SINTEF
75 år

Modeling a 100% Renewable Electricity System

Arild Helseth, SINTEF Energi

RES100 – Modeling a 100% Renewable Electricity System

- Knowledge building project (KSP) 2024-2027
- 18 MNOK, research council supports 78 %, industry 22%

Project Team

SINTEF

NTNU

Arild

Amund

Birger

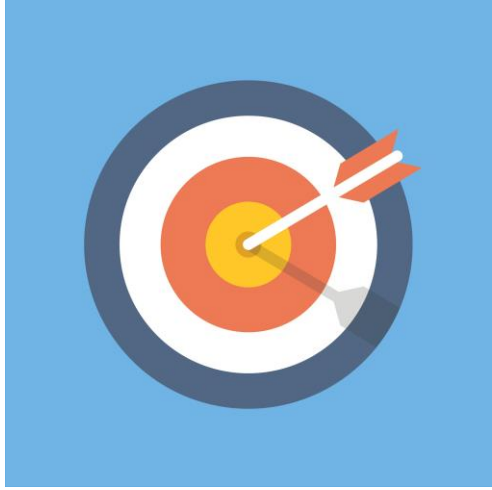
Stefan

Kristine

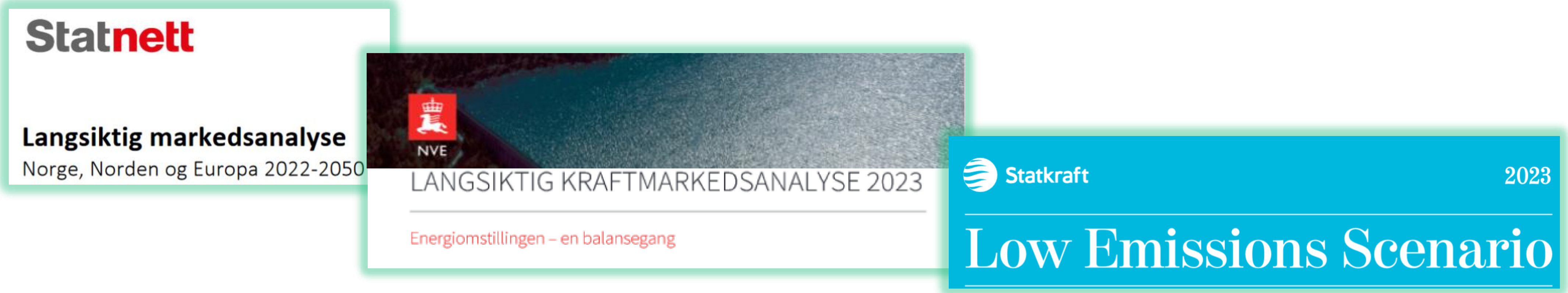
Hossein

SINTEF
75 år

Project Goal



Provide new insight into the power market modeling needs and knowledge about possible patterns for dispatch and price formation in the Nordic region in a 100% renewable European electricity system.



...

Modeling Framework

Establish a modeling framework that allows experimentation in RES100

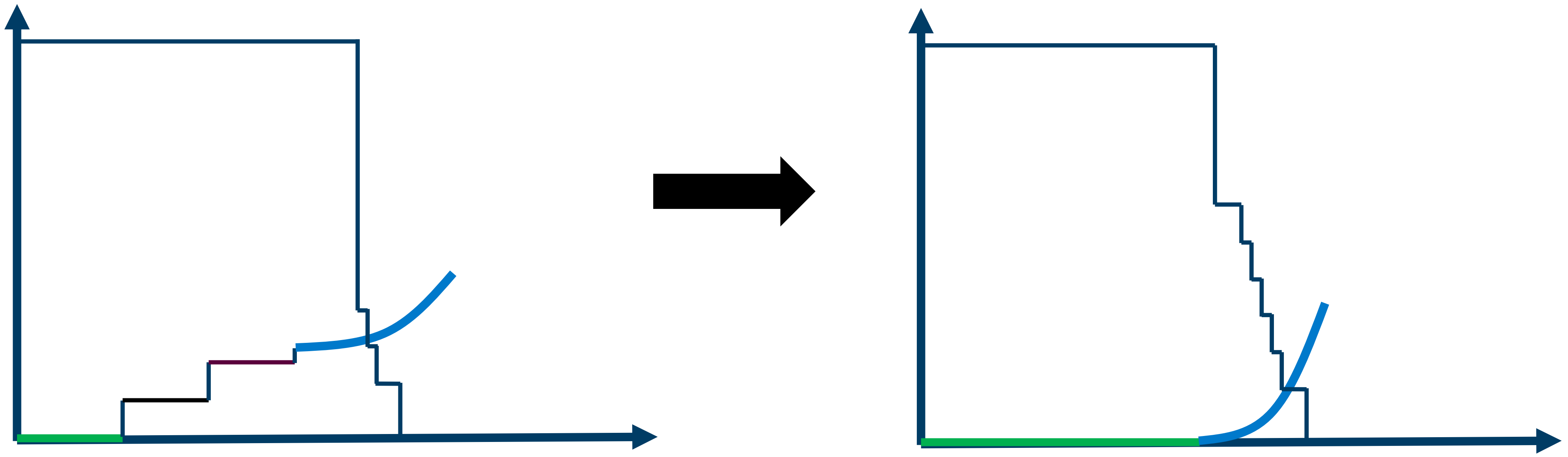
Criteria:
- Electricity system (Nordic/Northern Europe)
- Transparent methodology based on optimization
- Open-source code and data
- Reasonable computation times

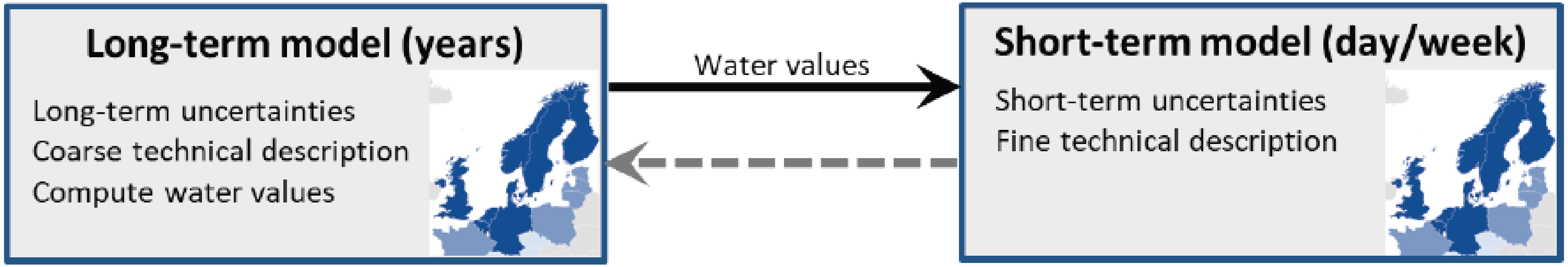
Analytic capability:
- Water values
- Price forecasting

Features:
- Hydropower operation
- Integration of new technologies

✓ Demonstration on existing datasets
✓ Guide further development of LTM

Impact on Prices & Water Values





SINTEF 75 år

Toolchain

Competence building needed when designing next generation LTM models!

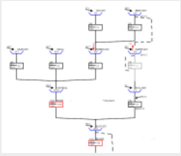
EMPS

Long-term Scheduling (years)
Stochastic
Aggregation/Disaggregation
Fundamental

Price forecasts

ProdRisk

Medium-term Scheduling (years)
Stochastic models
Semi-detailed hydropower
Price taker

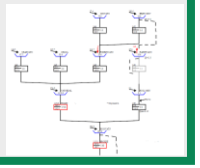


Water values

Price forecasts

SHOP

Short-term Scheduling (weeks)
Deterministic models
Detailed hydropower
Price taker



ReSDDP

- SDDP, aggregated system
- Take details into account

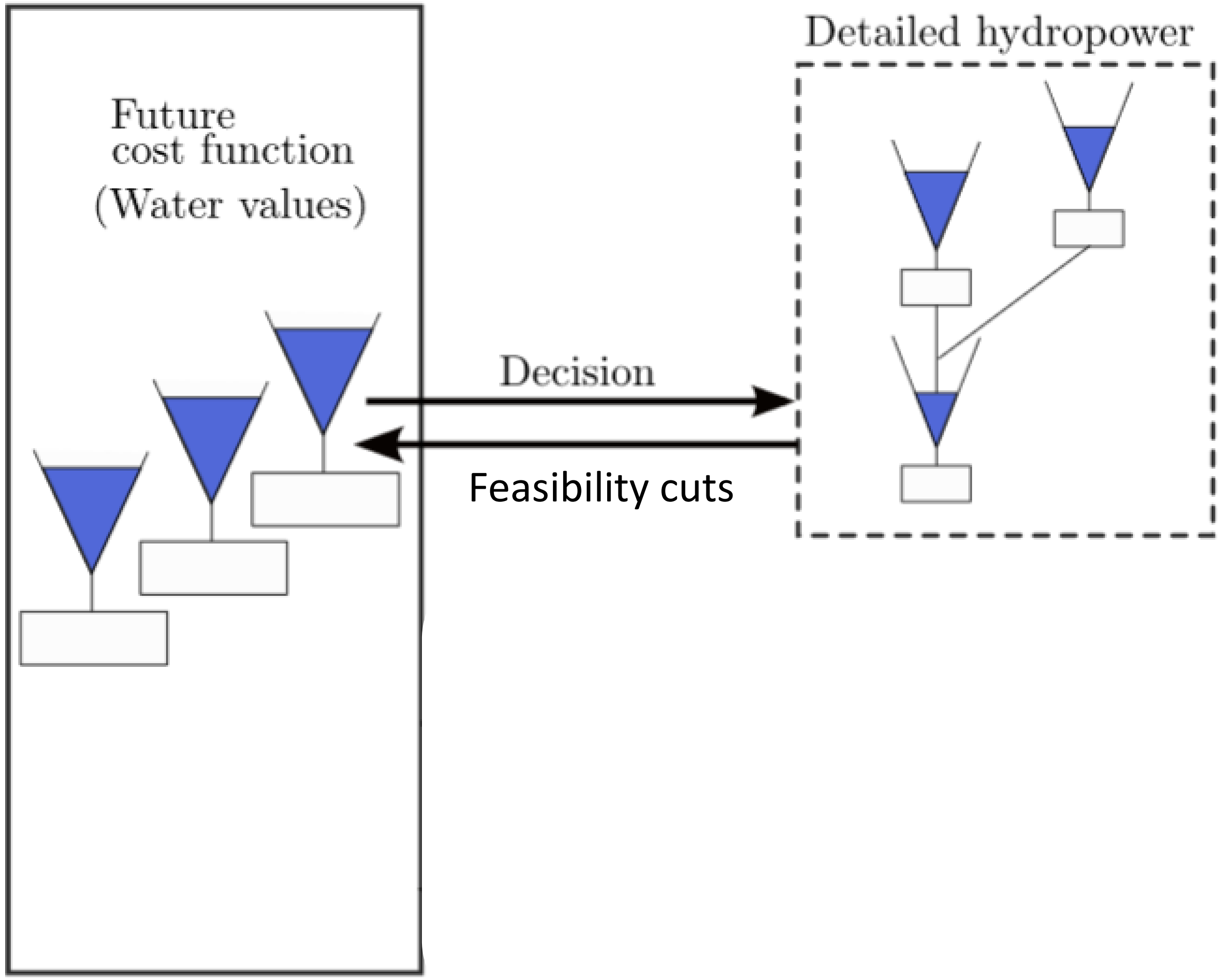
Water values

ReSIM

- Detailed simulation
- Dispatch and Prices

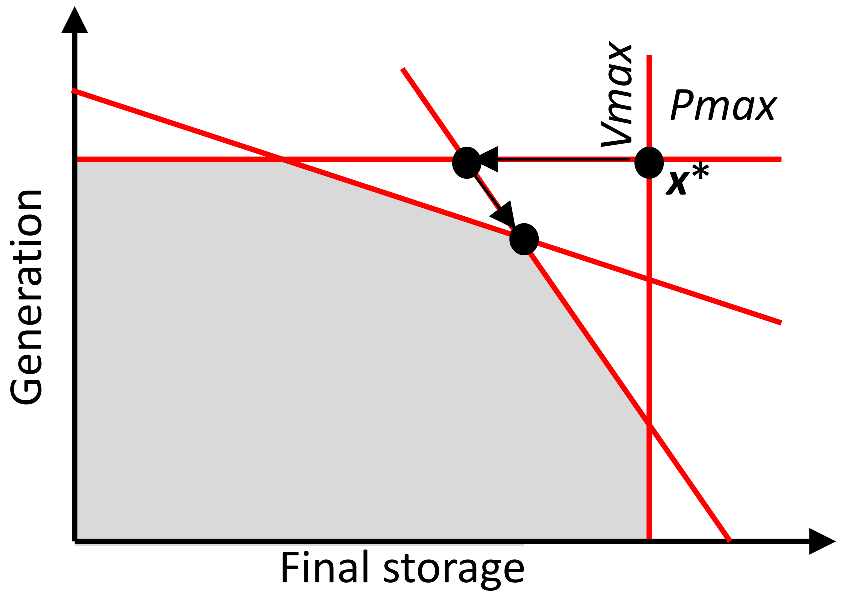
Decomposition – Illustrated

- ✓ Long-term uncertainty
- ✓ SDDP



Feasibility Spaces

1) Optimize single-stage problem with aggregated hydro
2) Send trial schedule (***x****: generation and final storage) and state (***s****: initial storage and inflow) to detailed hydro
3) Map aggregated storage and inflow to detailed system
4) Test if schedule is feasible on detailed hydro
5) If not: return feasibility cut and return to 1)

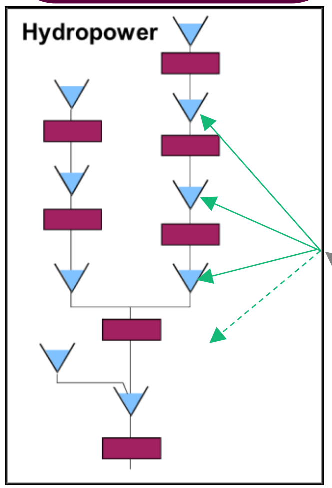


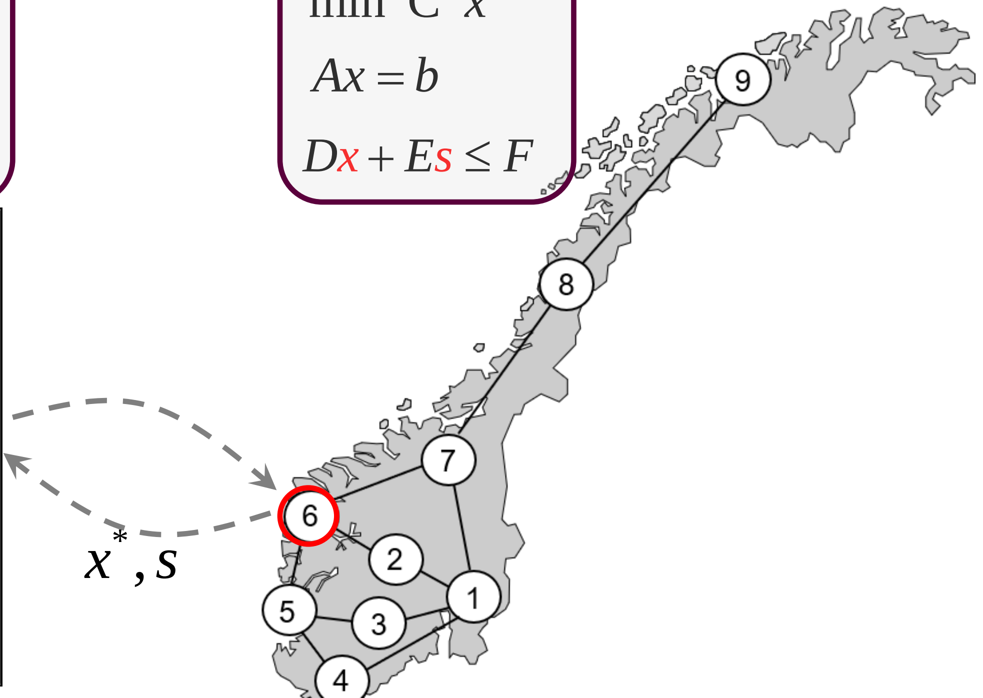
We create the feasibility space a priori

Discretize and test x and s**

$$\begin{aligned} &\min \ z \\ &Ay = b(s^*) \\ &Dy + z \geq x^* \end{aligned}$$

$$\begin{aligned} &\min \ C^T x \\ &Ax = b \\ &Dx + Es \leq F \end{aligned}$$

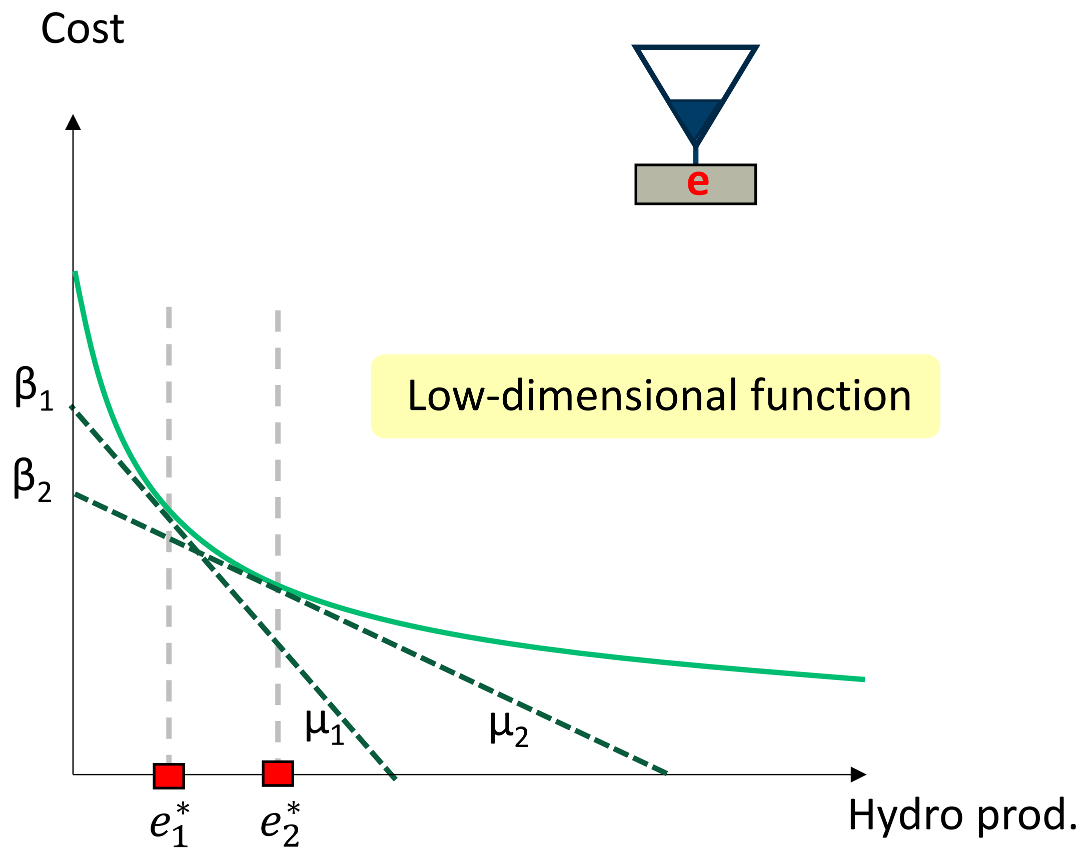




Decisions:

- Generation
- Final storage
- Ramping capability
- Reserve capacity

Residual Market



Low-dimensional function

Large-scale LP!

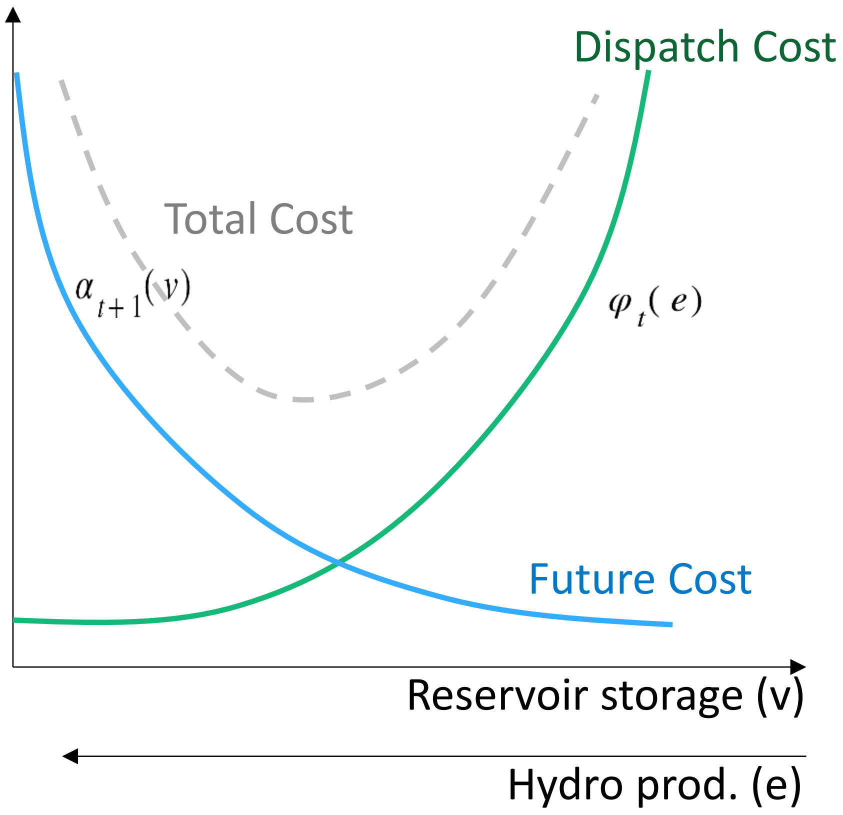
Short-term uncertainty

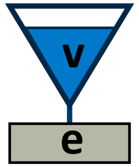
Φ(e) = min Dispatch Cost
s.t.
Power balance (hourly)
Technical constraints (hourly)
Hydropower operation (hourly)
Weekly production = e : μ

Scenario 1
Scenario 2
Scenario 3

$$\phi \geq \sum_{s=1}^{NS} p_s \beta_s - \sum_{s=1}^{NS} p_s \mu_s e$$

Decomposition – Illustrated

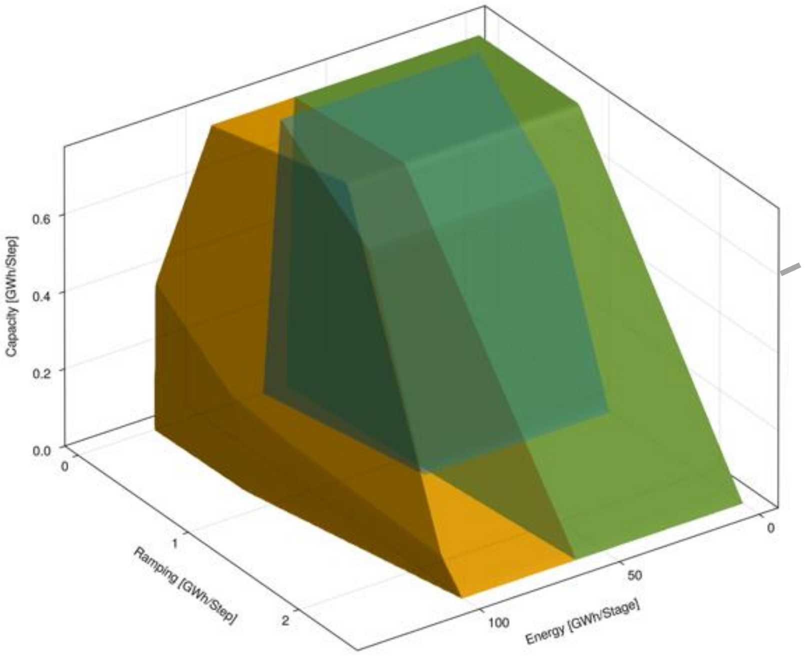


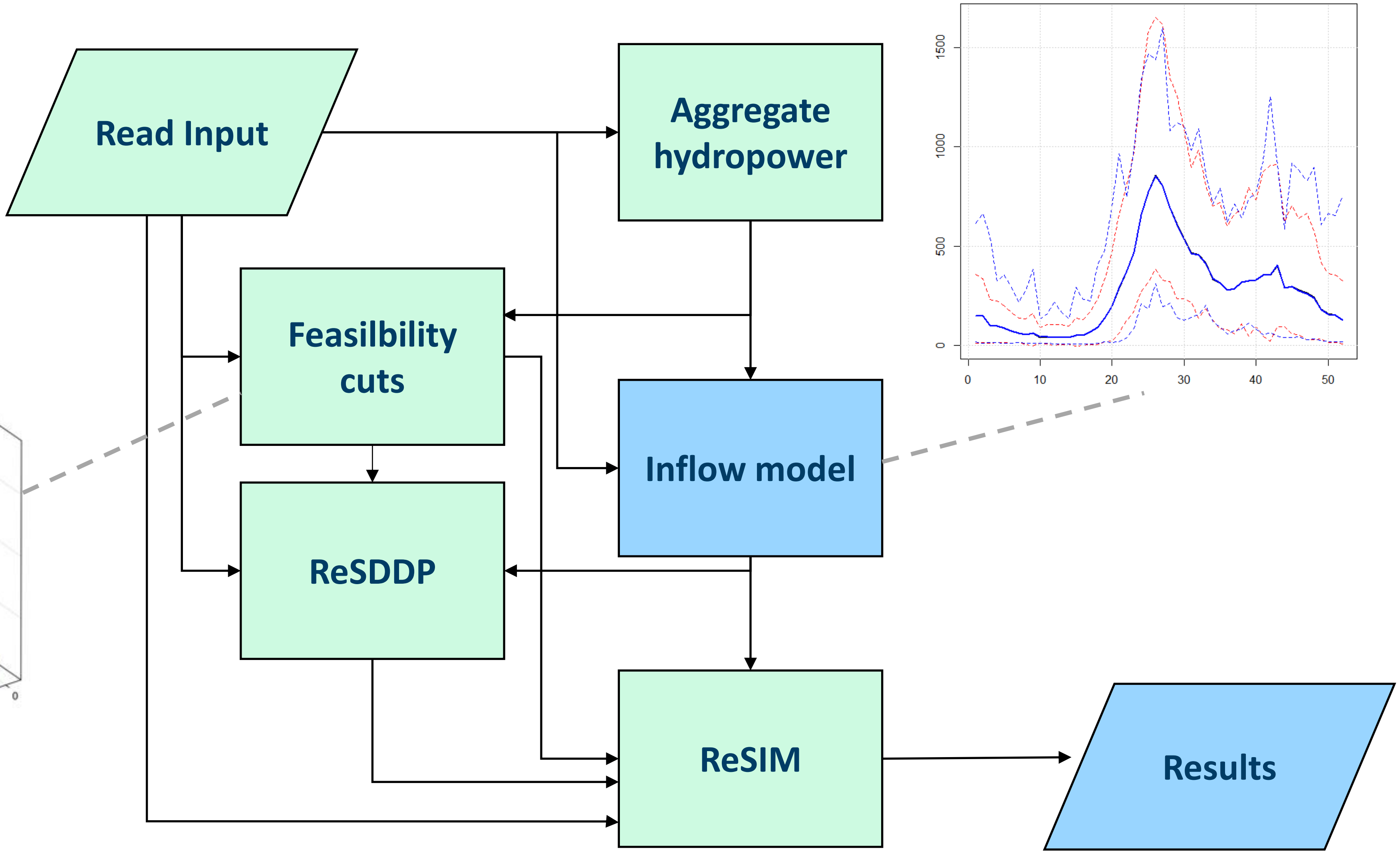


Future cost approximated
Addition: Dispatch cost approximated
→ «Residual demand for hydro»
→ Similar concept as classical water value method

Model structure

EMPS v10 data





Code available at:
`https://gitlab.sintef.no/res100/ReSDDP`

Dataset

- 2050 scenario from HydroConnect
  - Expansions by Fraunhofer (Scope)
  - Simulated by Fansi

- Composition:
  - 24 areas with hydropower
  - 23 areas with offshore wind
  - 17 areas with hydrogen

Average annual production in TWh

Country	Hydro	Wind	Solar	Demand
Norway	157	51	7	201
Sweden	69	140	9	215
Finland	16	114	3	144
Denmark	0	105	8	73
Germany	0	573	250	843
Great Br.	5	468	176	651

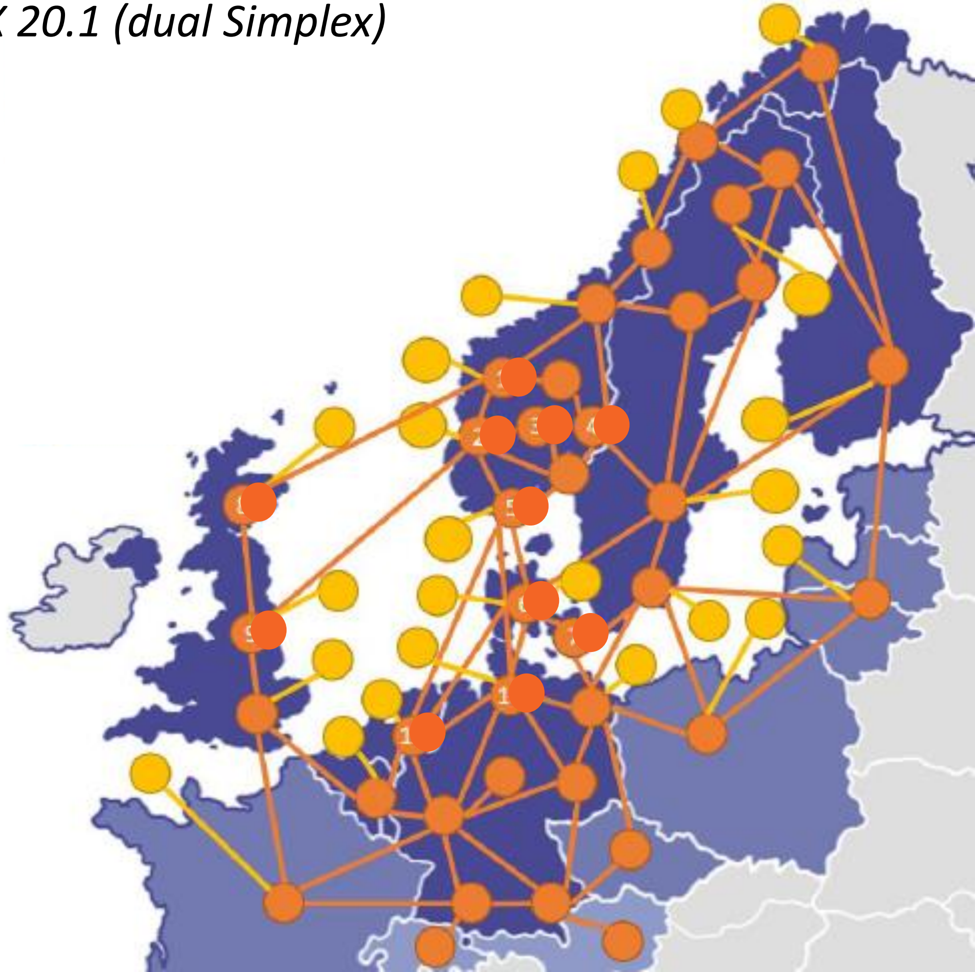
Dataset

~a few days

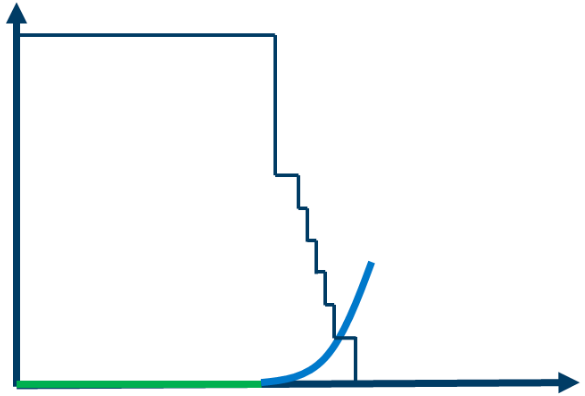
- *Intel Core i9-13900K proc.*
- *24 cores, 32 GB RAM*
- *CPLEX 20.1 (dual Simplex)*

ReSDDP parameterization

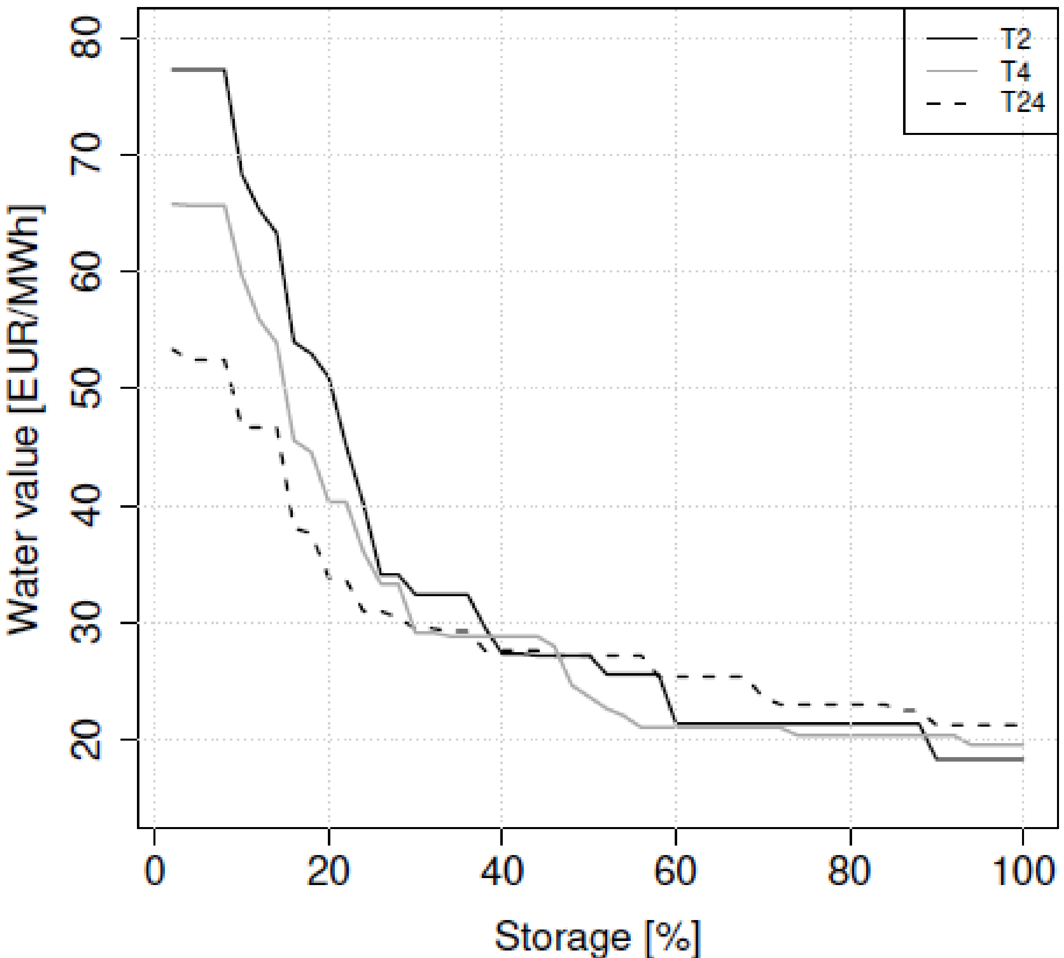
- Uncertainty
  - Inflow:
    - 40 forward samples
    - 10 «backward openings»
  - Wind/Solar:
    - 5 scenarios
- Time resolution
  - T24 (24 hour)
  - T4 (4 hour)
  - T2 (2 hour)
- Convergence: max. 300 iter.



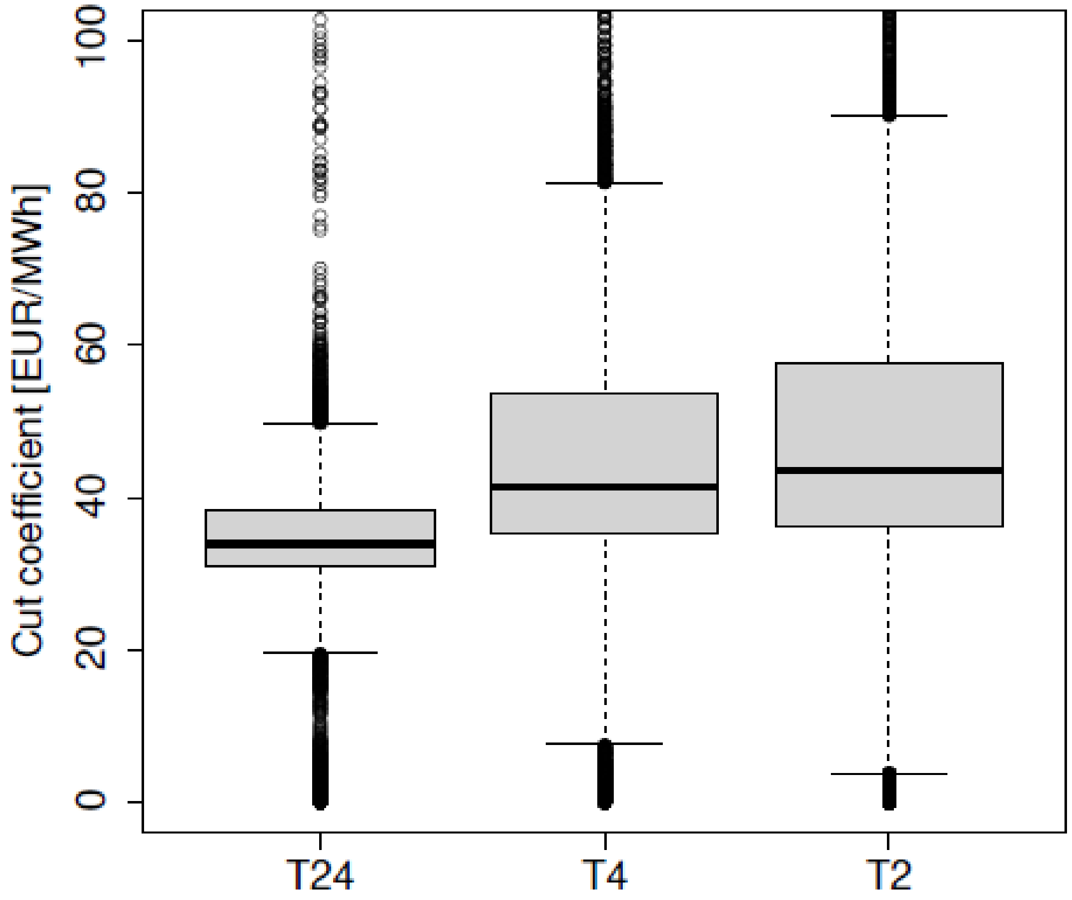
Water values



Hallingdal, week 15



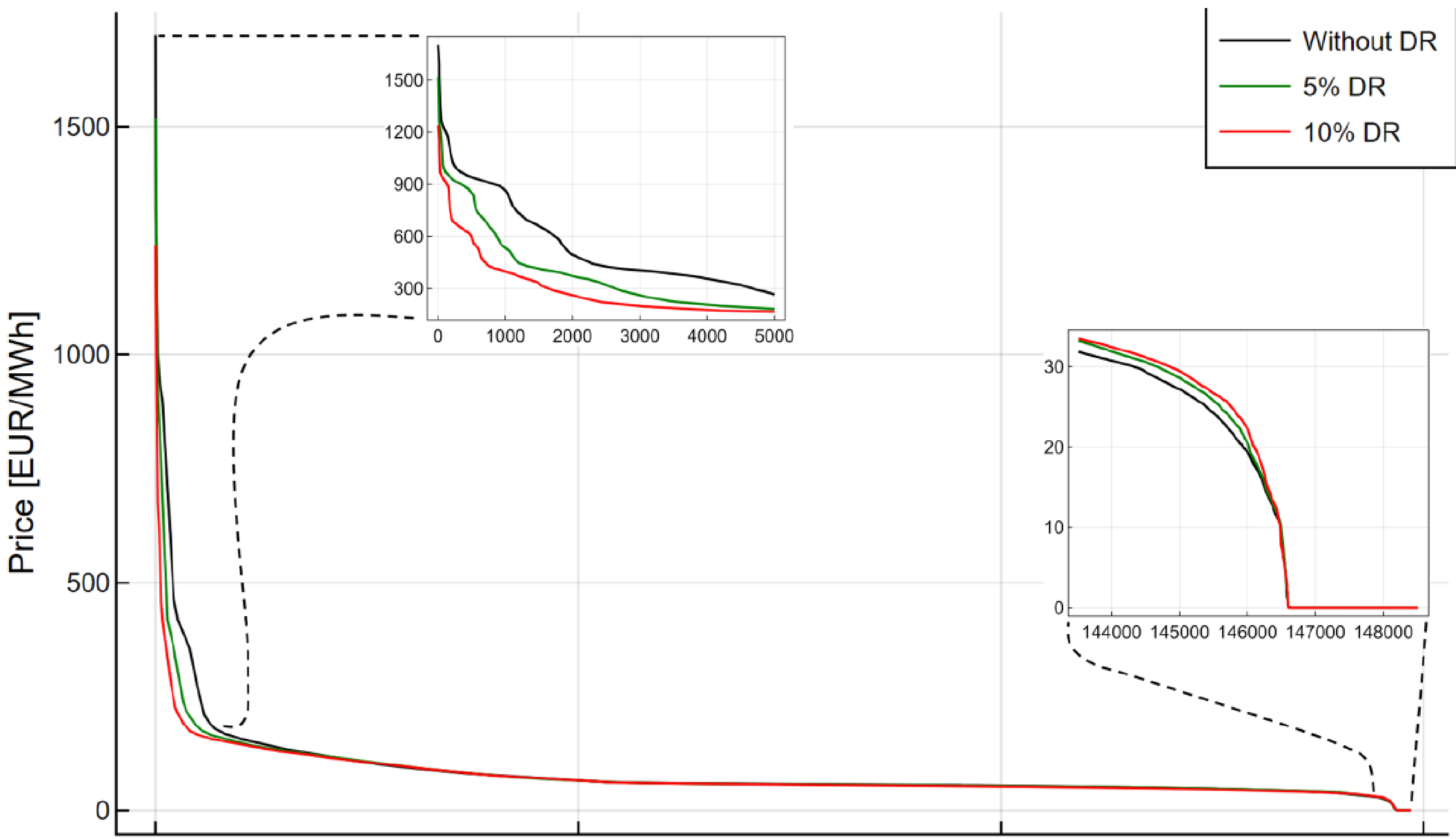
Hallingdal, week 15



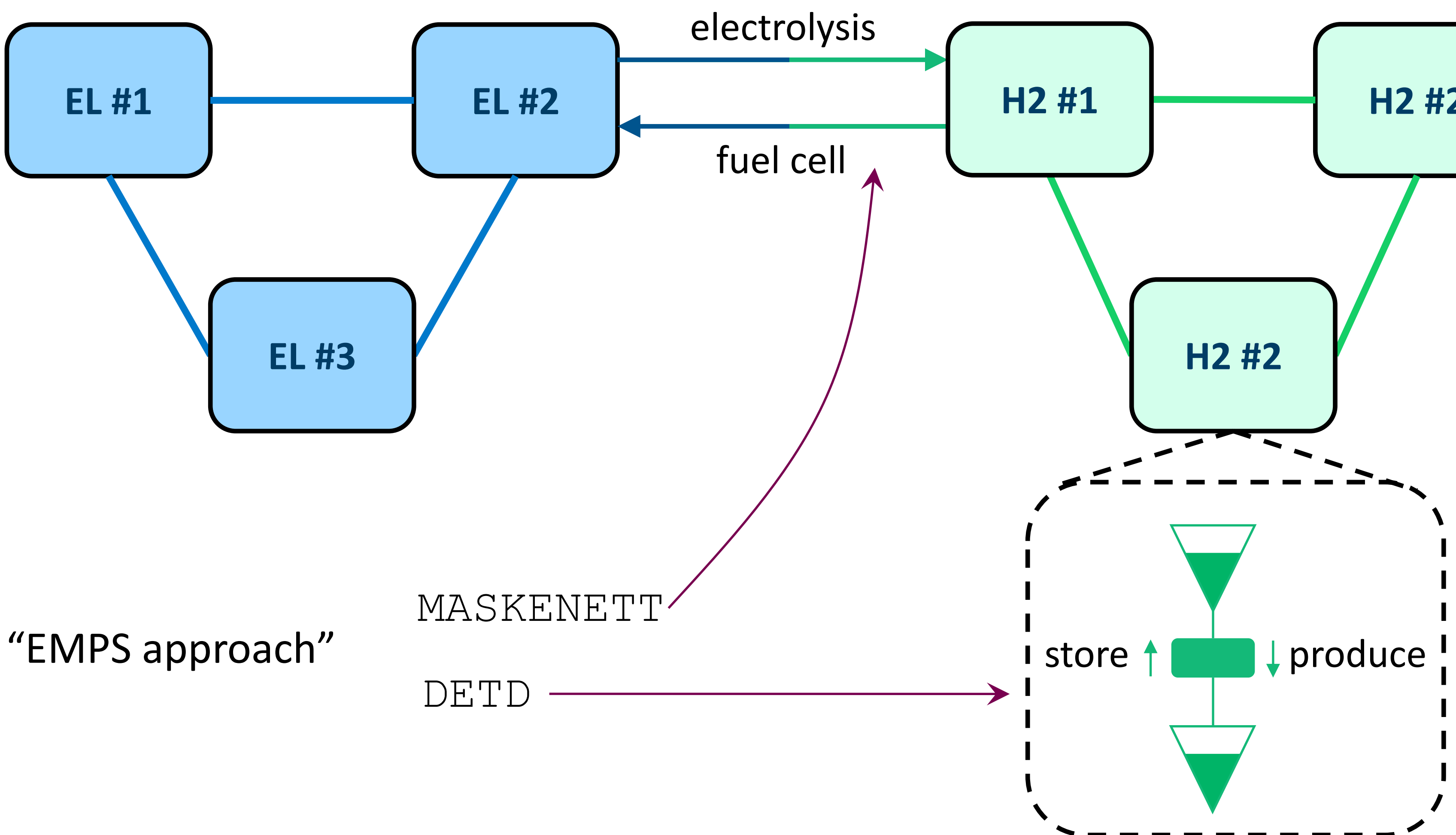
Demand Response

- ✓ Load Shedding
- ✓ Load Shifting
  - Within week
  - Linear model
    - Load shift limits
    - Load recovery time
    - Additional constraints to limit simultaneous charge/discharge

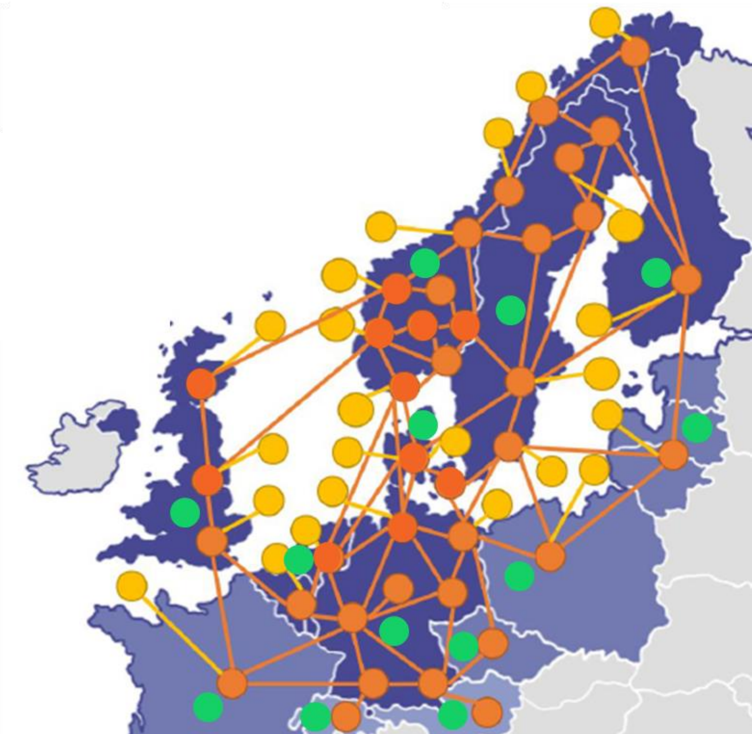
Load recovery: 4 hours



Power-Hydrogen Market Dynamics



Impact of modelling choices:
- ✓ H2 flexibility
- ✓ H2 storage valuation



"EMPS approach"

75 år med teknologi for et bedre samfunn

sintef.no/75