Multi-timescale challenges in sector-coupled energy systems

Marta Victoria, PhD
Assistant Professor
mvp@mpe.au.dk
@martavictoria_p
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

- Costs assumptions
- Network topology
- Time series for wind, solar, and hydro generation
- Economic optimization subject to constraints
  - System cost
  - Generation and storage capacities per nodes
  - Interconnection capacities among nodes
  - Dispatch time series
  - Market prices, required CO₂ price

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

Economic optimization subject to constraints

\[
\min \left( \sum_n \text{generation costs} + \text{storage costs} + \text{transmission costs} + \sum_{n,t} \text{variable costs} \right)
\]

Subject to constraints:

\[
generation + \text{balance} = \text{demand} \iff \lambda_{n,t} \quad \forall n, t
\]

\[
\sum \text{emissions} \leq \text{CAP}_{\text{CO}_2} \iff \mu_{\text{CO}_2}
\]

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)
Study: Early transformation pays off

Victoria et al., Nature Commun. (2020)
Study: Early transformation pays off

- 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.

Victoria et al., Nature Commun. (2020)
The need for balancing at different time scales

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

Victoria et al., Nature Commun. (2020)
The need for balancing at different time scales

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.

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