Hydropower's ability to sustain high production for week-long periods

18/3-2025

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Work together with:
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Agenda:

1. Motivation
2. Method
3. Results
4. Summary

Why are we interested in this ?

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- What do we do during periods of high demand and low winds?
  - Dunkelflaute occur simult. in all North and Baltic Sea countries for approximately 3.5% of the year [Bowen et al. 2021]
  - Dunkelflaute are more likely during high-demand periods
- Transmission or nuclear failure

- Finding operational limits for hydropower to include in energy system models

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What is the maximum production level that hydropower can sustain over a longer period?

?

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Stress-tests in FORSA – a detailed hydropower model

Hourly electricity prices

Daily inflow at each reservoir and plant

- Maximizing profits
- Perfect foresight
- Only day-ahead market

Detailed representation of 92% of HP in Sweden

Hourly production

Hourly water levels and flows

Revenues

Agenda:

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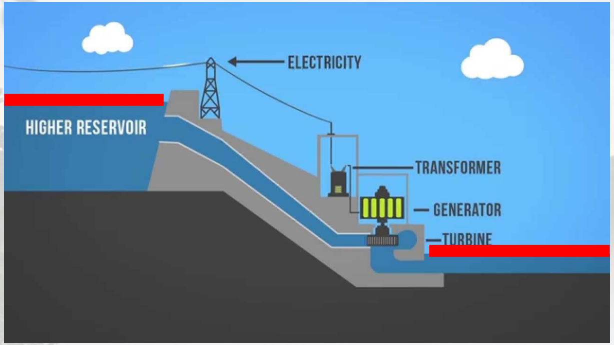
$$E = m \cdot g \cdot h \cdot \eta$$



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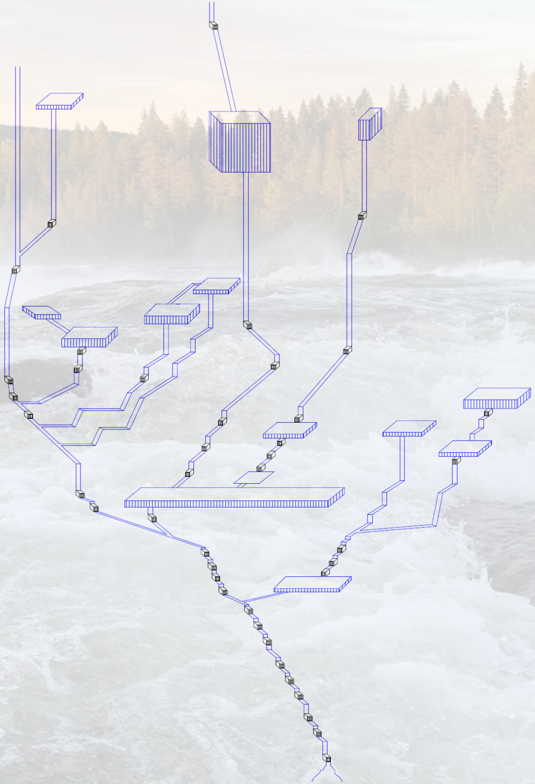

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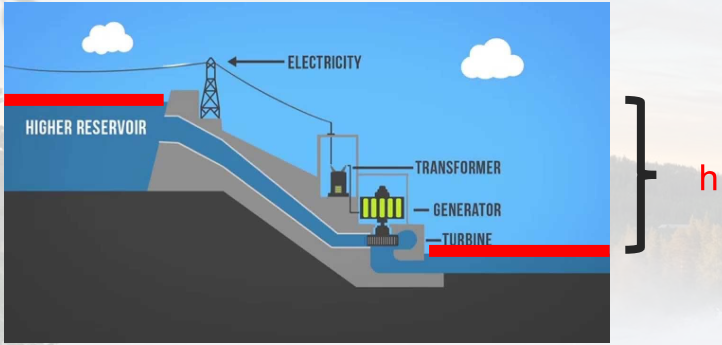

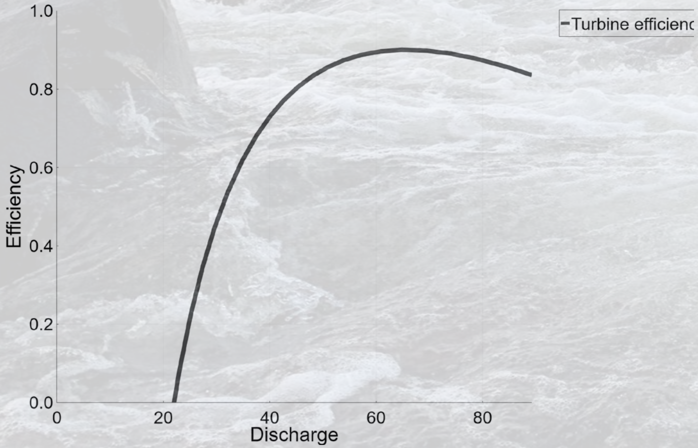

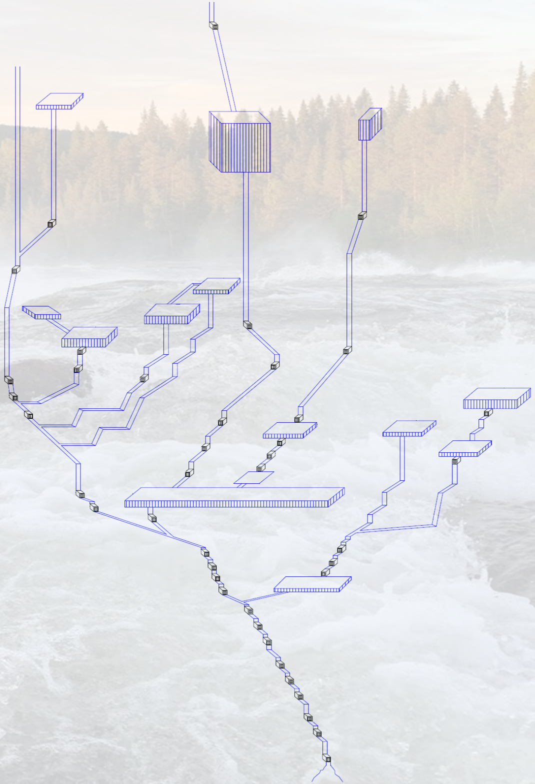

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Coverage

	Total	SE1	SE2	SE3	SE4
Share [%]	92	98	99	72	0
Modeled [GW]	15.1	5.2	8.0	1.9	0
Installed [GW]	16.4	5.4	8.1	2.6	0.3

Rivers included: Luleälven, Skellefteälven, Umeälven, Ångermanälven, Indalsälven, Ljungan, Ljusnan, Götaälv (Klarälven+Uvån+Nedan Vänern)

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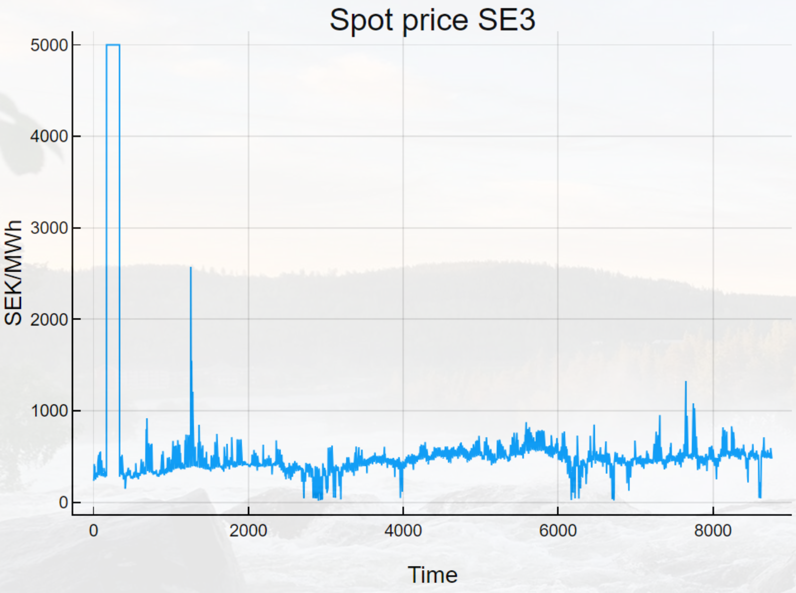

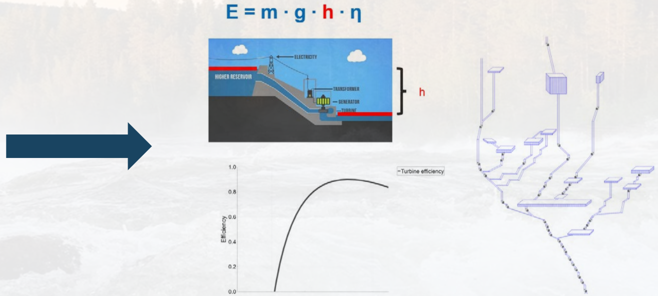

What if we give very high incentives to sustain high output?

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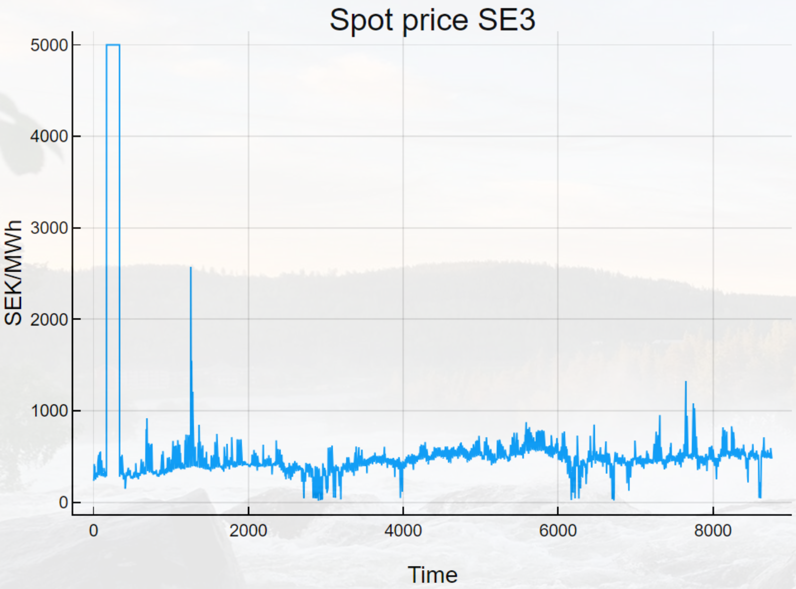

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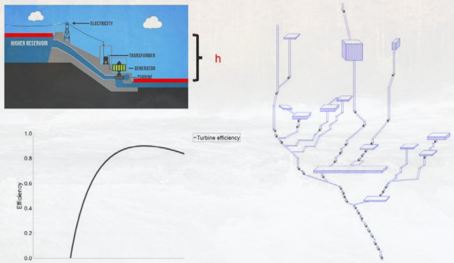

- High price period of 1,2 or 3 weeks
- Each month
- 5 years
- 10 rivers

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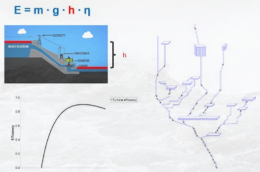
What is the maximum production level that hydropower can sustain over 1,2,3 weeks?



Your guess?

- Sustained output (%)
- Factors that matter for the result? (That we should do sensitivity analysis on)

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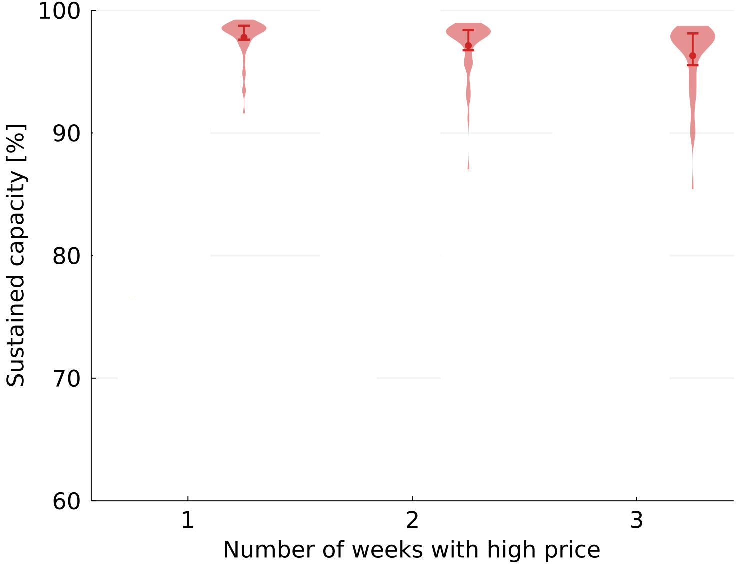

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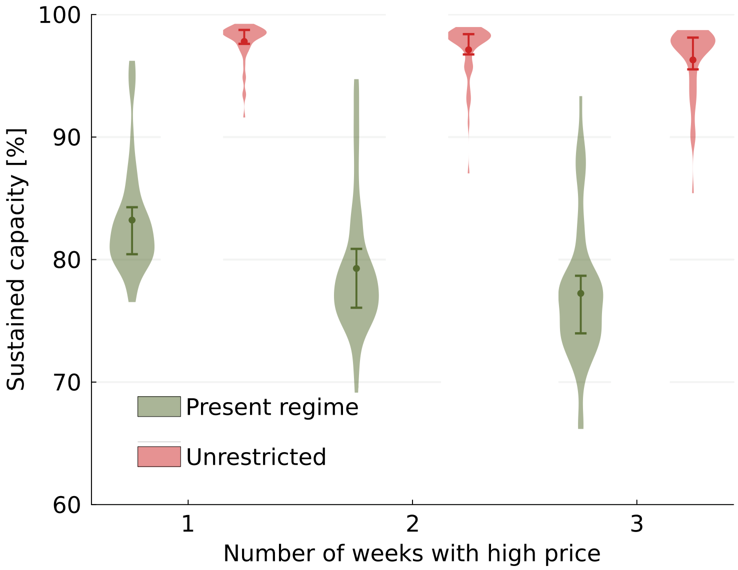

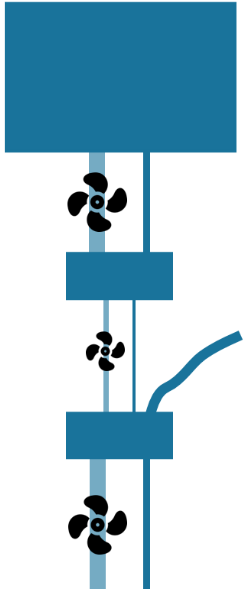

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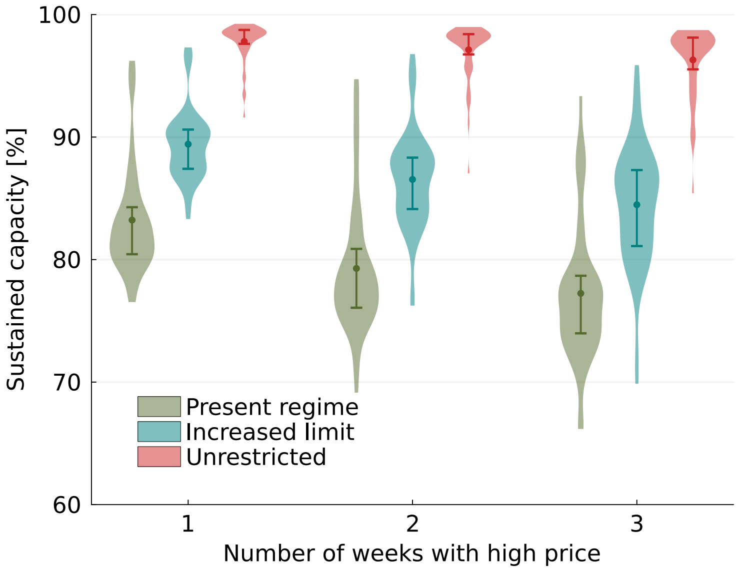

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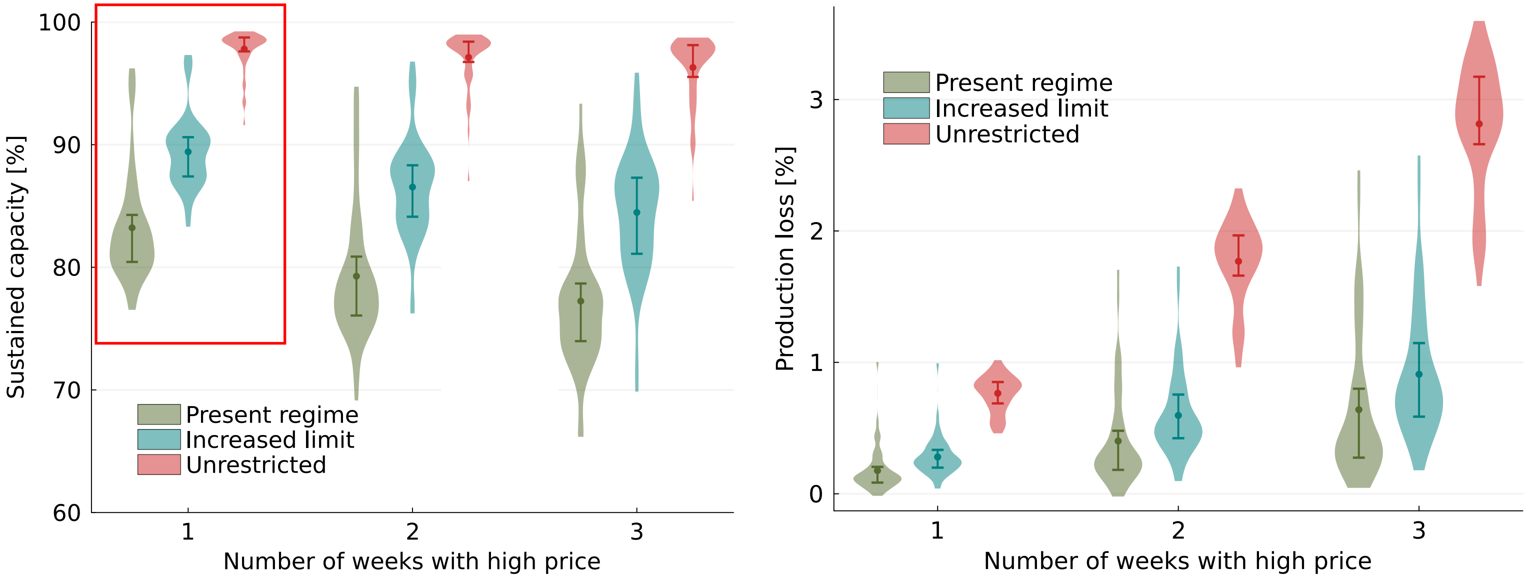

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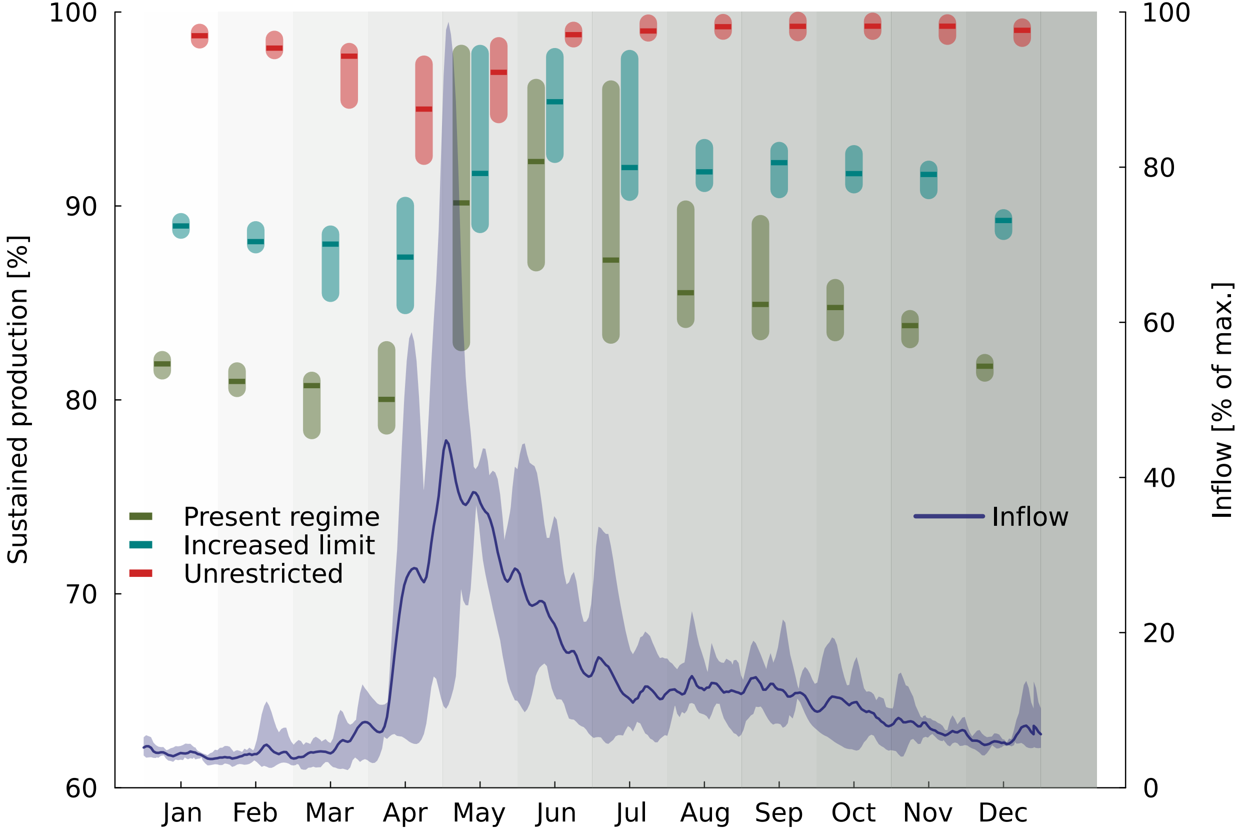

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Key results

- Swedish HP can produce at around 80% for 1-3 weeks ≈ half of peak demand
    - However, it varies between 65-95% depending on when capacity is needed

- Sustaining high output over 1 week → ≈ 0.3% - 1% loss of annual production

- Spillage at bottlenecks increases sustained output
    - E.g. Releasing 20% higher flows in bottlenecks → + 1 GW for 1-3 weeks

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Relevance

How this study can affect policy (1), practice (2), or research (3)

1. Informs policy-makers when they evaluate the trade-off between HP flexibility and ecosystems

2. Gives producers numbers on the benefits of removing bottlenecks

3. Informs modellers about realistic production profiles for HP

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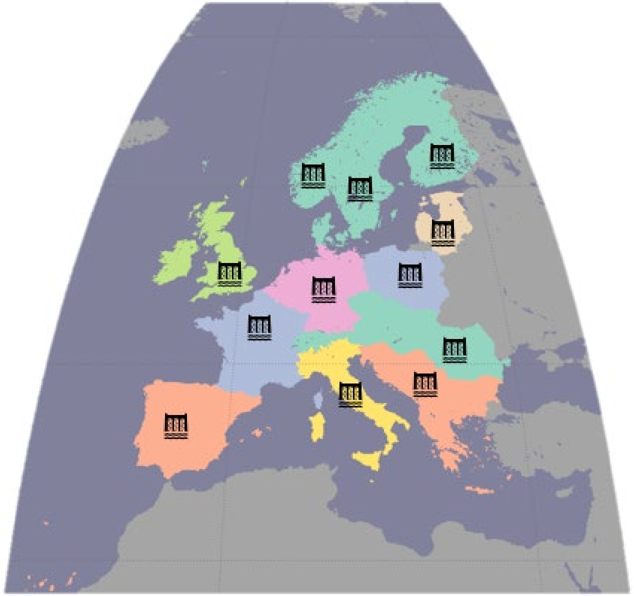
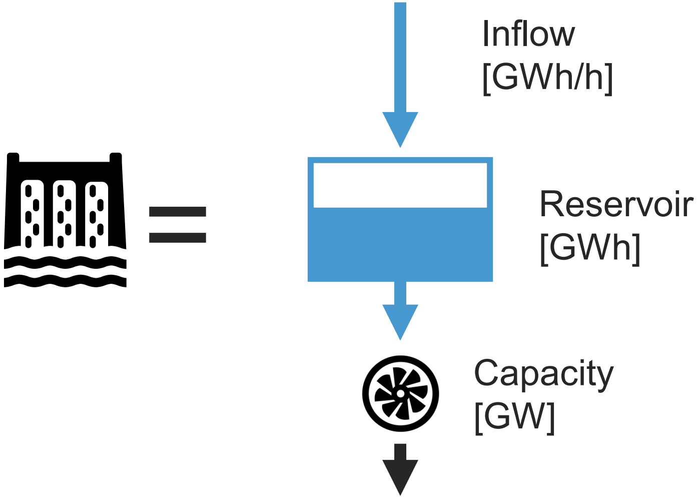
Extra slides in case of discussion follows:

Hydropower in most energy system models:





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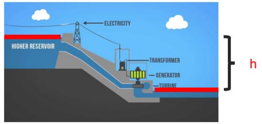
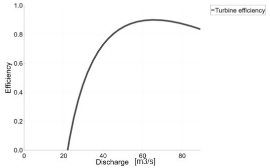
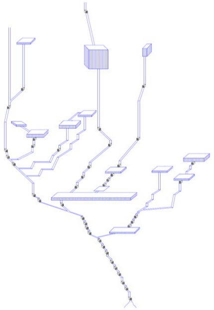
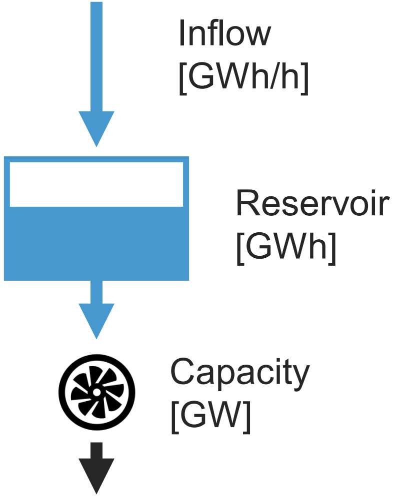






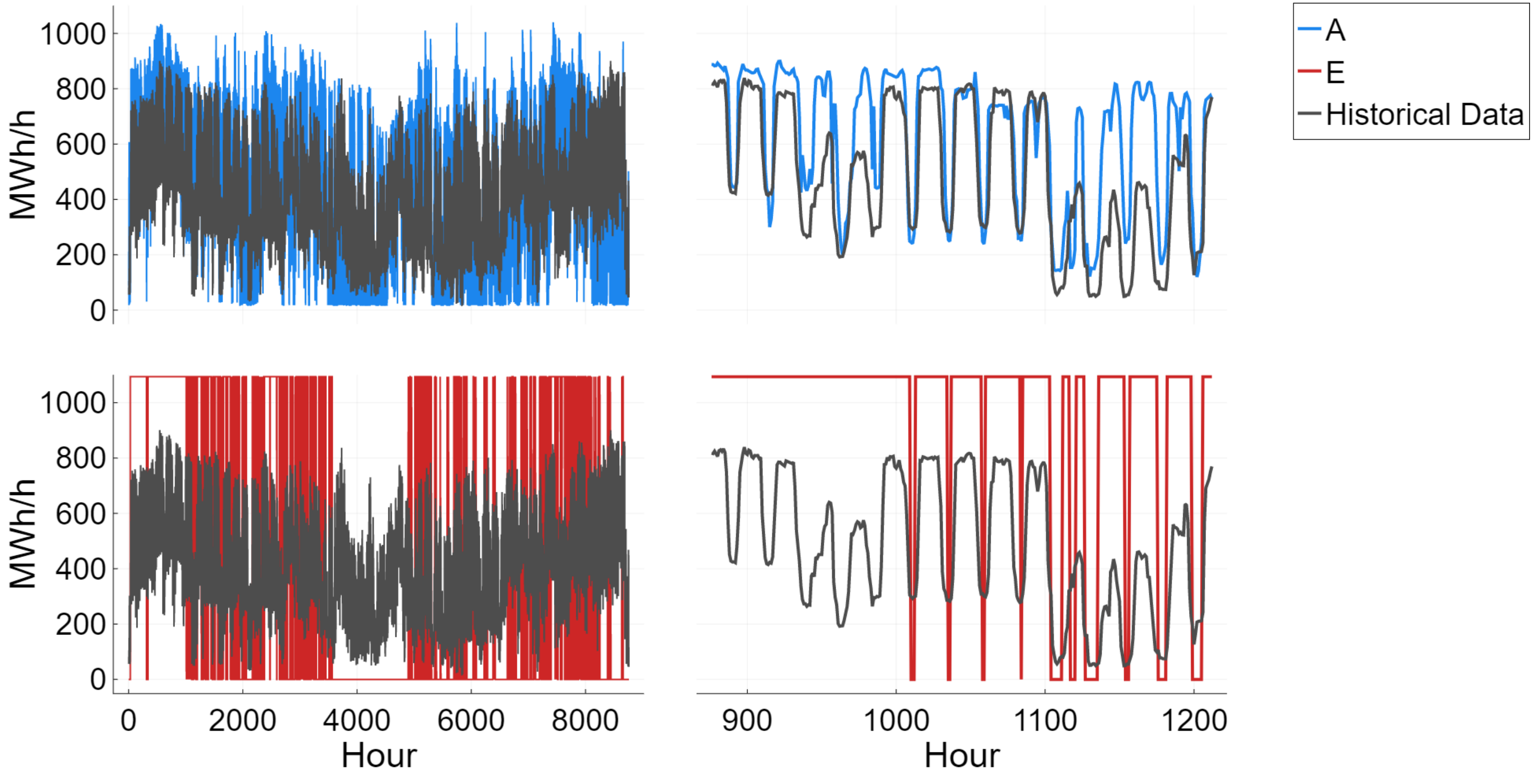
VS

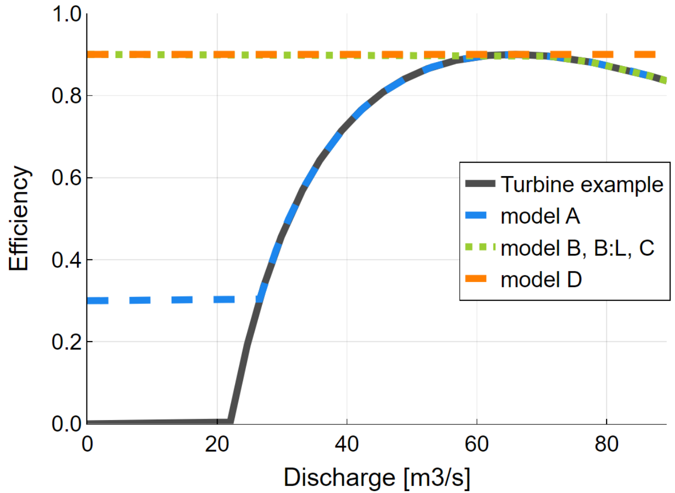
E



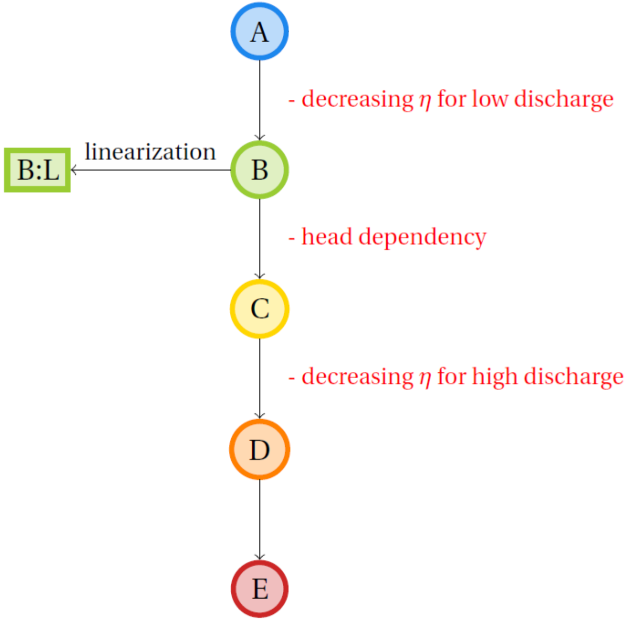
2025-04-07

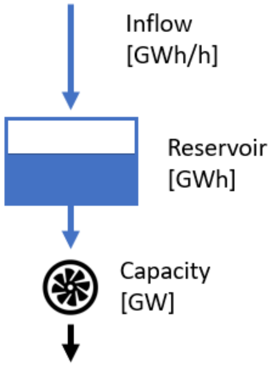
Hydropower production - 2019





Model name	Network effect	Head dependent	Turbine efficiencies	Type
A	Yes	Yes	Nonconvex	NLP
B	Yes	Yes	Convex	NLP
B:L	Yes	Yes	Convex	LP
C	Yes	No	Convex	LP
D	Yes	No	Constant	LP
E	No	No	None	LP





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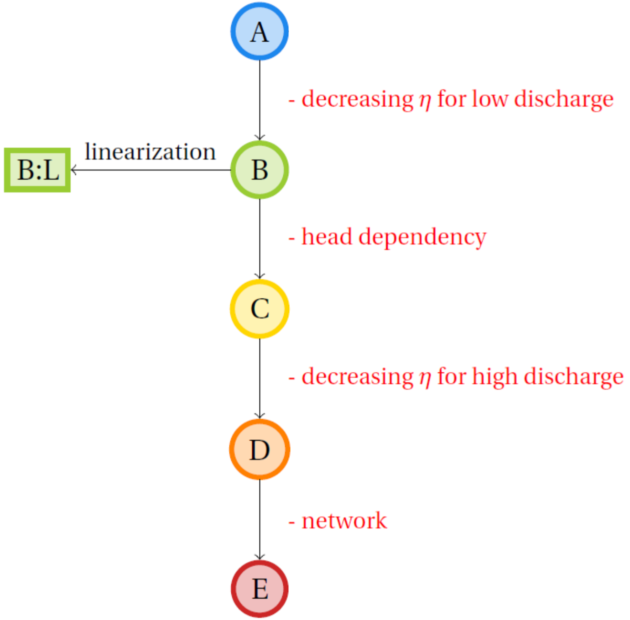
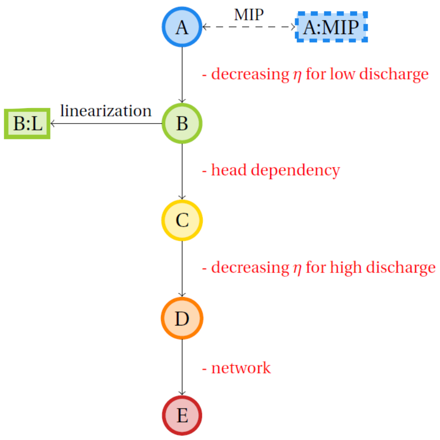
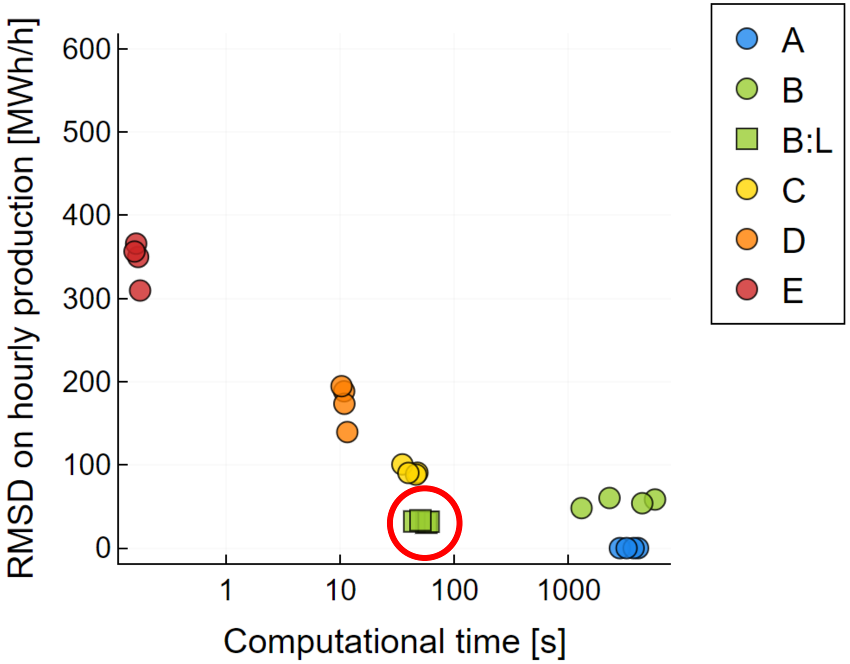
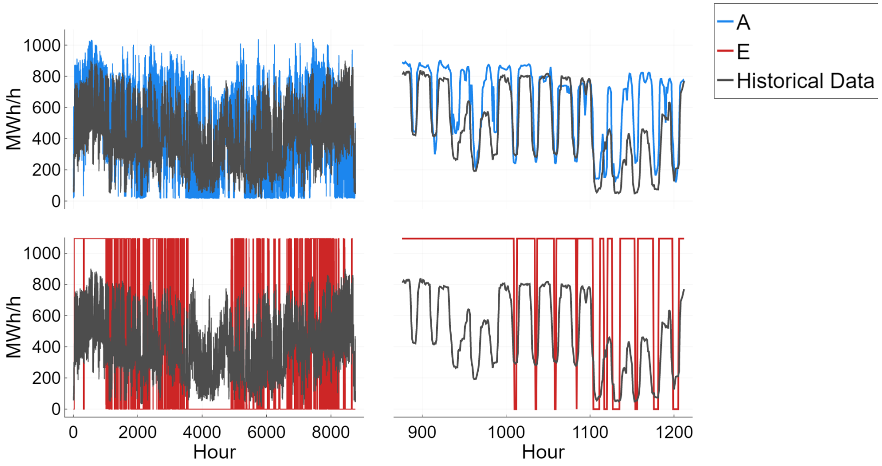


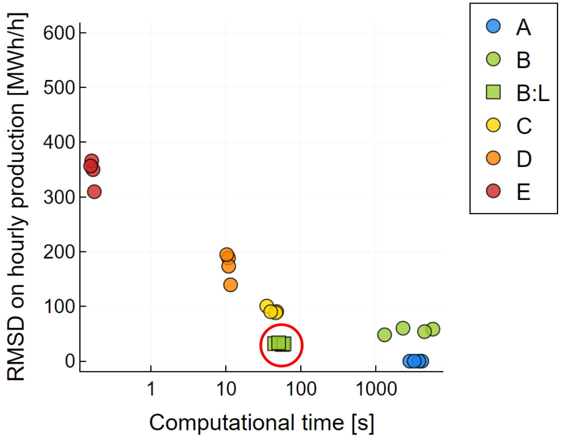
Accuracy vs Computational time



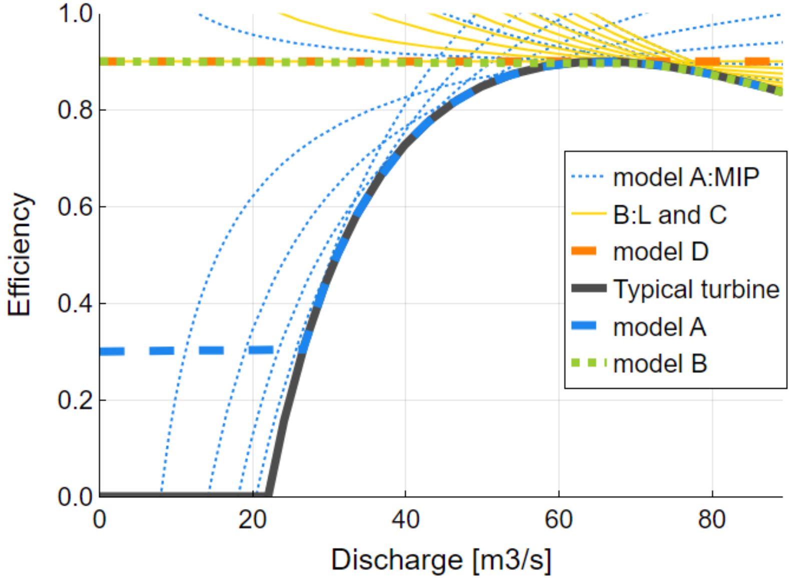


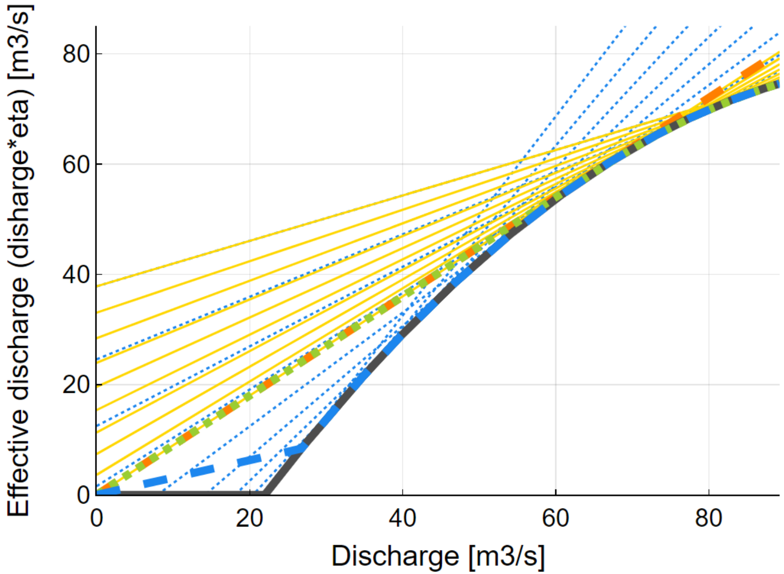
Summary





Fälth, H.E., Mattsson, N., Reichenberg, L. and Hedenus, F., 2023. Trade-offs between aggregated and turbine-level representations of hydropower in optimization models. *Renewable and Sustainable Energy Reviews*


1.0
0.8
0.6
0.4
0.2
0.0
Efficiency
0
20
40
60
80
Discharge [m3/s]
model A:MIP
B:L and C
model D
Typical turbine
model A
model B


80
60
40
20
0
Effective discharge (disharge*eta) [m3/s]
0
20
40
60
80
Discharge [m3/s]