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Optimising capacity expansion for future renewable energy systems

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Modelling challenges in power system planning

- Historically, the most relevant objective in power system planning has been to meet the load duration curve at minimum cost
- The growing share of variable renewable energy generation brings additional challenges to the modelling

Temporal representation	• Screening curve • Time slices • Representative periods • Full resolution
Unit constraints	• Unit commitment • Stylized constraints
Spatial representation and power flow	• Copper plate • Power transport • DC power flow • AC power flow
Short-term uncertainty	• Balancing market for forecast errors • Operating reserves
Power system stability	• Operating reserves • Inertia requirements etc.
Capacity adequacy	• Planning reserve margin or other capacity adequacy requirement • Capacity value of alternative sources • LOLE etc.
Energy system integration	• Electricity, heat, gas, etc. • Power-to-X • Customer behaviour
Long-term uncertainty	• Interannual variations • Uncertainty in demand, fuel prices, etc.

Helistö, N, Kiviluoma, J, Holttinen, H, Lara, JD, Hodge, B-M. Including operational aspects in the planning of power systems with large amounts of variable generation: A review of modeling approaches. *WIREs Energy Environ*. 2019;e341. https://doi.org/10.1002/wene.341

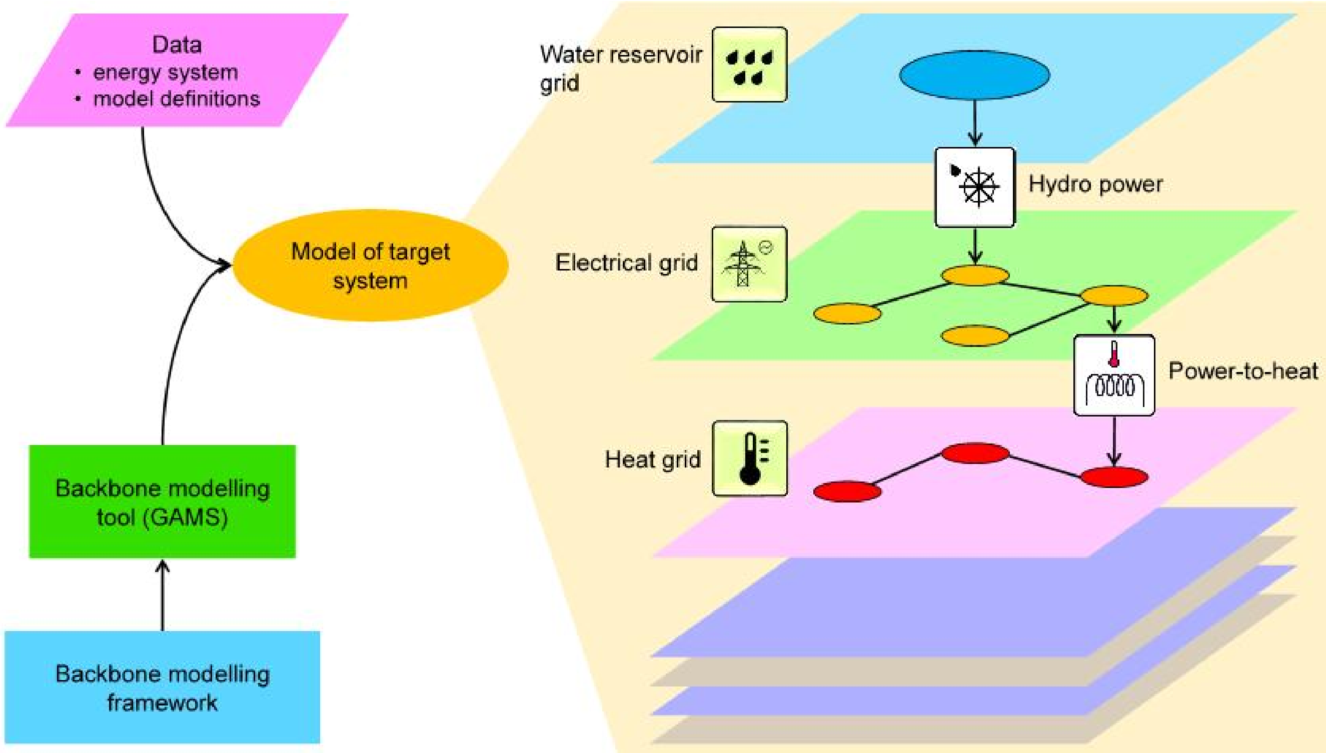
Findings from a review of 47 variable generation integration studies

- Using a low temporal resolution or only few representative days is not enough
- Taking into account operational constraints of power plants and power grids is important
  - Especially together with various policy constraints, such as target shares for renewables or CO_2 limits
- Adequate representation of potential flexibility sources – also in other energy sectors – becomes necessary
- Clear need for further model development and data acquisition

- Recommendations:
  - Informed selection of the model for power system planning
  - Appropriate interpretation of the model results that accounts for the underlying simplifications and assumptions in each model, as well as the purpose of modelling

Helistö, N, Kiviluoma, J, Holttinen, H, Lara, JD, Hodge, B-M. Including operational aspects in the planning of power systems with large amounts of variable generation: A review of modeling approaches. *WIREs Energy Environ*. 2019;e341. https://doi.org/10.1002/wene.341

Backbone – an adaptable energy systems modelling framework



Helistö, N, Kiviluoma, J, Ikäheimo, J, Rasku, T, Rinne, E, O'Dwyer, C, Li, R, Flynn, D. Backbone – an adaptable energy systems modelling framework. https://cris.vtt.fi/en/publications/backbone-an-adaptable-energy-systems-modelling-framework

Backbone capabilities

- Investment planning and operational scheduling
- Features and constraints
  - Stochastic parameters
  - MIP-based unit commitment
  - Multiple reserve products
  - Storage units
  - Controlled and uncontrolled energy transfers
  - Multiple energy sectors

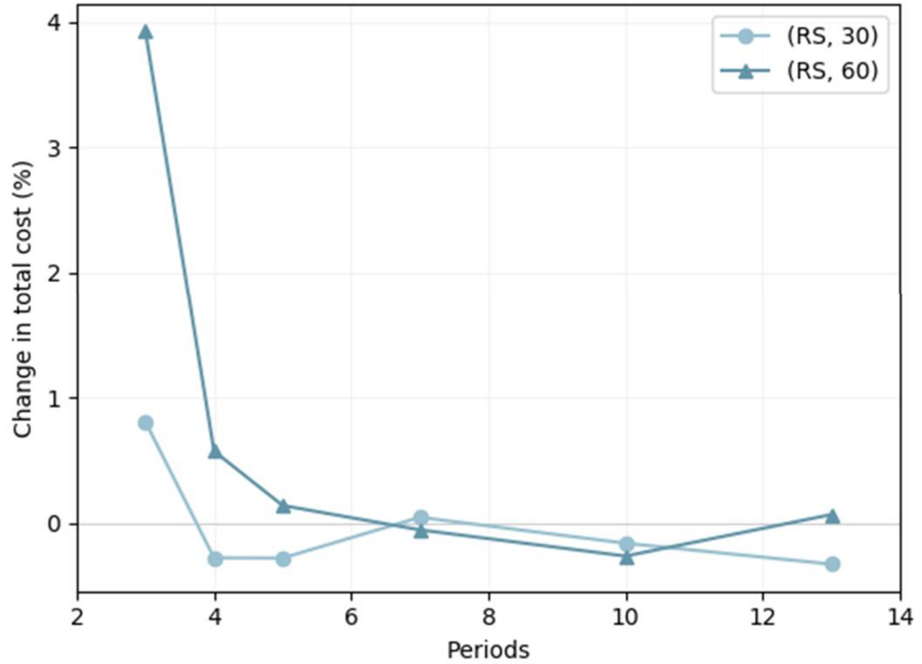
- Available with open-source license (GAMS license needed)
  - https://gitlab.vtt.fi/backbone/backbone

Number of representative weeks

- Comparing the total annual costs (investment and operational)
  - 3-13 representative periods (weeks) compared to full year

- 4-5 representative weeks seem to be enough…
- … but what are the most important operational constraints in the planning problem?

RS: random sampling
CO_2 price (€/tonne): 30/60



Helistö, N, Kiviluoma, J, Reittu, H. Concurrent selection of representative slices from multiple historic time series of power generation for long term power system optimization. To be submitted.

Cases

Case	Reserves*	Ramp limits	Temporal scope	Temporal resolution	Online variables**	Inv. variables
01 reference			5 weeks	1 h		linear
02 reserves	yes		5 weeks	1 h		linear
03 ramp limits		yes	5 weeks	1 h		linear
04 full year			full year	1 h		linear
05 online LP			5 weeks	1 h	linear	linear
06 online LP, invest MIP			5 weeks	1 h	linear	integer
07 online MIP, invest MIP			5 weeks	1 h	integer	integer
08 online LP, reserves	yes		5 weeks	1 h	linear	linear
09 online LP, ramp limits		yes	5 weeks	1 h	linear	linear
10 online LP, ramp limits, 15 min		yes	5 weeks	15 min	linear	linear
11 online LP, ramp limits, 5 min		yes	5 weeks	5 min	linear	linear

* with penalties (for violating the reserve requirement equation)
** and corresponding start-up and shutdown variables & costs, as well as minimum load

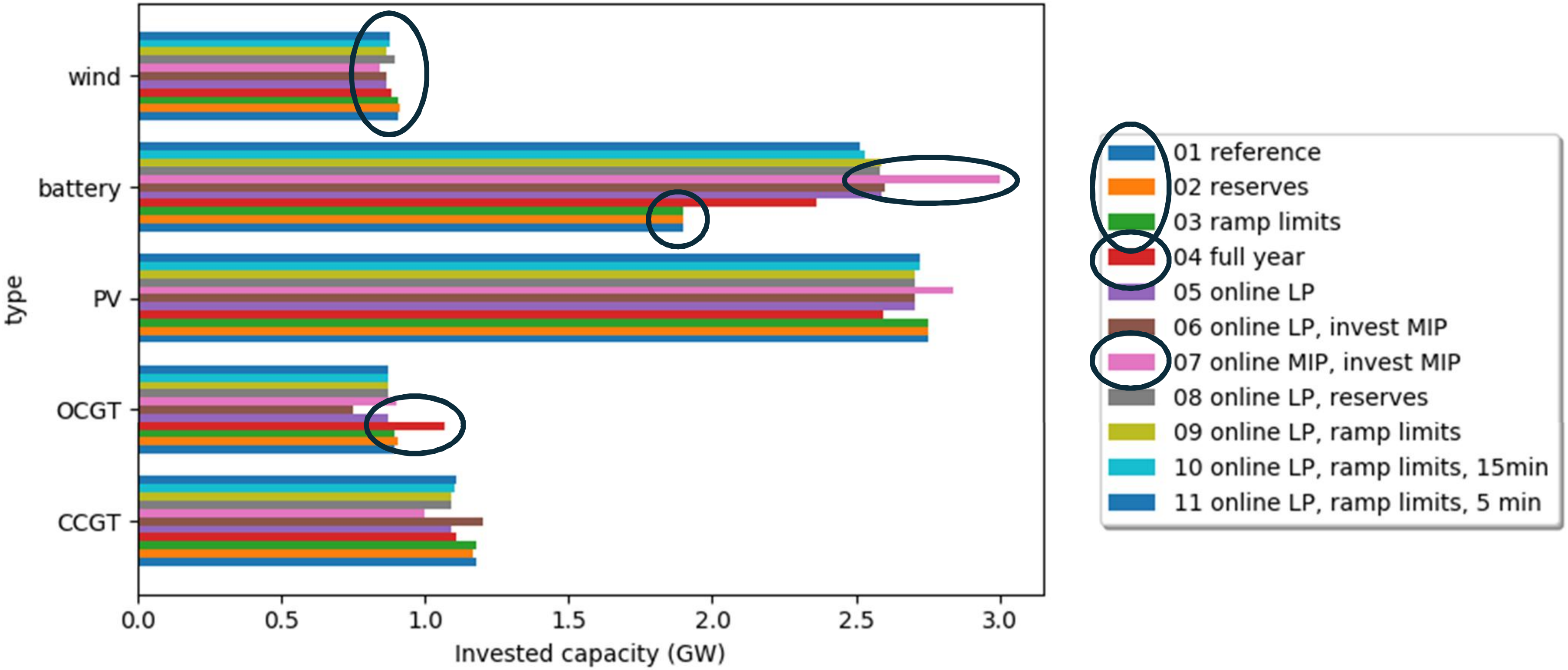
Input

- RTS-GMLC* time series (wind, PV, load; 5 min resolution)
- Greenfield system (no existing power plants)
- Copper plate (no power transfers)
- CO_2 price EUR 50 per tonne, natural gas price EUR 30 per MWh, nuclear fuel price EUR 5 per MWh
- 6 investment options

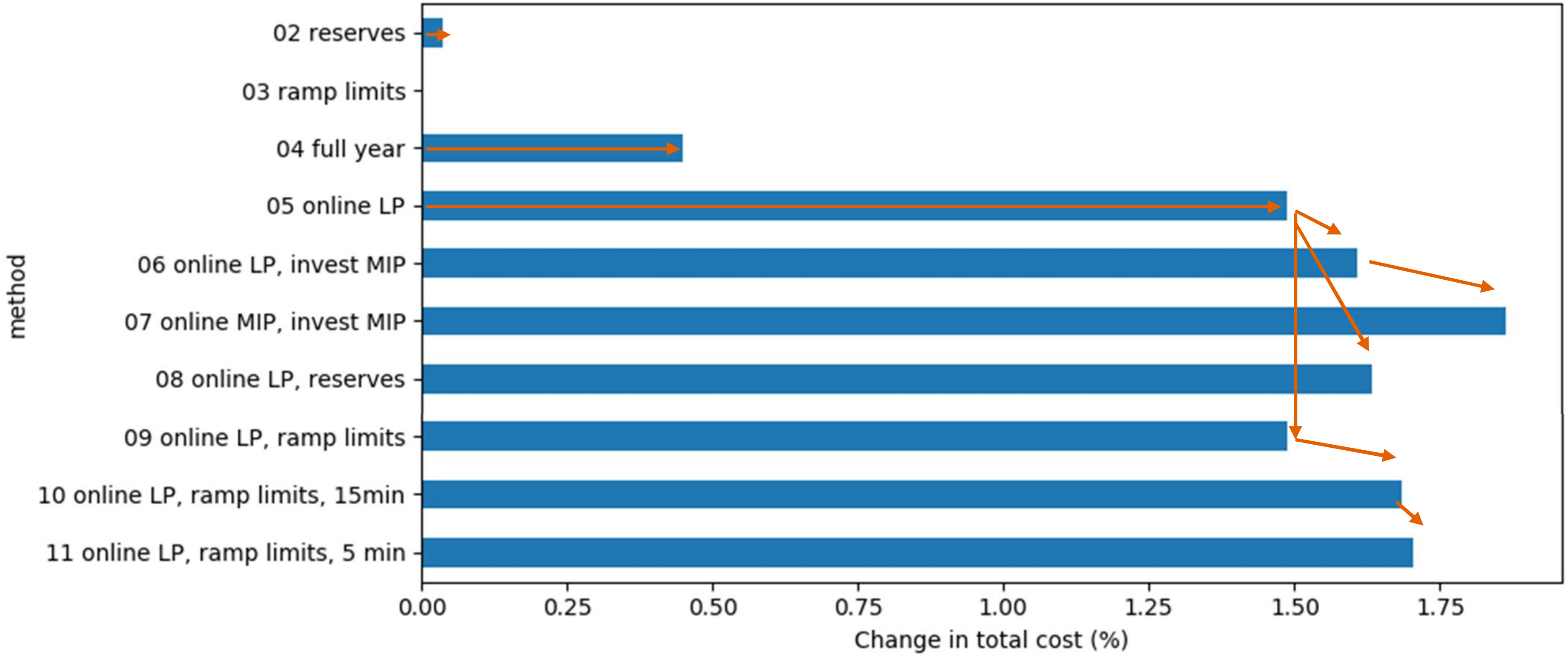
	Unit size (MW)	Inv. cost (€/kW)	Fixed O&M cost (€/kW/a)	Lifetime (a)	Var. O&M cost (€/MWh)	Start cost (€/MW)	Max. eff. (%)	Min. load (%)	Ramp rate (p.u./min)
OCGT	50	550	20	35	1	25	45	20	0.4
CCGT	200	850	20	35	1	50	60	40	0.05
wind		1100	20	20					
PV		650	10	30					
nuclear	800	4500	95	40	2	100	34	70	0.0125
battery		200	10	30			90		

*Reliability Test System - Grid Modernization Lab Consortium
https://github.com/GridMod/RTS-GMLC

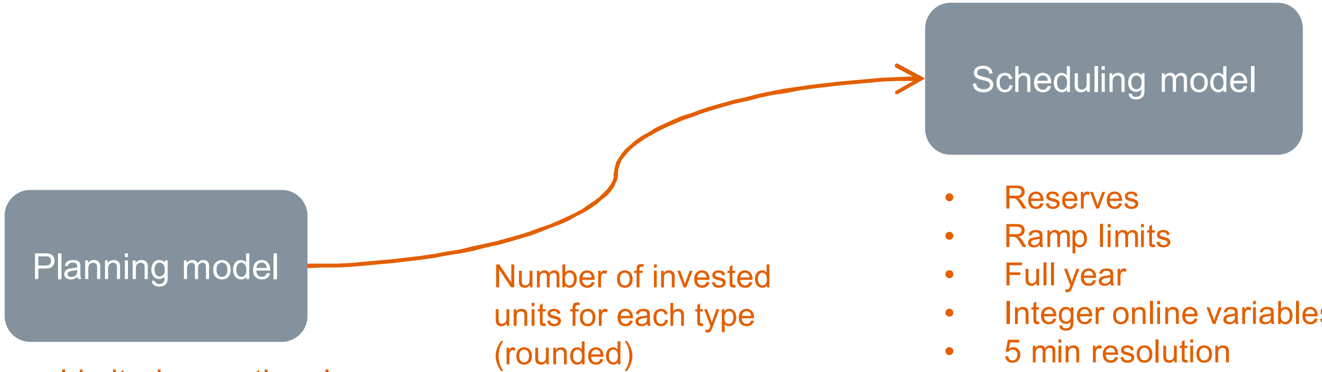
Investment results



Total costs compared to the reference case



Checking the feasibility of the planning outcome



- Limited operational constraints

- Reserves
- Ramp limits
- Full year
- Integer online variables (MIP)
- 5 min resolution

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Conclusions and future work

- Growing share of wind power and PV changes the modelling challenges in power system planning
  - Adequate temporal representation
  - Operational constraints of power plants and power grids
  - Flexibilities from other energy sectors

Next steps in the case study

- Check the feasibility of the planning outcomes using a scheduling model
- How to consider storage state evolution between the representative periods
- How to best capture peak net load periods to ensure a sufficient amount of available capacity
- Other operational detail combinations
- Other test systems with correlated time series

beyond the obvious

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