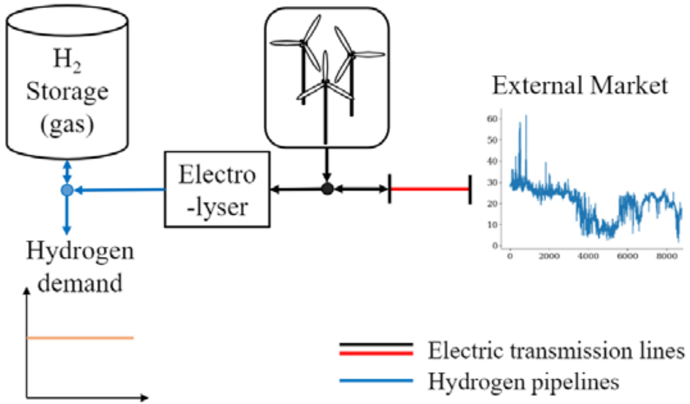
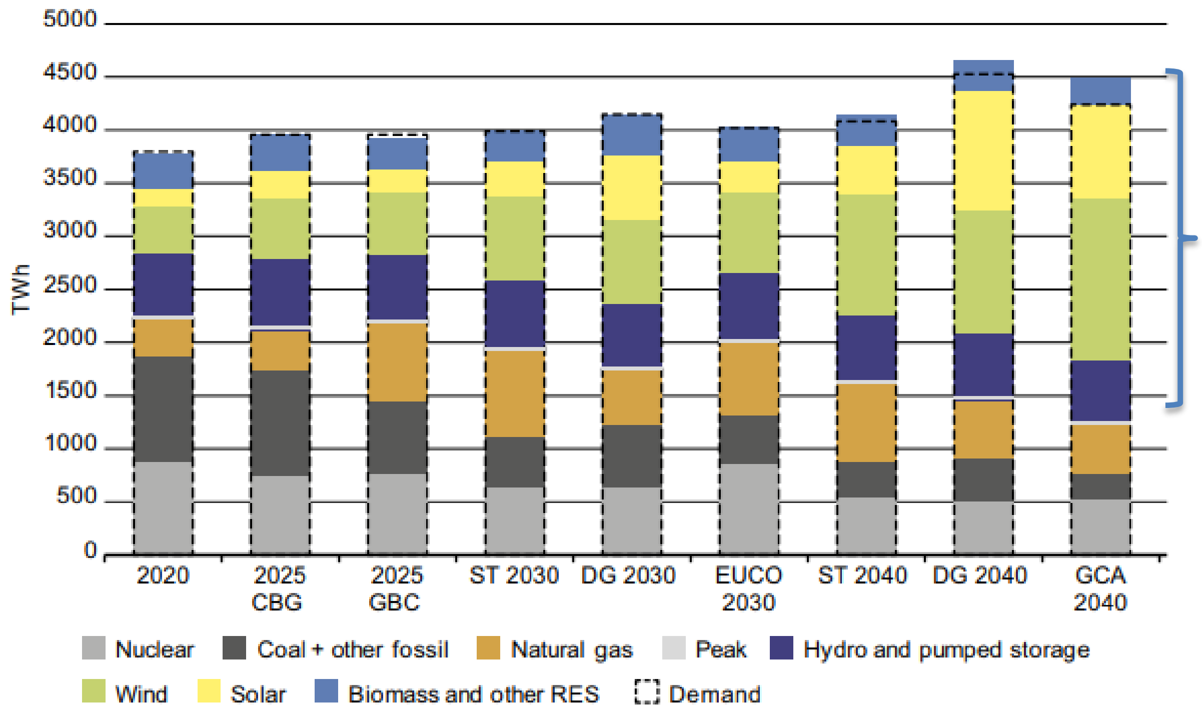
Integration of renewables in large-scale hydrogen production



Magnus Korpås, Espen Flo Bødal
Dept. of Electric Power Engineering
Hyper Closing Seminar
Dec. 11-12, 2019, Brussels

European grid operators (ENTSO-E) expects large-scale RES integration

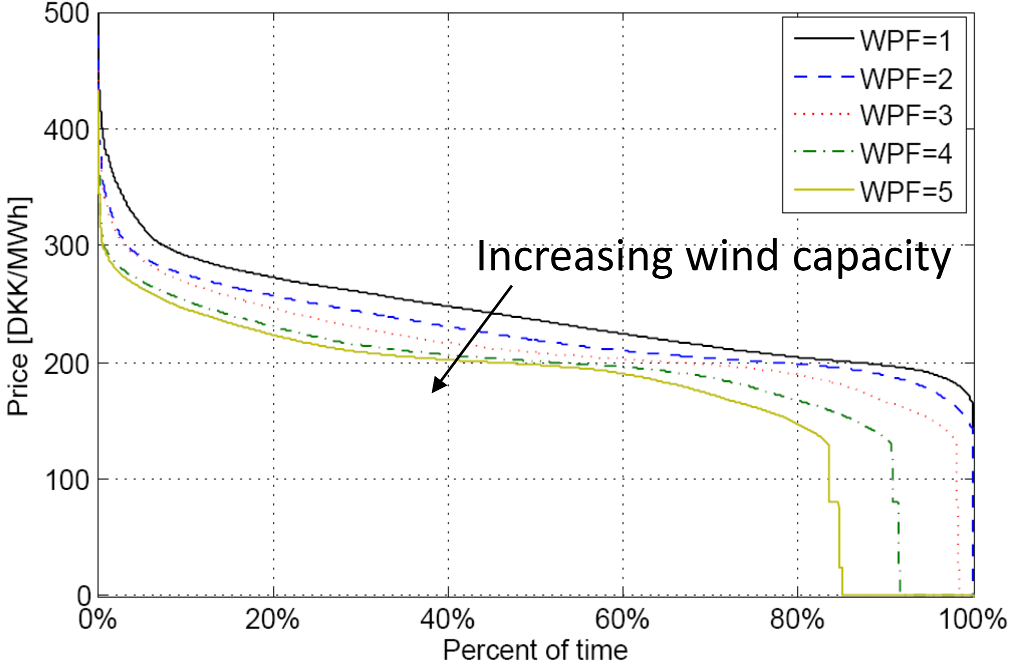


- Variable RES will dominate generation
- Ca 100 000 MW offshore wind in the North Sea

Figure: ENTSO-E TYNDP

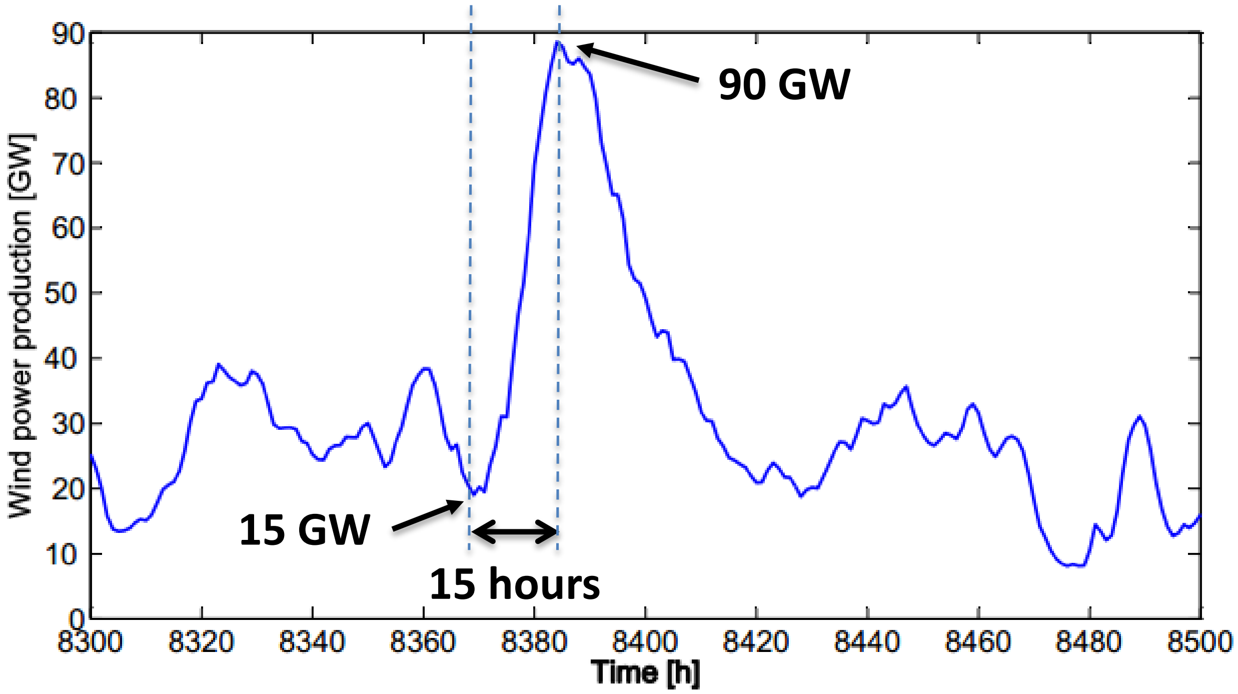
The merit-order effect reduces price

- Variable renewables have zero marginal cost
  - Periods with zero (or negative) prices becomes more common



Trötscher, Korpås
PSCC 2008

Why flexibility matters



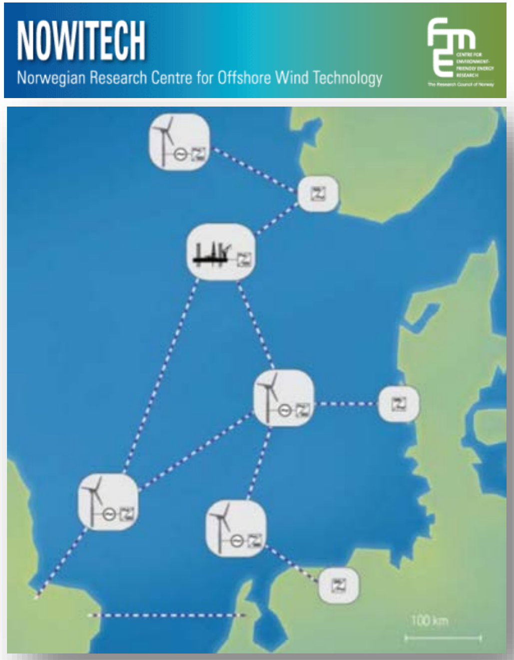


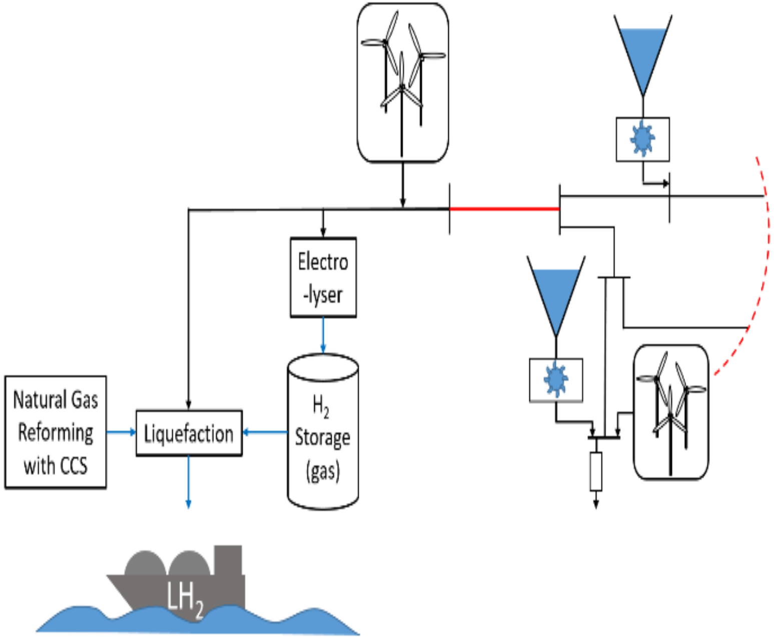
Figure: T. Aigner, Phd thesis, NTNU, 2013

H2 production from renewables in Northern Europe

- Nordic power surplus will increase significantly
- Huge onshore and offshore wind potential in Norway
  - Many projects on wait due to low prices and/or low grid capacity
- The hydrogen path is a promising alternative for utilization of the vast renewable energy potential
  - Especially in the North
- Methods for the design, sizing and operation strategy of the electrolysis path must be developed
  - Using surplus wind/hydro for hydrogen..
  - or producing hydrogen as the main operting strategy?
  - Optimal integration in the whole LH2 production and export chain

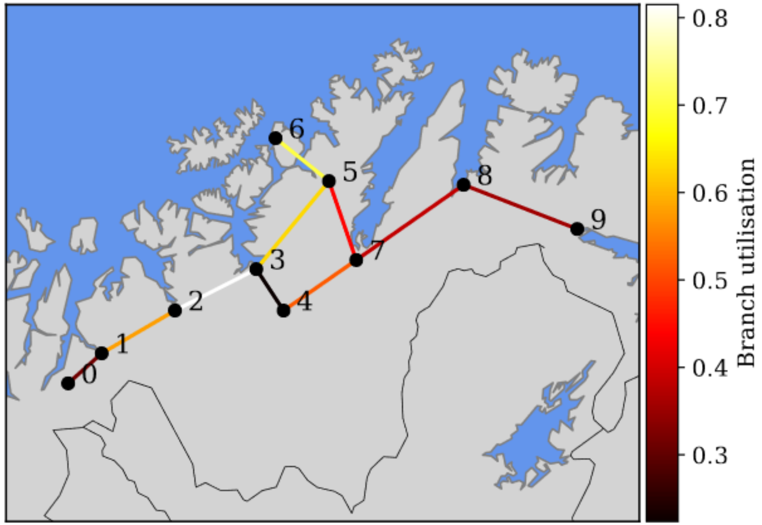
Model of regional power system with wind, hydro and hydrogen production

- Centralized optimization
  - Maximize profit from power exchange
  - Minimize investment cost
  - One year horizon, hourly time stages
- Storage balance
  - Hydropower and hydrogen storage
  - Hydrogen demand given as input
- Energy balance
- Realistic grid model
- Plant modelling
  - Power plant capacities, electrolyser and storages



Case Study: Northern Norway

- Finnmark in northern Norway
- Existing LNG facility
- Suitable site for H2 prod from NG
- Very good wind potential
- Some existing hydro power
- Weak transmission grid
- Liquification alone requires significant electric power
- Electrolyser options



Maximize electrolyzer utilization (and minimizing need for hydrogen storage)

OR Install overcapacity in electrolyser and hydrogen storage (Increase flexibility)

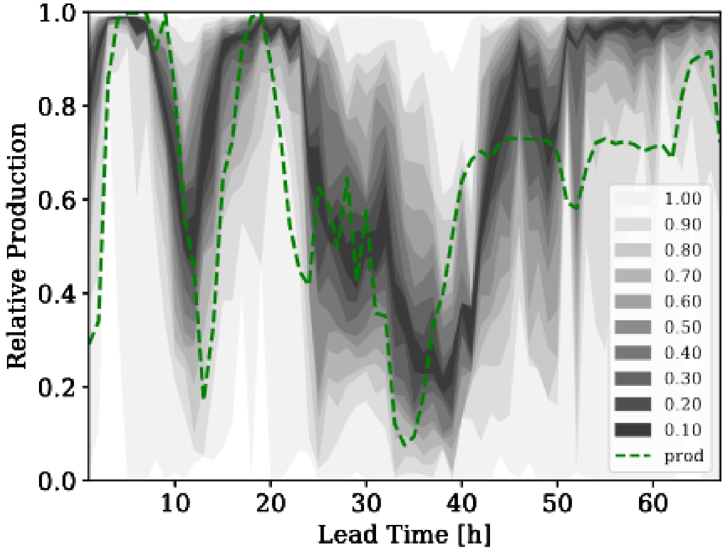
Flexible or continous H2 production in contstrained power grids?

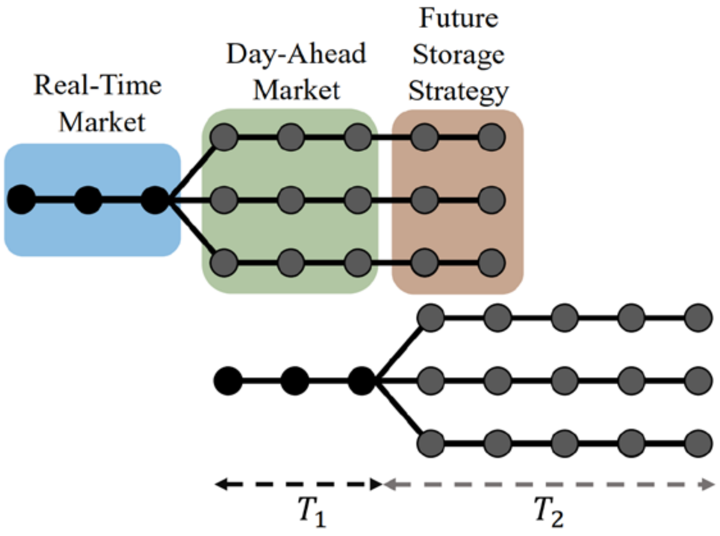
- Even flexible H2 production leads to **high degree of H2 storage utilization** and requires additional electrolysers
  - From 108 MW to 130 MW capacity for 10 hour storage)
- Flexibility is important to **increase power system security** due to the new demand from the H2 system
- Flexibility helps **integrate more wind power** without high levels of curtailment
- A strong grid favors continuous H2 production

Wind power uncertanty

- In the previous analysis, wind power variability was treated as known with 100 % accuracy
  - This is a normal assumption in cost-benefit analyses of energy systems
  - Do not capture the **imbalance cost** of wind in the market
- How important is it to include wind power uncertainty in the models?
  - How does it affect hydrogen storage strategies?
  - Does it change the optimal hydrogen system investments?

Operational model of H2 production including balancing cost for wind



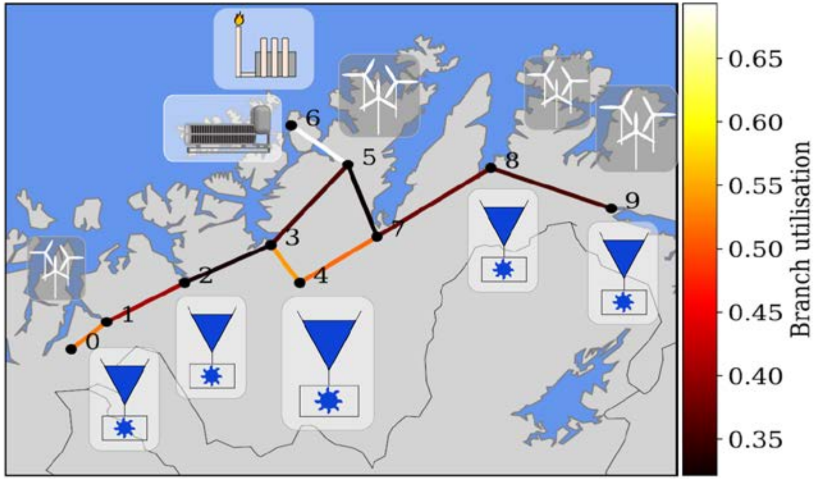


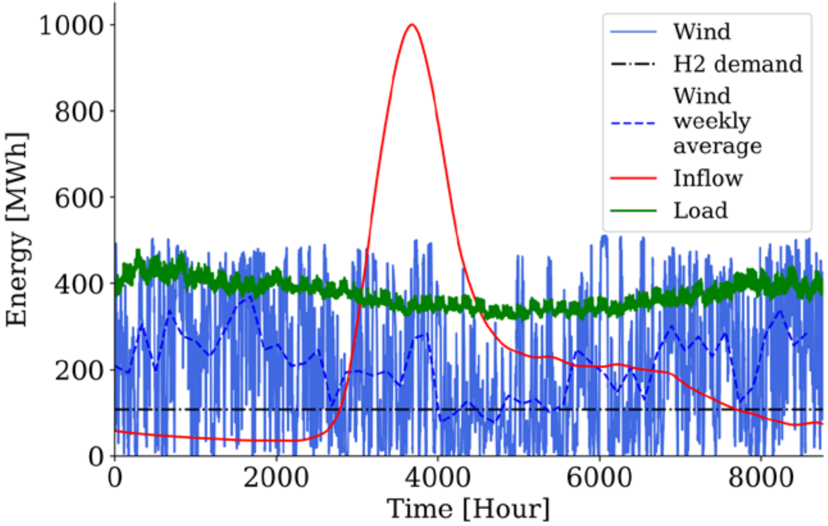
Impacts of wind power uncertanty

- A high imbalance penalty was set to test the model
- Case study shows:
  - Uncertainty model reduced costs by 5.6% compared to standard model
  - Perfect forecast reduced costs by 37.6%
  - Robust approach: Similar solutions for 60 different wind samples

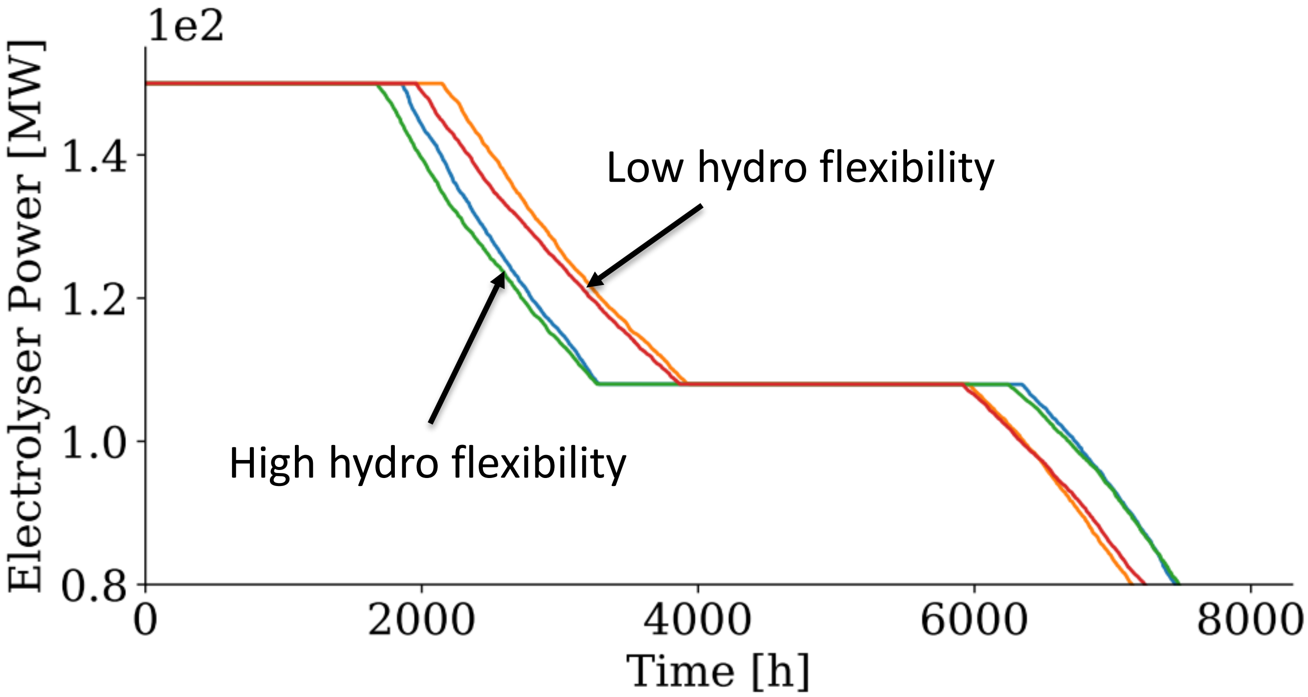
  - *Same main conclusion as before: Flexible H2 production increases the supply security in constrained grids.*

Utilizing hydropower flexibility for H2-production

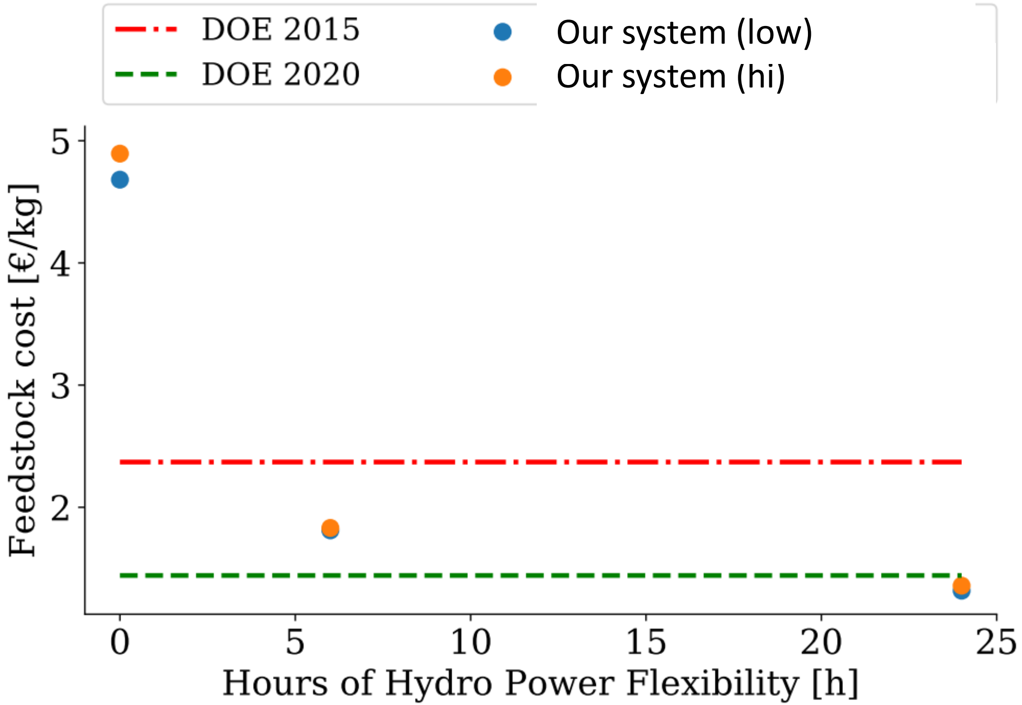




More hydro flexibility gives more stable H2 production



Flexible hydro production reduces H2 costs in constrained grids



Conclusions

- H2 production and liquefaction increases the optimal amount in wind power in constrained grids
- Power consumption of liquifier can be challenging from a grid perspective
- It is optimal to «oversize» the electrolyzer+H2storage to operate in a flexible manner
  - Reveal grid constraints, utilize more wind, reduce wind imbalance costs
- Flexible hydropower in North of Norway can be utilized to bring H2 production costs further down
- Current work: Capture the value of H2 flexibility (production and storage) in H2 plant investment model

Extras

Hyper and the power grid: Published and accepted publications

- E. F. Bødal, M. Korpås. **Regional Effects of Hydrogen Production in Congested Transmission Grids with Wind and Hydro Power.** 14th Int. Conf. on the European Energy Market - EEM 2017.
- E. F. Bødal, M. Korpås. **Production of Hydrogen from Wind and Hydro Power in Constrained Transmission grids, Considering the Stochasticity of Wind Power**. *EERA DeepWind'2018 Conf.*
- E. F. Bødal, M. Korpås. **Value of Hydro Power Flexibility for Hydrogen Production in Constrained Transmission Grids**. Int. J. of Hydrogen Energy, Accepted, 2019.

Hyper and the power grid: Papers in progress

- E. F. Bødal, D. , A. Botterud, D. Mallapragada, M. Korpås. **Towards Large Scale Hydrogen Production: Centralized versus Local Production.** In preparation for Applied Energy
  – Cooperation with MIT
  – Using case study from Texas
  – Supervision of master student: Case for North-Western Europe

- E. F. Bødal, Audun Botterud, M. Korpås. **Representing Short-Term Uncertainties in Capacity Expansion Planning Using an Rolling-Horizon Operation Model.** In preparation for IEEE Transactions on Power Systems
  – Cooperation with MIT
  – Generalised investment model for any combination of renewables and storage
  – Future work: Apply model to the wind-hydrogen Finnmark case

Operational model based on stochastic optimization