Heuristics for Transmission Expansion Planning in Low-Carbon Energy System Models

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HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

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Long-Term Energy System Optimisation

Cost-effective pathways to reduce greenhouse gas emissions → optimisation models

Simultaneous investment planning of generation, storage and **transmission** → trade-offs

$$\textbf{Minimise} \left(\textbf{Yearly system costs} \right) = \sum_{n} \left(\textbf{Annualised capital costs} \right) + \sum_{n,t} \left(\textbf{Operational costs} \right)$$

subject to **linear optimal power flow** constraints,
the **variability & potentials** of renewable energy,
and **emission reduction** targets.

Linearised Power Flow without capacity expansion

Decision Variable **Parameter** **Susceptance** **Labels of Heuristics**

$$\overbrace{|f_{ij,t}|}^{\text{power flow between nodes i and j at time t}} \leq \overbrace{F_{ij,t}}^{\text{line capacity}}$$

$$f_{ij,t} = \overbrace{b_{ij}}^{\substack{\text{line susceptance} \\ b_{ij}=\frac{1}{x_{ij}}}} \cdot \overbrace{(\theta_{i,t} - \theta_{j,t})}^{\text{voltage angle difference}}$$

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Transmission Expansion Planning Problem **(MINLP)**

If line capacity can be **extended** discretely, the problem becomes **nonconvex**...

$$|f_{ij,t}| \leq \overbrace{\left(1 + \frac{\Gamma_{ij}}{\tilde{\gamma}_{ij}}\right)}^{\substack{\text{relative increase of capacity} \\ \text{by investment } (\Gamma_{ij} \in \mathbb{N}) \\ \text{w.r.t. initial \# circuits } (\tilde{\gamma}_{ij})}} \cdot \overbrace{\tilde{F}_{ij}}^{\text{original line capacity}}$$

... and **nonlinear** ...

$$f_{ij,t} = \overbrace{\left(1 + \frac{\Gamma_{ij}}{\tilde{\gamma}_{ij}}\right) \tilde{b}_{ij}}^{b_{ij}} \cdot (\theta_{i,t} - \theta_{j,t})$$

... which we can transform to an **MILP** using a **Big-M disjunctive relaxation**.

Heuristic 1: Relaxation of Line Investment Variables

Reminder: **Labels of Heuristics**

Discrete investment decisions — heur-int

$$\Gamma_{ij} \in \mathbb{N}_{\geq 0}$$

are relaxed to allow each line to be **expanded continuously**, i.e. — heur

$$\Gamma_{ij} \in \mathbb{R}$$

Heuristic 2: Iterative Update of (Discretized) Line Impedances

Pursue an **iterative** approach (convergence tolerance or iteration limit)

iter(-seqdisc)

$$f_{ij,t} = \overbrace{\left(1 + \frac{\Gamma_{ij}}{\tilde{\gamma}_{ij}}\right) \tilde{b}_{ij}}^{b_{ij}} \cdot (\theta_{i,t} - \theta_{j,t}) \qquad \longrightarrow \qquad f_{ij,t} = b_{ij}^{(k)} \cdot (\theta_{i,t} - \theta_{j,t})$$

First iteration $\rightarrow$ **initial susceptances**

$$b_{ij}^{(1)} = \tilde{b}_{ij}$$

Subsequent iterations $\rightarrow$ current **optimal line investment** $\Gamma_{ij}^{*(k)}$ (or rounded)

$$b_{ij}^{(k+1)} = \left(1 + \frac{\Gamma_{ij}^{*(k)}}{\tilde{\gamma}_{ij}}\right) \tilde{b}_{ij} \qquad \forall k > 1$$

Heuristic 3: Post-facto Discretization of Line Investment Variables

Following the iterations,
fractional decisions must be **fitted to valid investment choices**:

postdisc

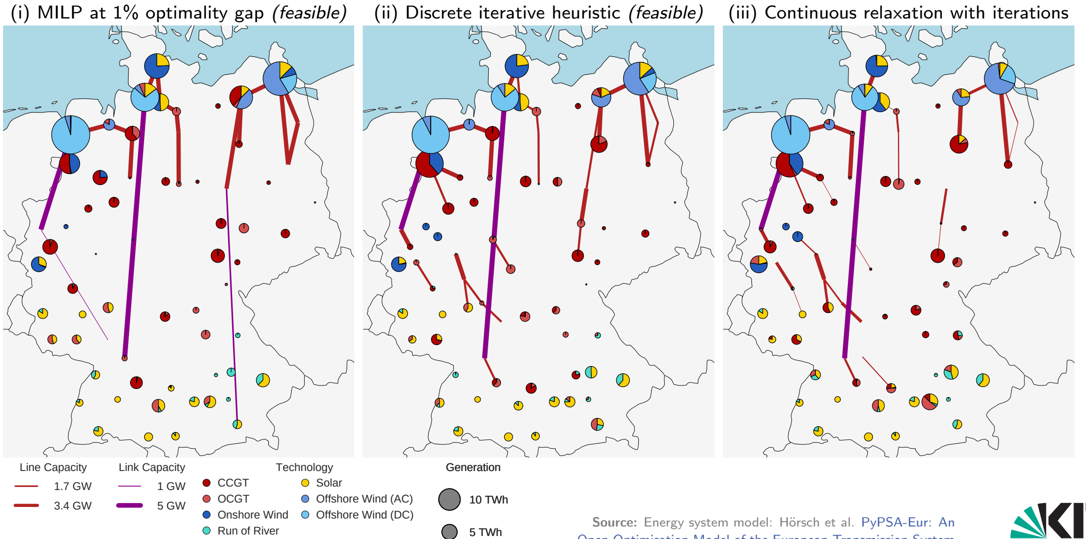
1. Round relaxed line capacities nearest discrete choice (threshold $z = 0.3$)
2. Fix line capacities & rerun generation expansion only.

Optionally:

postdisc_mult

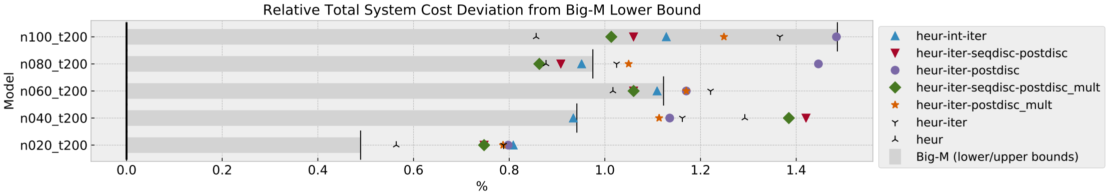
3. Repeat for multiple discretization thresholds (z) & choose configuration with lowest costs.

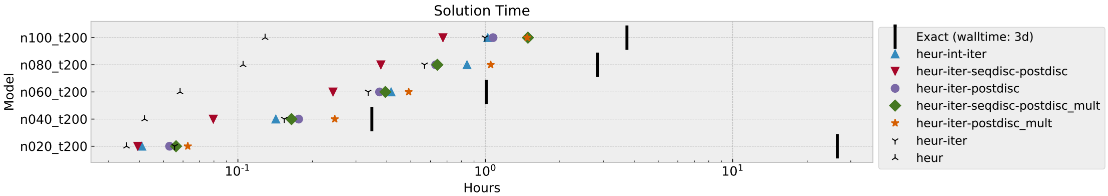
Results: Generation and Transmission Expansion



Source: Energy system model: Hörsch et al. PyPSA-Eur: An Open Optimisation Model of the European Transmission System

Results: Accuracy & Speed





Conclusion

When **co-optimizing** generation, transmission and storage infrastructure
discrete line expansion is computationally prohibitive (to date).

The heuristics **mirror optimal line investment** of the MINLP
close enough in view of **attainable optimality gaps**
but with **immense time savings**!

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Resources

EEM 19 — 16TH INTERNATIONAL CONFERENCE ON THE EUROPEAN ENERGY MARKET
18-20 September 2019, Ljubljana, Slovenia
IEEE | IEEE PES Power & Energy Society

Find the slides:

https://neumann.fyi/files/eem19-tepheuristics.pdf

Send an email:

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Find the energy system model:

Code: https://github.com/pypsa/pypsa-eur

Documentation: https://pypsa-eur.readthedocs.io

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