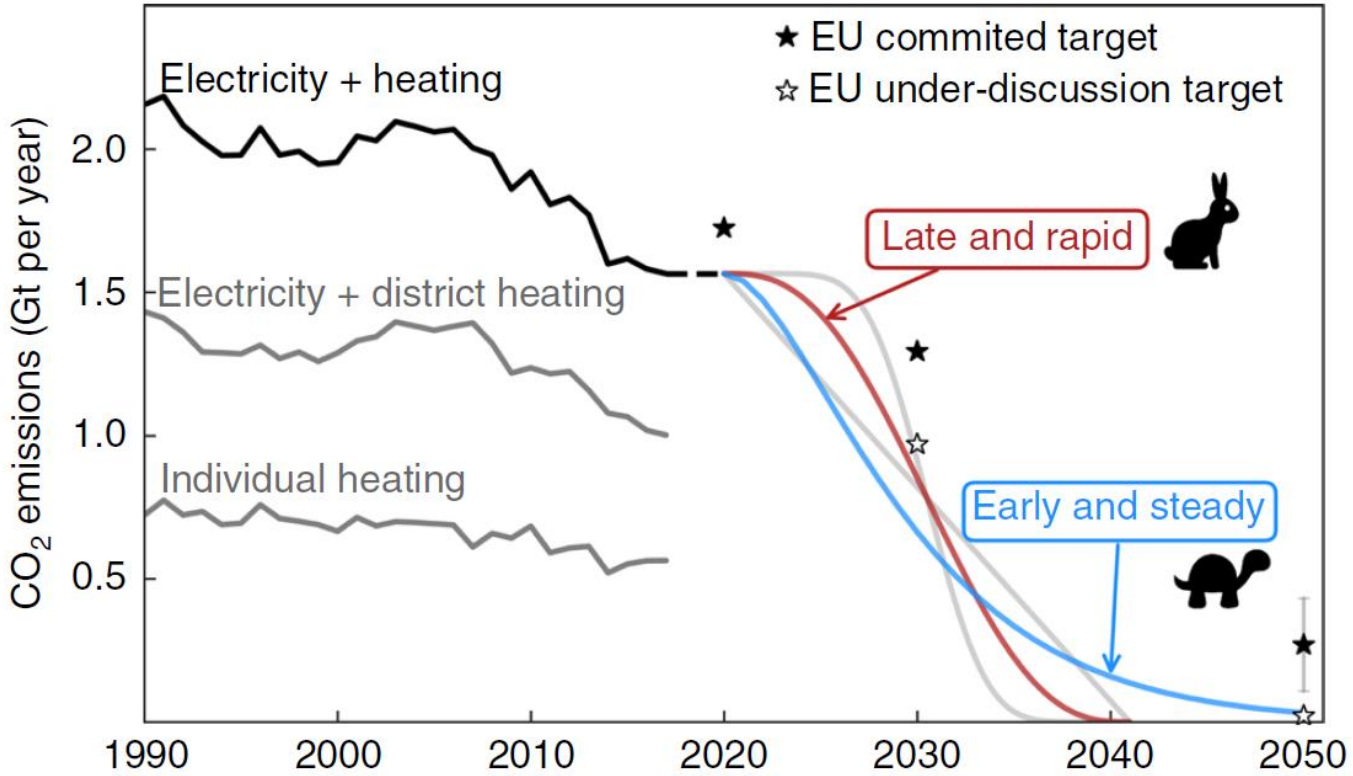


open model and data https://github.com/PyPSA/pypsa-eur-sec
ensures transparency and reproducibility

Study: Early transformation pays off

The cumulative carbon dioxide emissions from the European electricity and heating sector between 2020 and 2050 must remain below 21 Gt CO_2 to meet the Paris Agreement.

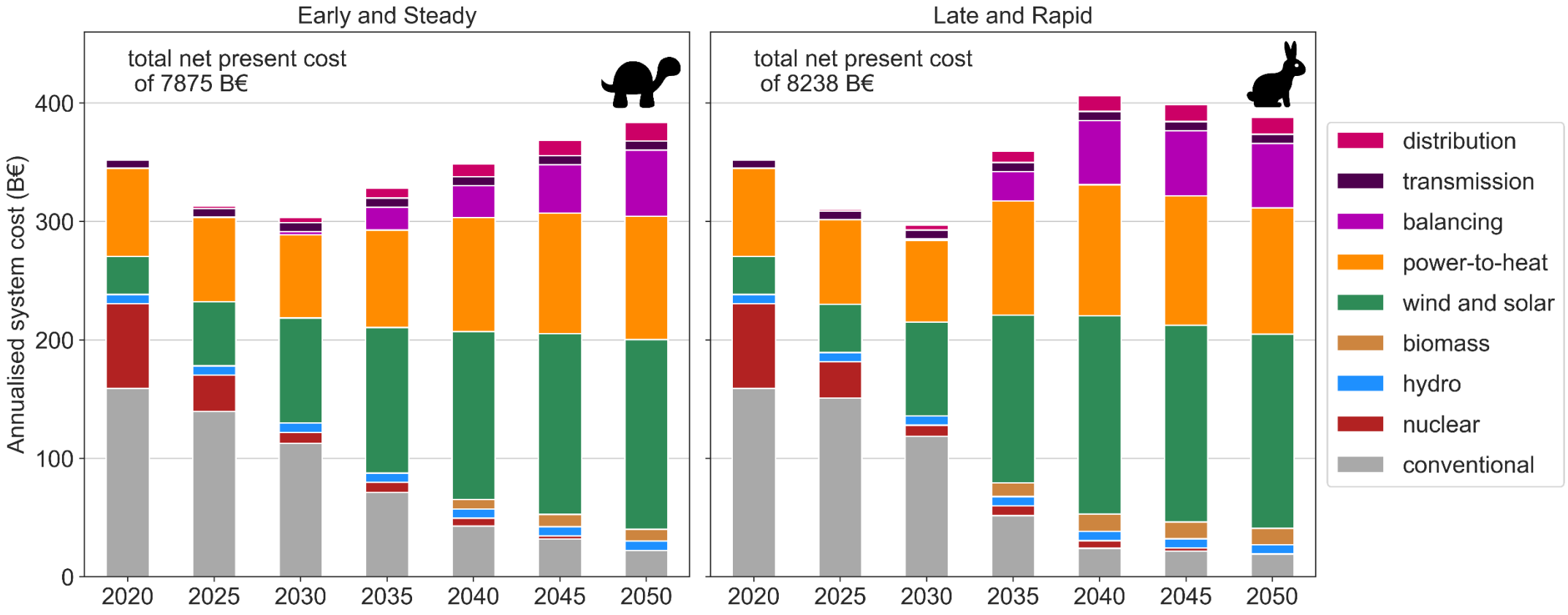
We use myopic approach to model the transition.



Victoria et al., Nature Commun. (2020)

Study: Early transformation pays off

The Early and Steady path is less expensive.



Victoria et al., Nature Commun. (2020)

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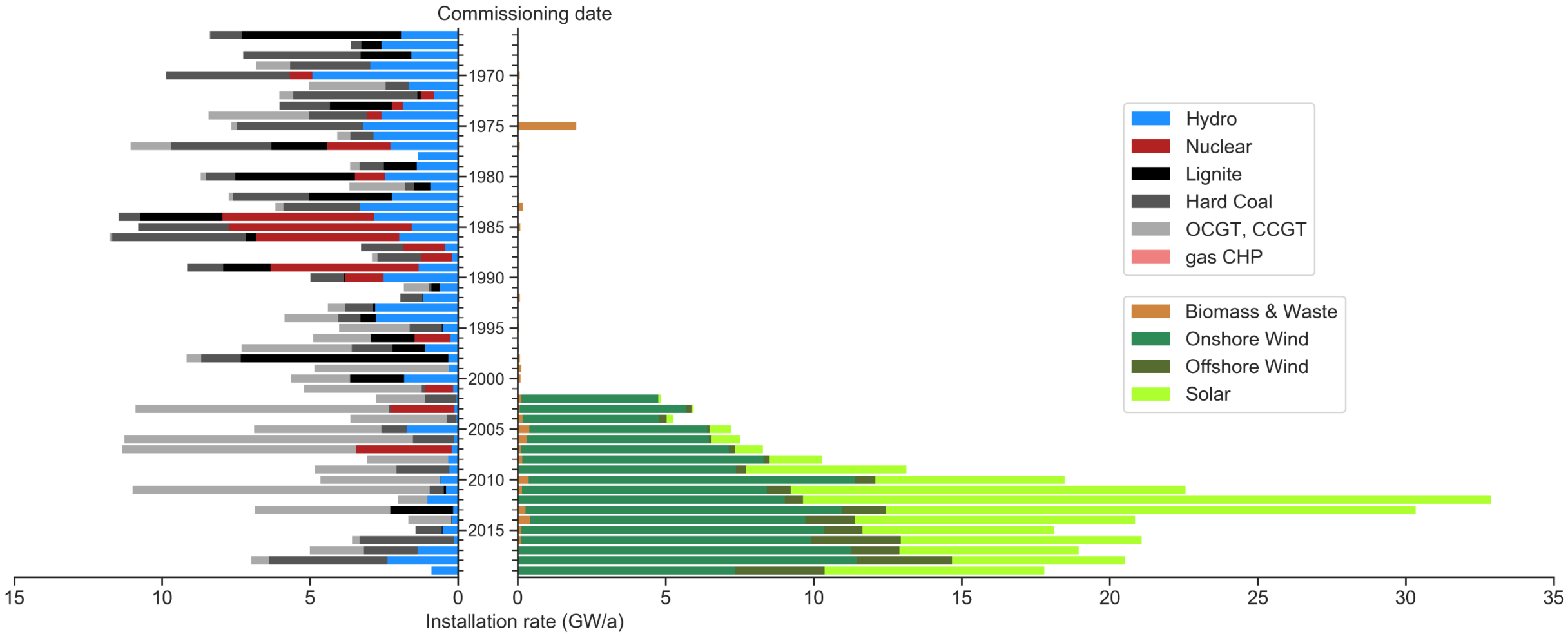

Victoria et al., Nature Commun. (2020)

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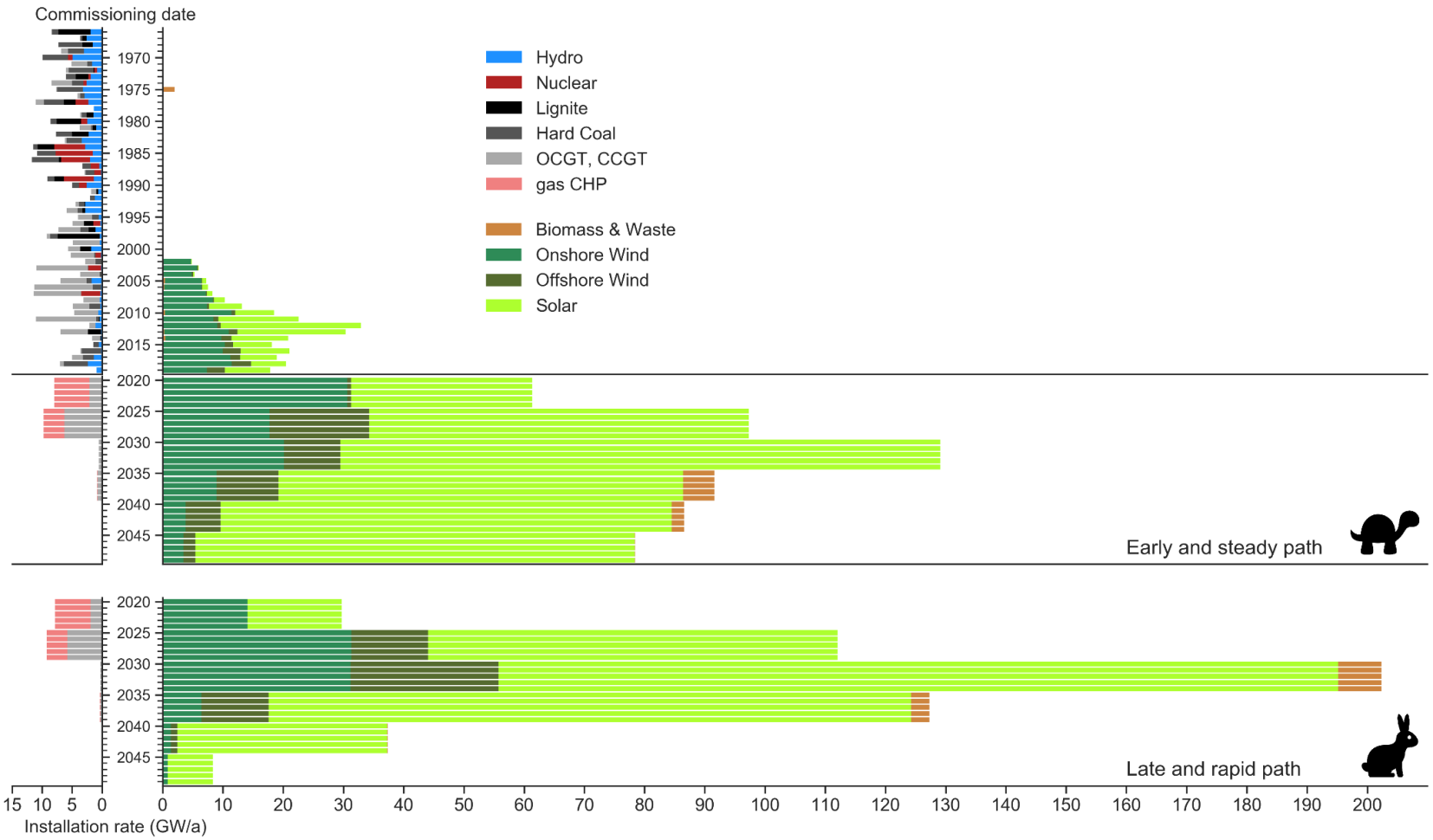
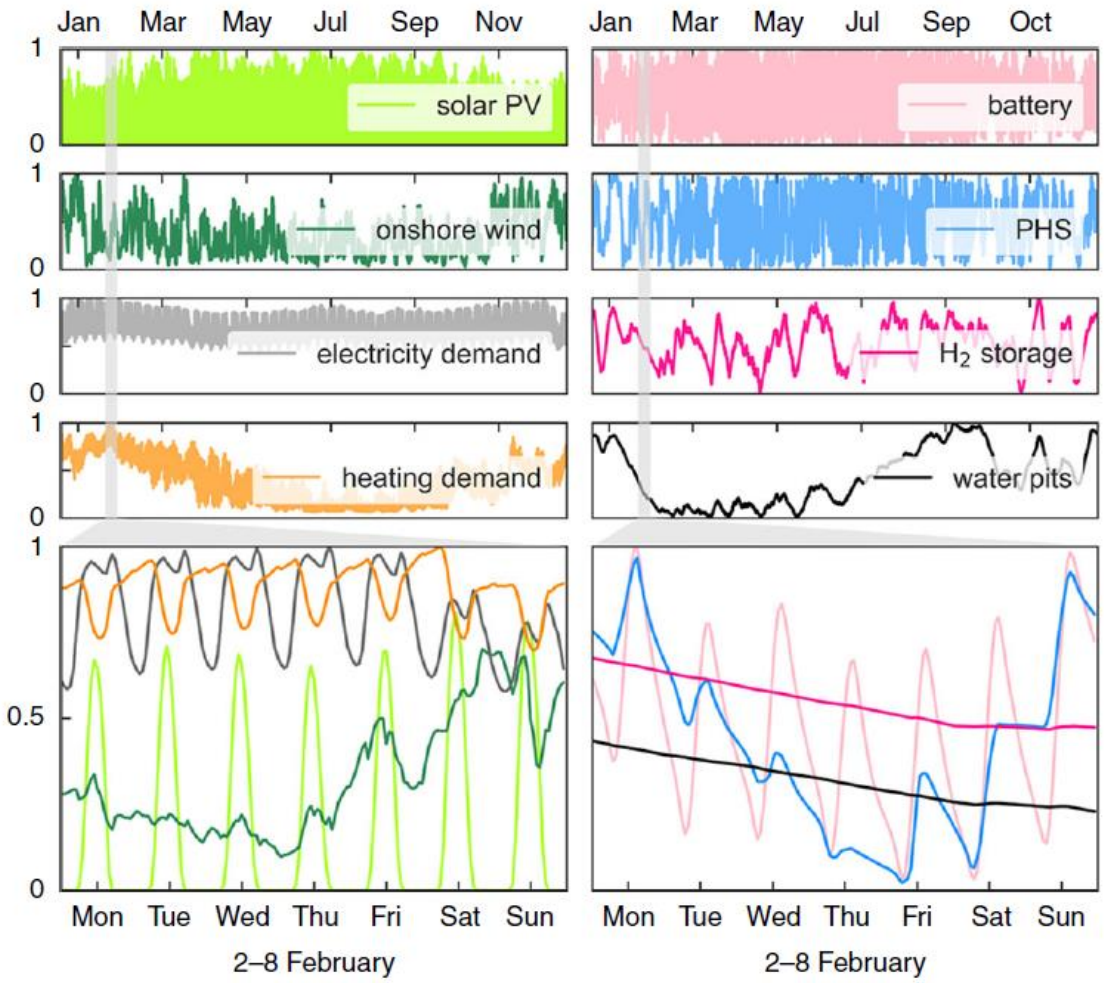


Victoria et al., Nature Commun. (2020)

- Almost no new fuel-based electricity generation.
- Massive deployment of solar PV and wind, bioenergy play a small role
- Build rates similar to highest historical values.

The need for balancing at different time scales

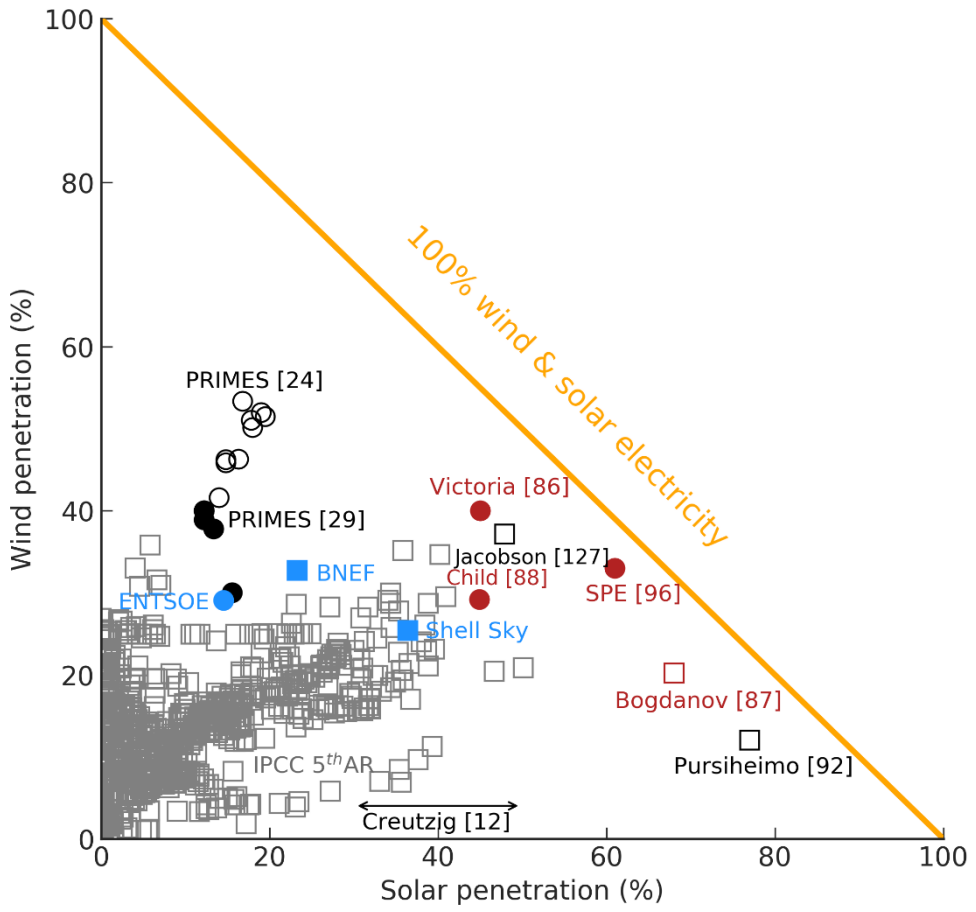


Victoria et al., Nature Commun. (2020)

Main features captured by hourly uninterrupted time stepping:

- solar and wind power generation smoothed by the grid and storage
- the role of long-term storage
- system operation during cold spells

The need for balancing at different time scales



Victoria et al., Joule (2021)

Joule
Perspective
Solar photovoltaics is ready to power a sustainable future

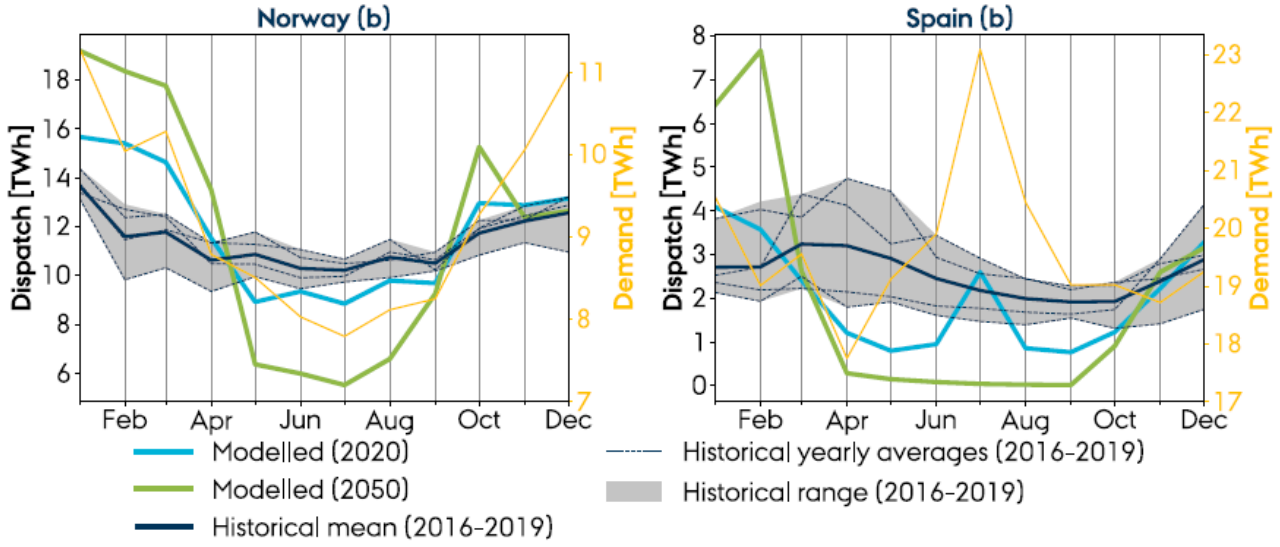
Marta Victoria,[1,2,13,*] Nancy Haegel,[3] Ian Marius Peters,[4] Ron Sinton,[5] Arnulf Jäger-Waldau,[6] Carlos del Cañizo,[7] Christian Breyer,[8] Matthew Stocks,[9] Andrew Blakers,[9] Izumi Kaizuka,[10] Keiichi Komoto,[11] and Arno Smets[12]

Why PV and wind have been underestimated in many future energy scenarios?

- Out-of-date exogenous cost-assumption miss the fast cost evolution of solar PV.
- Poor modelling of balancing (low **time resolution**, not including **network** or **sector coupling**) penalizes wind and solar.

Hydro as a balancing technology

The perfect foresight assumption is slightly too optimistic for hydro.

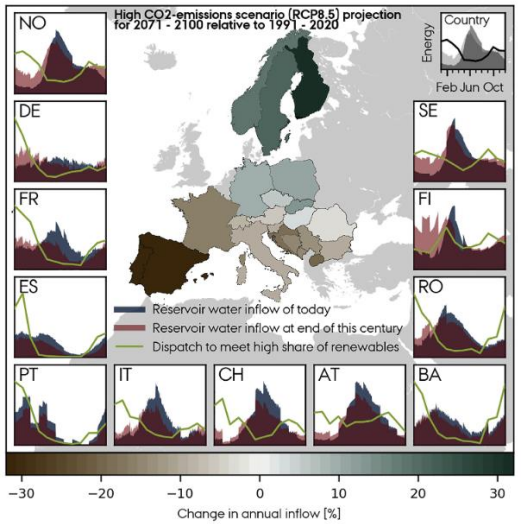


Gøtske and Victoria, iScience (2021)

Hydro inflow will be impacted by climate change

How to disentangle climate change signal from:

- Interannual variability
- Global Circulation Model - variability
- Regional Climate Model - variability



Check presentation by Ebbe Gøtske
Future operation of hydropower in Europe under high renewable penetration and climate change

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