NTNU – Trondheim
Norwegian University of
Science and Technology

Methods and Processes for Hydro-thermal Scheduling

Prof. Olav Bjarte Fosso

Dept of Electrical Power Engineering

Norwegian University of Science and Technology (NTNU)

Hydro Power’s role in an Integrated Energy System?




Hydro Power in Norway

- Electricity: ~ 100% hydro power
- Largest in Europe, nr 6 in the world
- 30% of hydro power cap. In European Union (50 % of storage)
- Installed capacity : ~ 29000 MW
- Generation average,: ~ 125 TWh
- Consumption: ~ 124 TWh
- Average inflow +- 20 %

Real-world problems characterized by

- Large physical models (Geographical and time horizon)
- Non-linear and non-convex with many local optimums
  - Final solution may depend on the starting point
  - Global optimal solution never guaranteed
- Binary variables complicates the solution process and may in some parts of the complete problem be important
- User-experience and ”non-mathematical” constraints (rule-based and state dependent) may be important

- Hydro scheduling is no exception regarding these problems

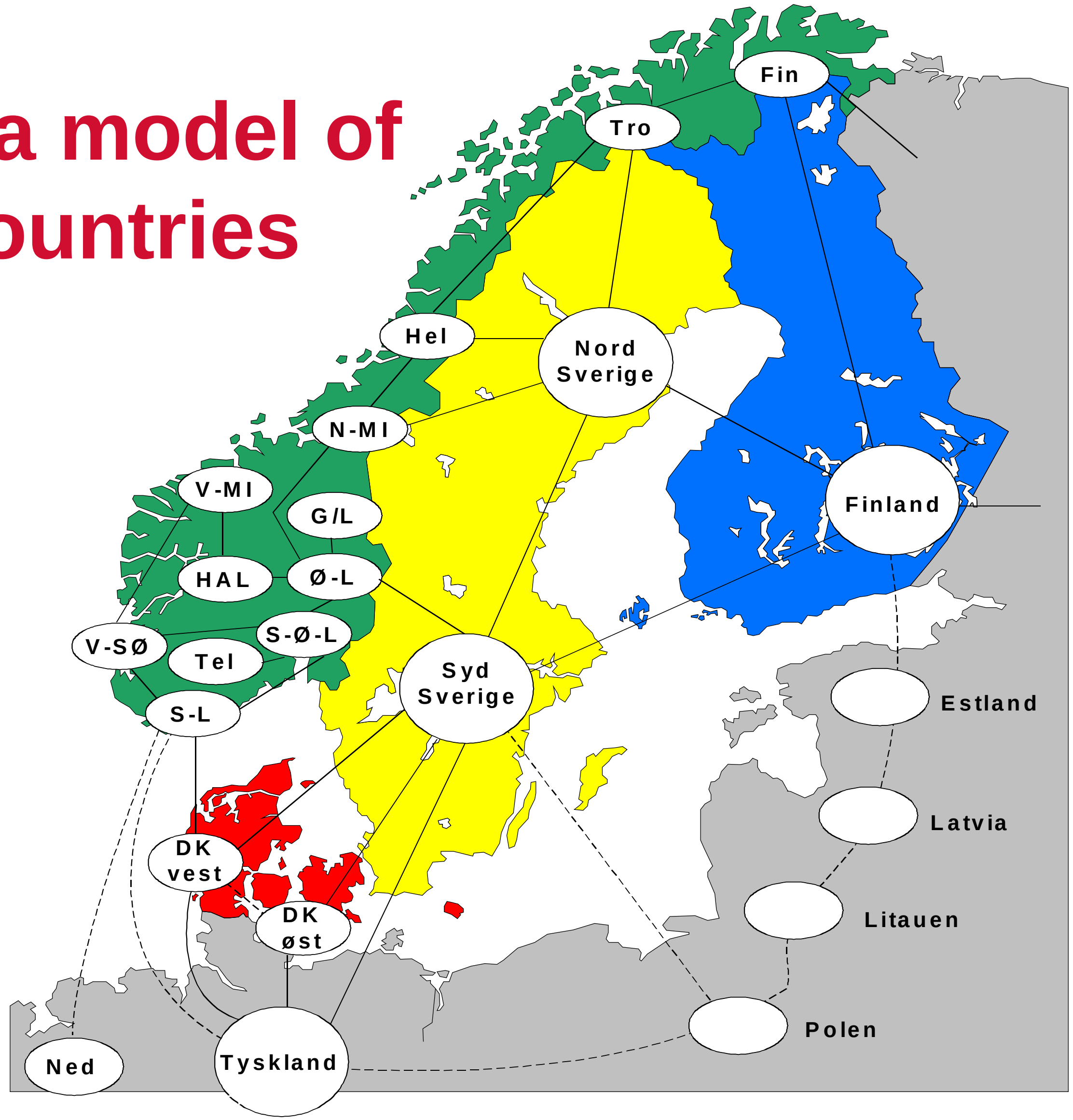
Challenges in hydro scheduling

- Cascaded reservoir systems with different storage capacity couples the decisions between the generation plants
- The storage capacity and variable inflow couples the decisons over time
  - Inflow range in Norwegian system: 95 – 140 TWh (Average load 125 TWh)
  - Significant storage capacity requires long planning horizons (Typical up to 5 years)
  - Other system characteristics dictates the time resolution
- The relative size of the hydro system compared to the thermal system call for different co-ordination principles (Peak shaving – similar size – hydro-dominated)

Large scale stochastic dynamic optimization

- Multi state
  - Typical more than 1000 different storages in an fundamental market model
    - Very varying storage size (from about three years to hours)
- Stochastic multidimensional
  - Inflow, wind, radiation
    - Correlated in time an space
      - Historical observations
      - Short-term forecast, snow pack information
  - Exogenous prices
- Multi stage
  - Weekly (split into intraweek time step)
  - Several year long planning horizon
- Transmission constrained
  - Several thousand nodes

Multi-area model of Nordic countries



Scheduling Hierarchy

(Norway – present practice)

Long term scheduling (1-5 years)
Stochastic models for optimazation
and simulation

↓ Reservoir levels
Marginal water values

Seasonal scheduling (3-18 months)
Multi-scenario
Deterministic optimization models

↓ Marginal water values
Reservoir boundaries

Short term scheduling (1-2 weeks)
Deterministic optimization models

↓ Plans

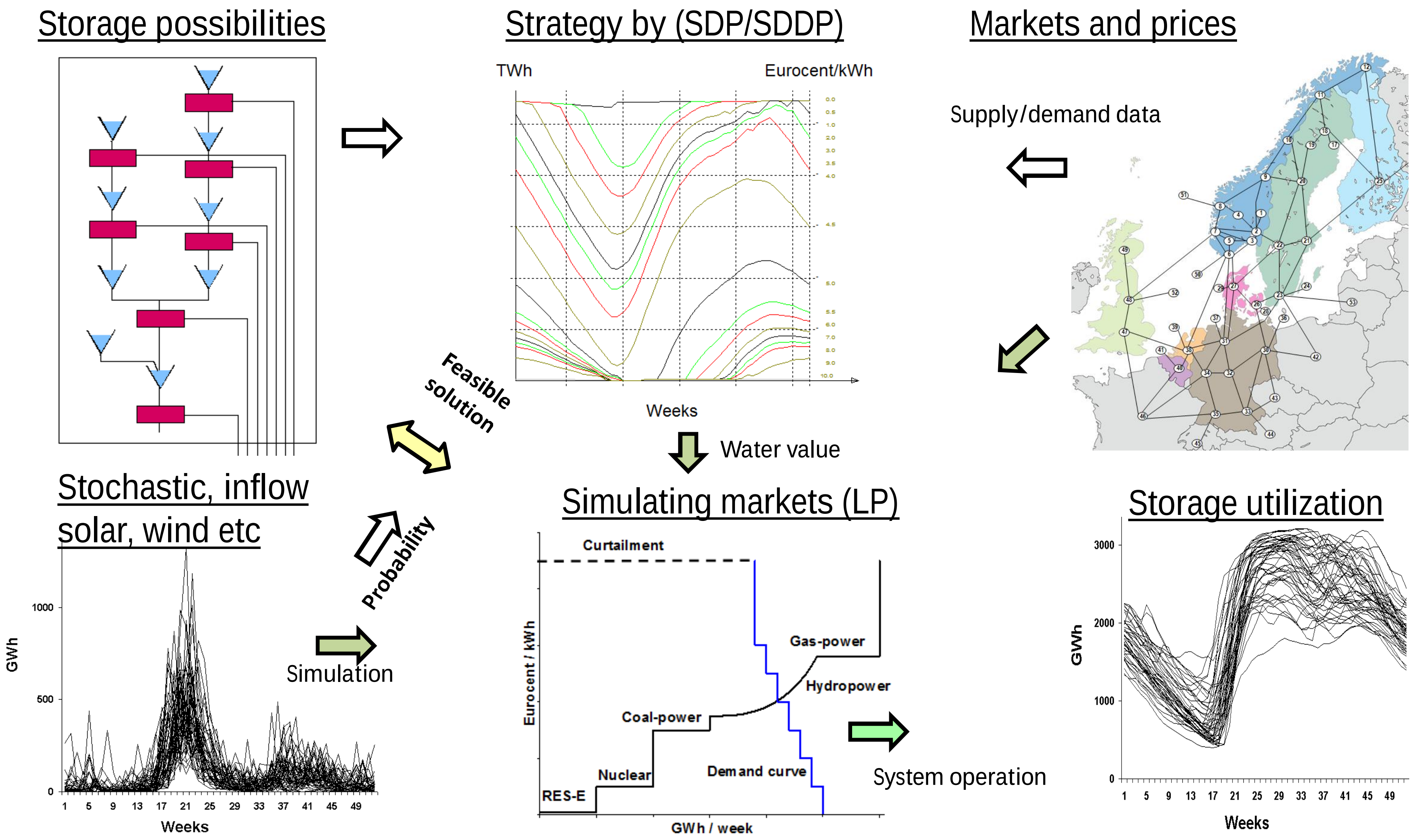
Detailed simulation (1 -12 weeks)
Verification of plans with
non-linear simulation

Methods in use

- SDP (Long-term)
  - Aggregated
  - Stochastic
- SDDP (Long / Mid-term)
  - Detailed
  - Stochastic
- Scenario-based (Mid-term)
  - Deterministic
- Deterministic (Short-term)
  - LP
  - MIP
  - DP
  - Lagrange relaxation

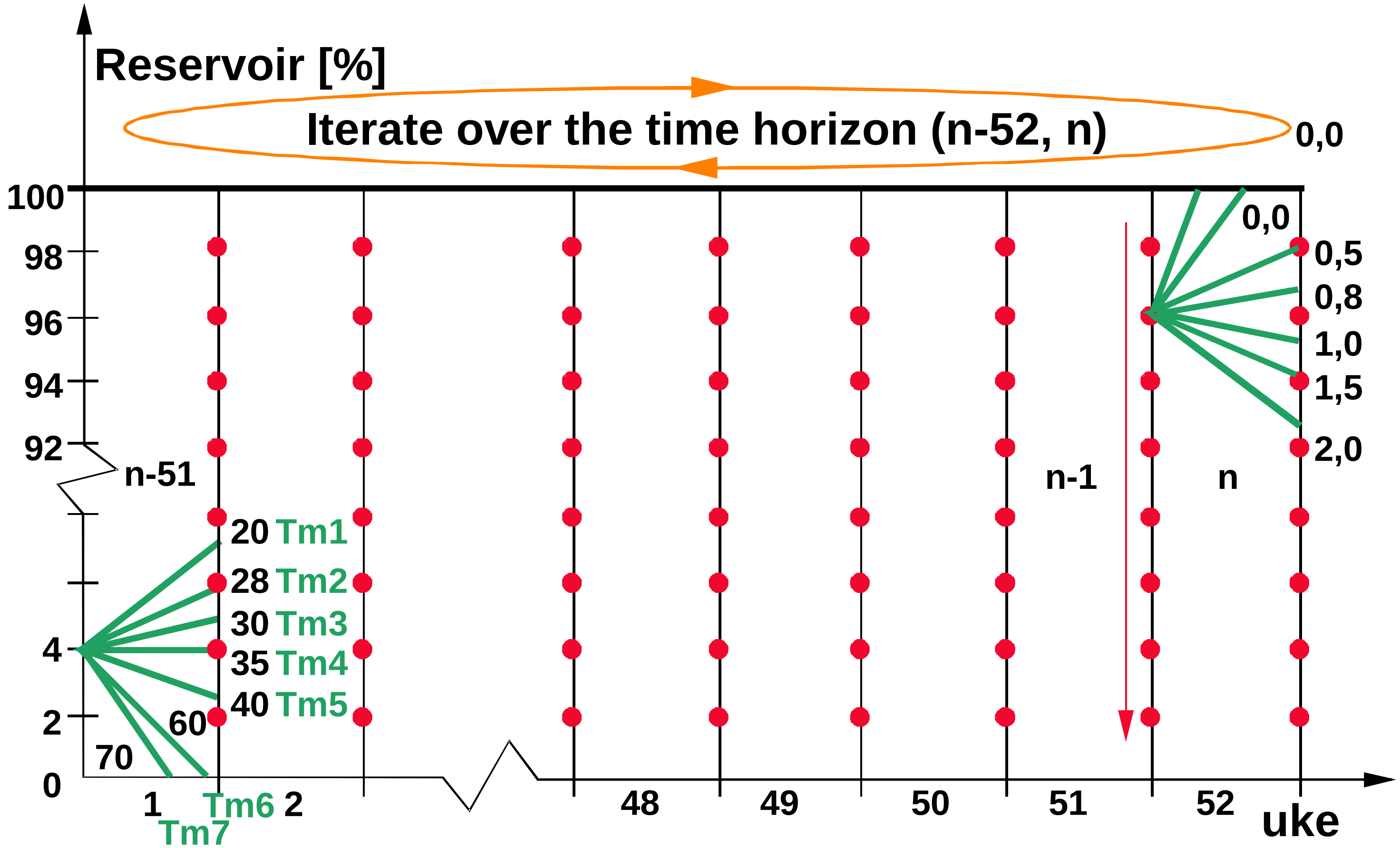
Longer-term scheduling

Simulation of markets with storages and weather uncertainty



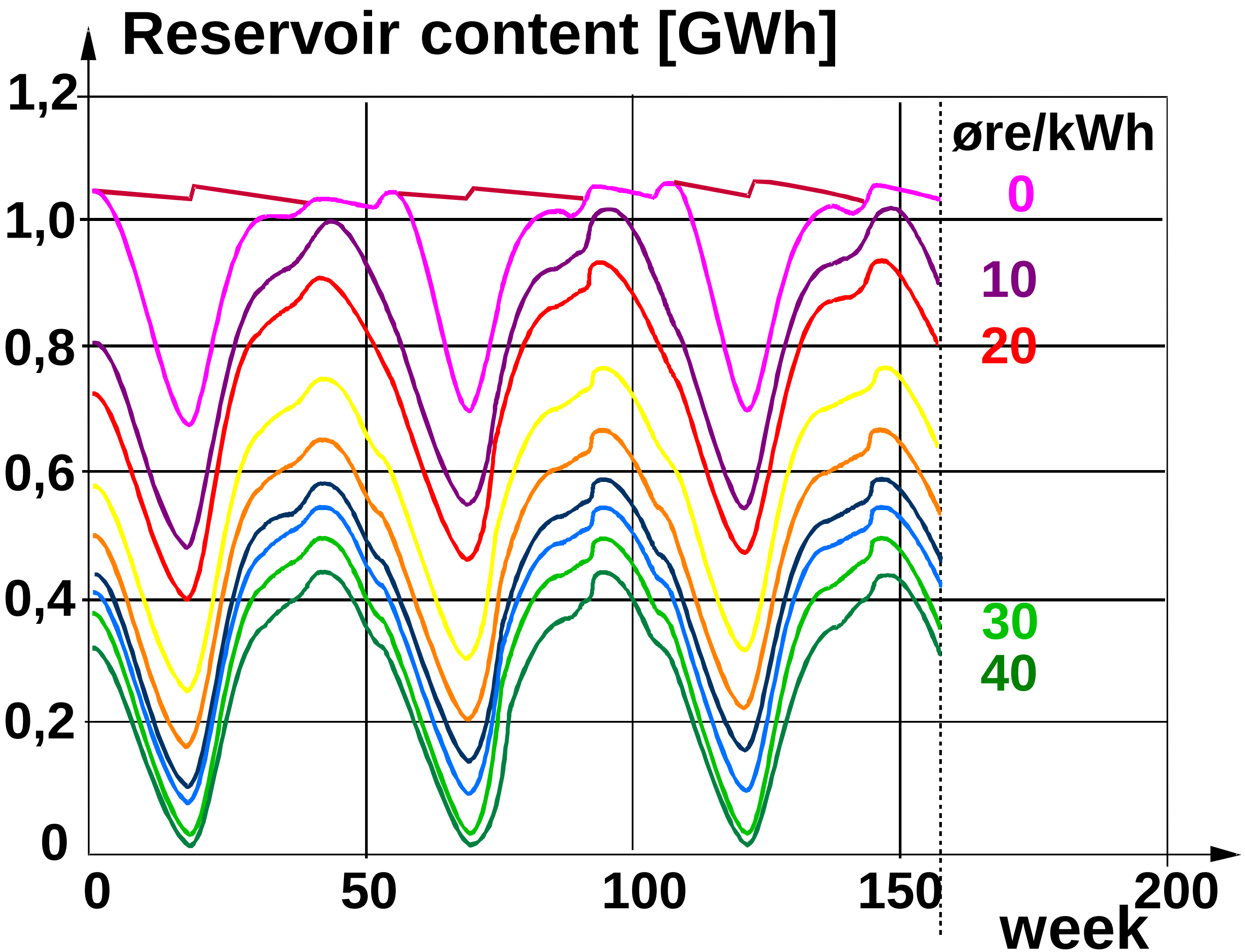
Courtesy: Birger Mo, SINTEF

Marginal water values calculated for all points over the time horizon



$$VV4 = \frac{20 \bullet 1 + 28 \bullet 5 + 30 \bullet 9 + 35 \bullet 20 + 40 \bullet 9 + 60 \bullet 5 + 70 \bullet 1}{(1 + 5 + 9 + 20 + 9 + 5 + 1)} = 37{,}2 \text{ [øre/kWh]}$$

Illustration of water values



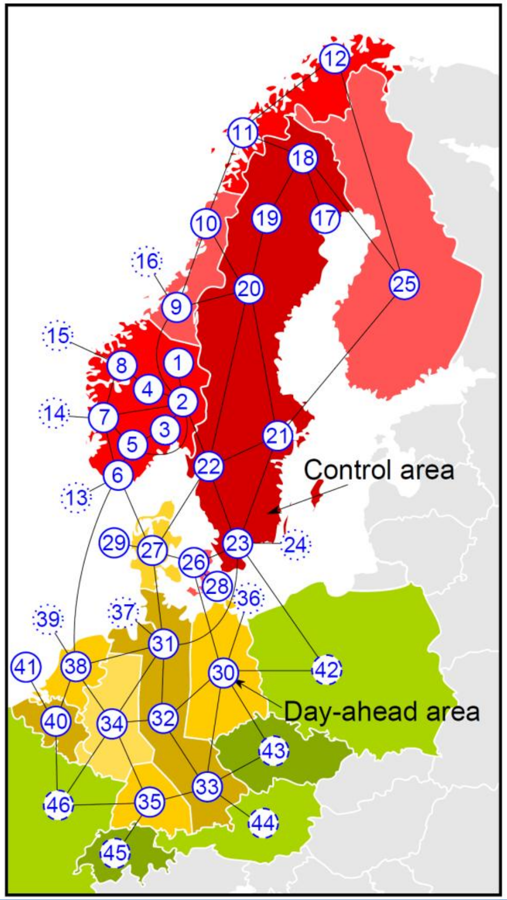
Application example – Integration of balancing markets

Fundamental model
Detailed water course description
About 300 thermal power plants
Transmission corridors (NTC)

Northern Europe
Denmark, Finland, Norway, Sweden
Germany, Netherlands, Belgium

System scenarios
2010 – current state of the system
2020 – a future state of the system

Several climatic years
Hydrology (Inflow)
Temperature
Wind speed

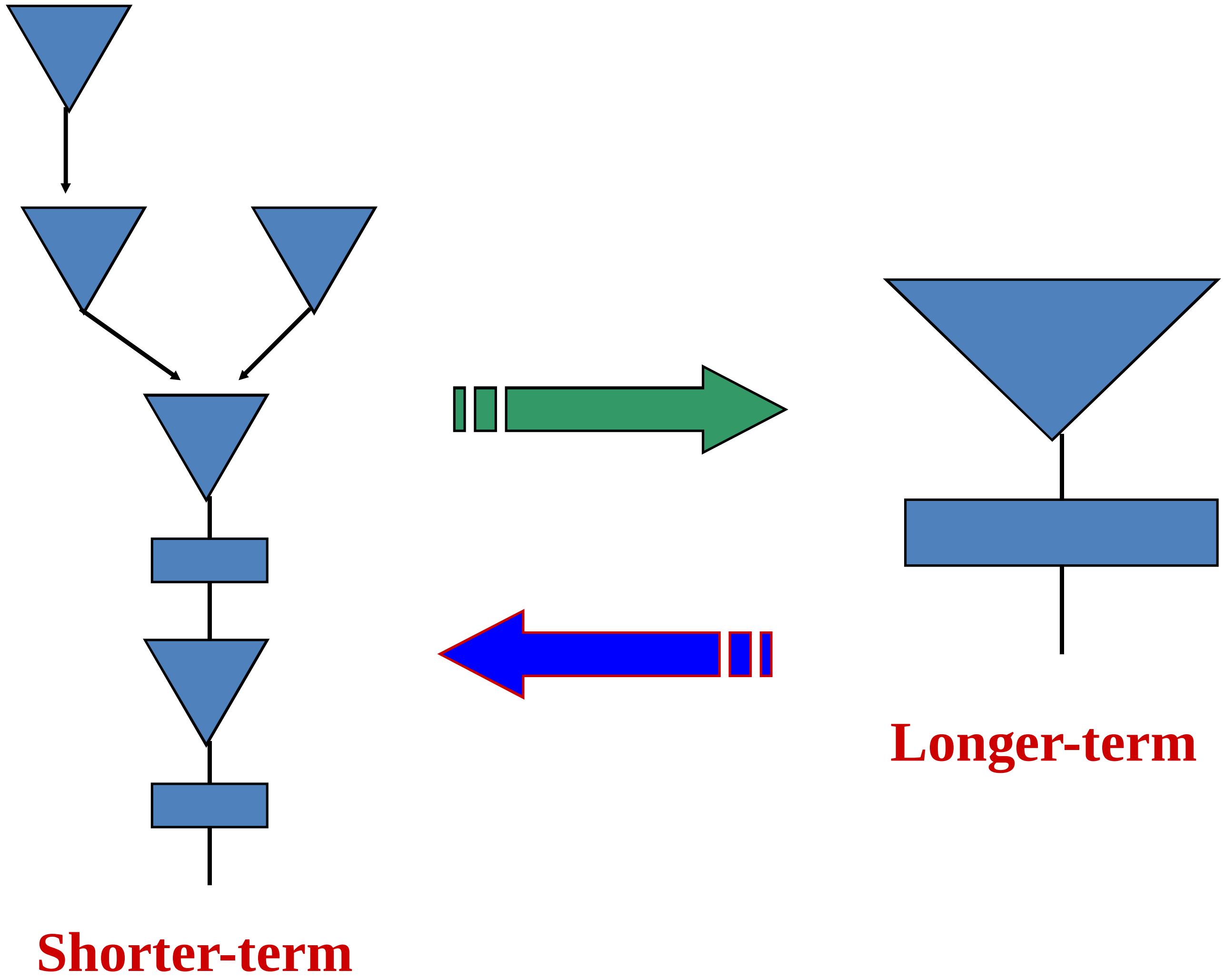


Coupling between models and planning levels

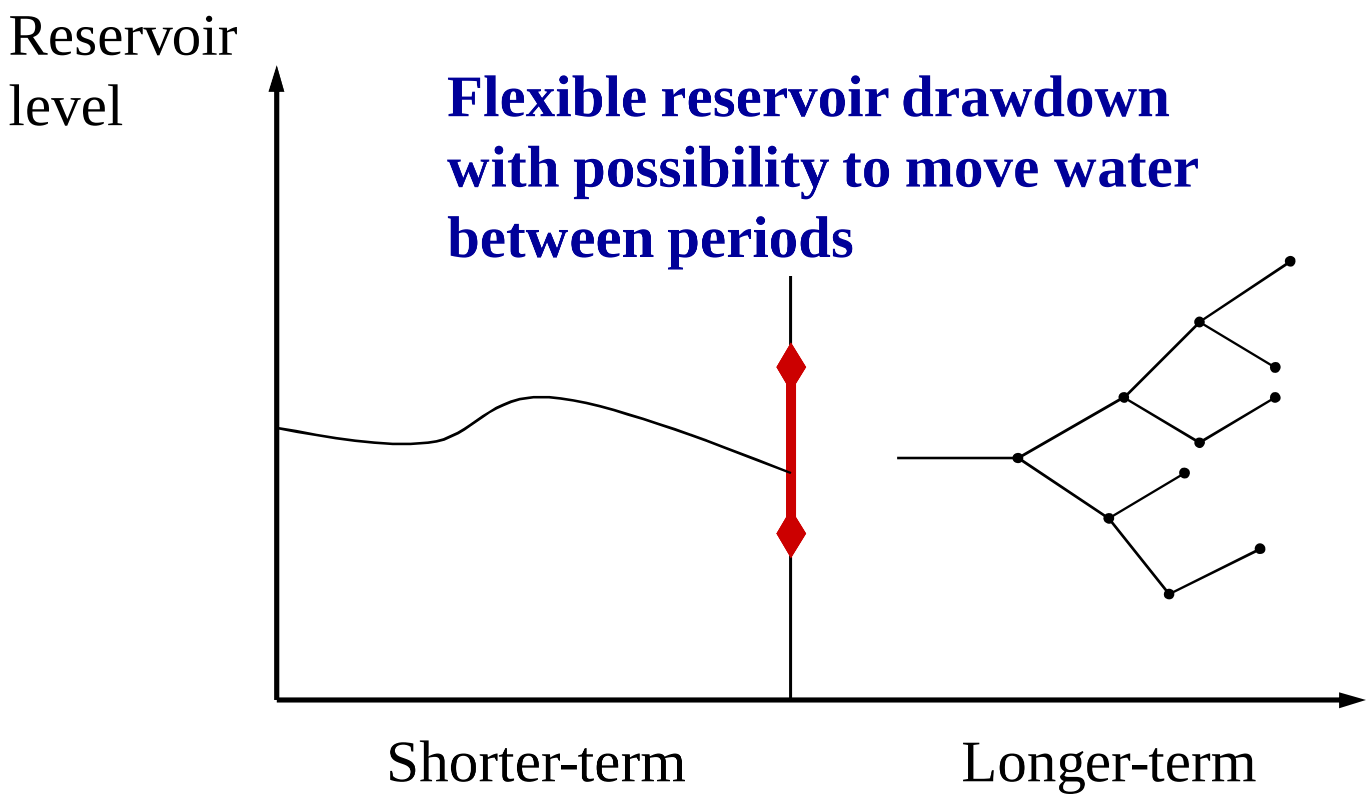
Coupling between planning levels

- Different models at different planning levels complicates the coupling and information flow
- The next level of analysis does not necessarily get input data of sufficient precision
- Aggregation / disaggregation challenges
- Coupling principles:
  - Price coupling (individual / aggregated)
  - Volume coupling

Aggregation / disaggregation challenges



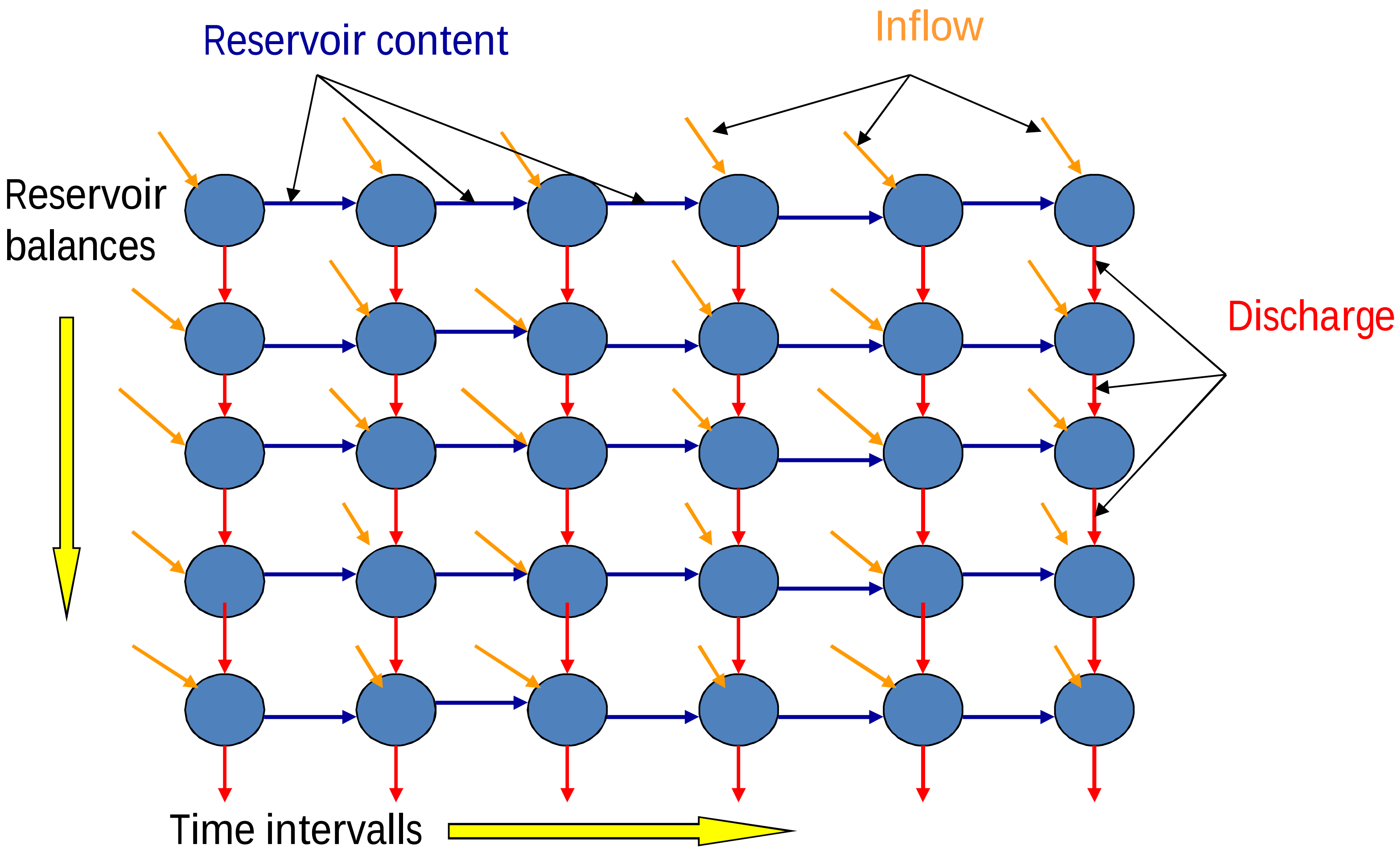
Coupling principle
Incremental water values



Puts certain requirements on the methods used in both periods

Short-term scheduling

Network formulation – short-term



Short-term hydro power optimization

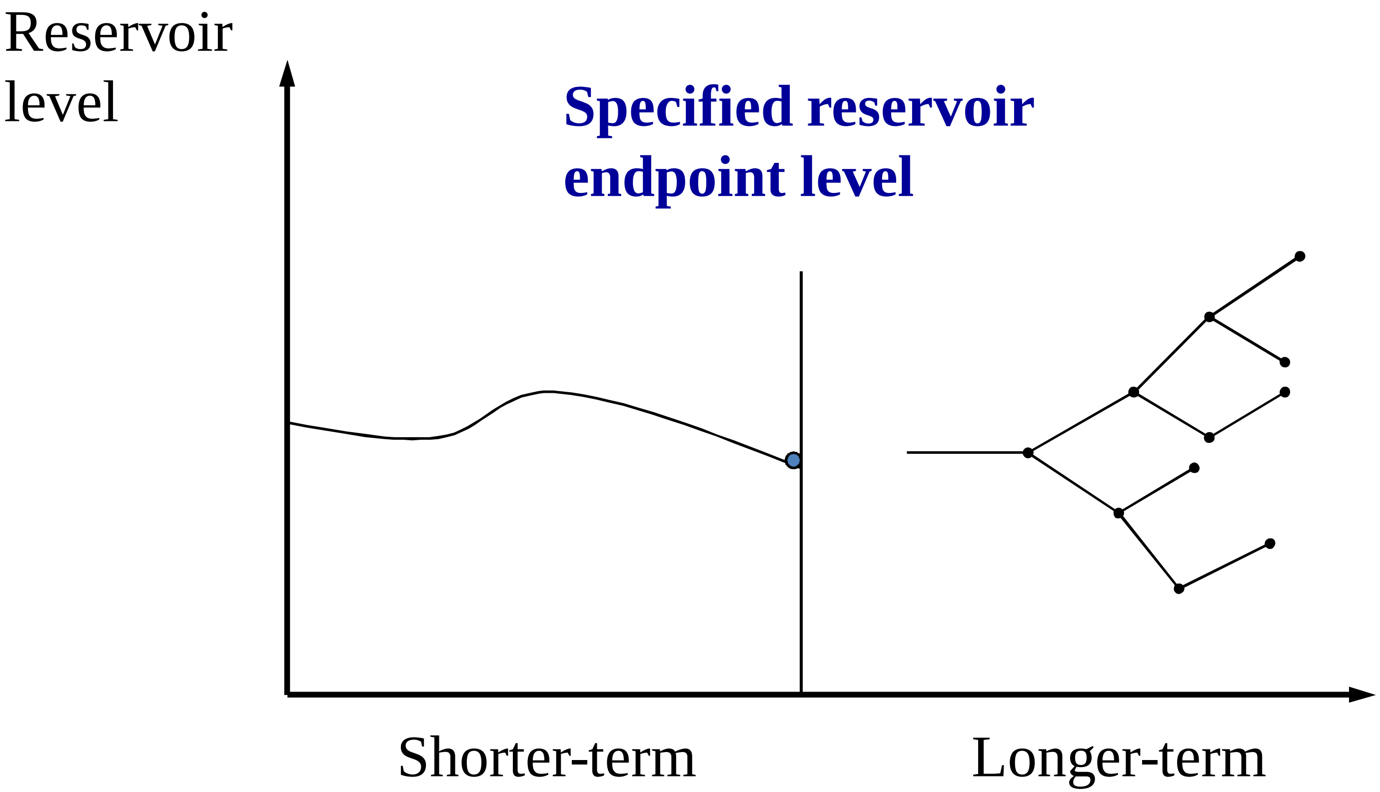
THANKS FOR YOUR ATTENTION

More information: http://www.ntnu.edu/energy

Linear programming

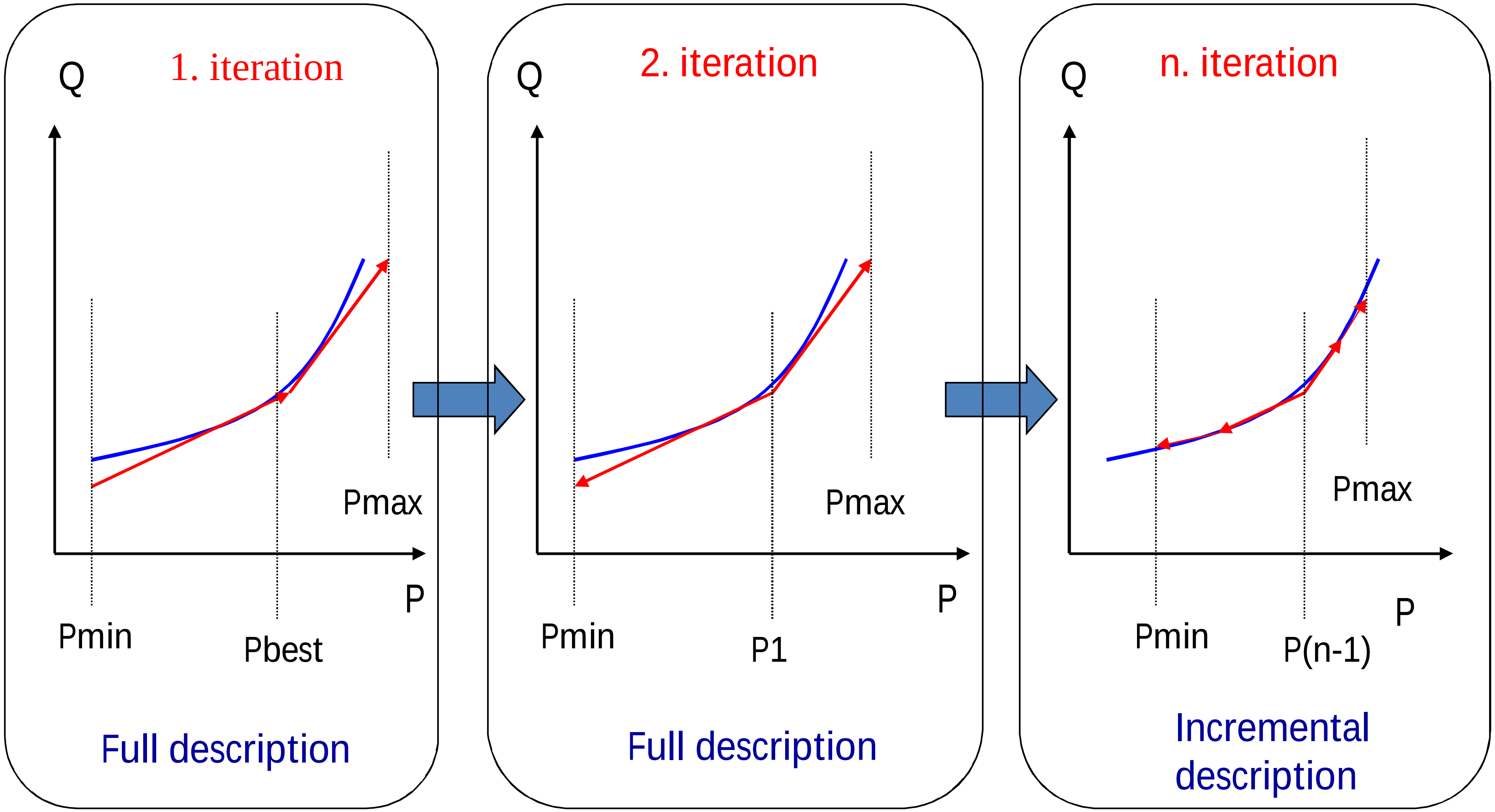
- Linear models are fundamental for most the modeling and simulation
- The experience shows that most of the physical problems can be solved by using linear models as building blocks
- Non-linearities can be handles by:
  - Piece-wise linear segments
  - Iteration for successive refinement
  - Integer variable and to check combinations
- Algorithms are available to solve very large problems fast

Coupling principle
Volume coupling

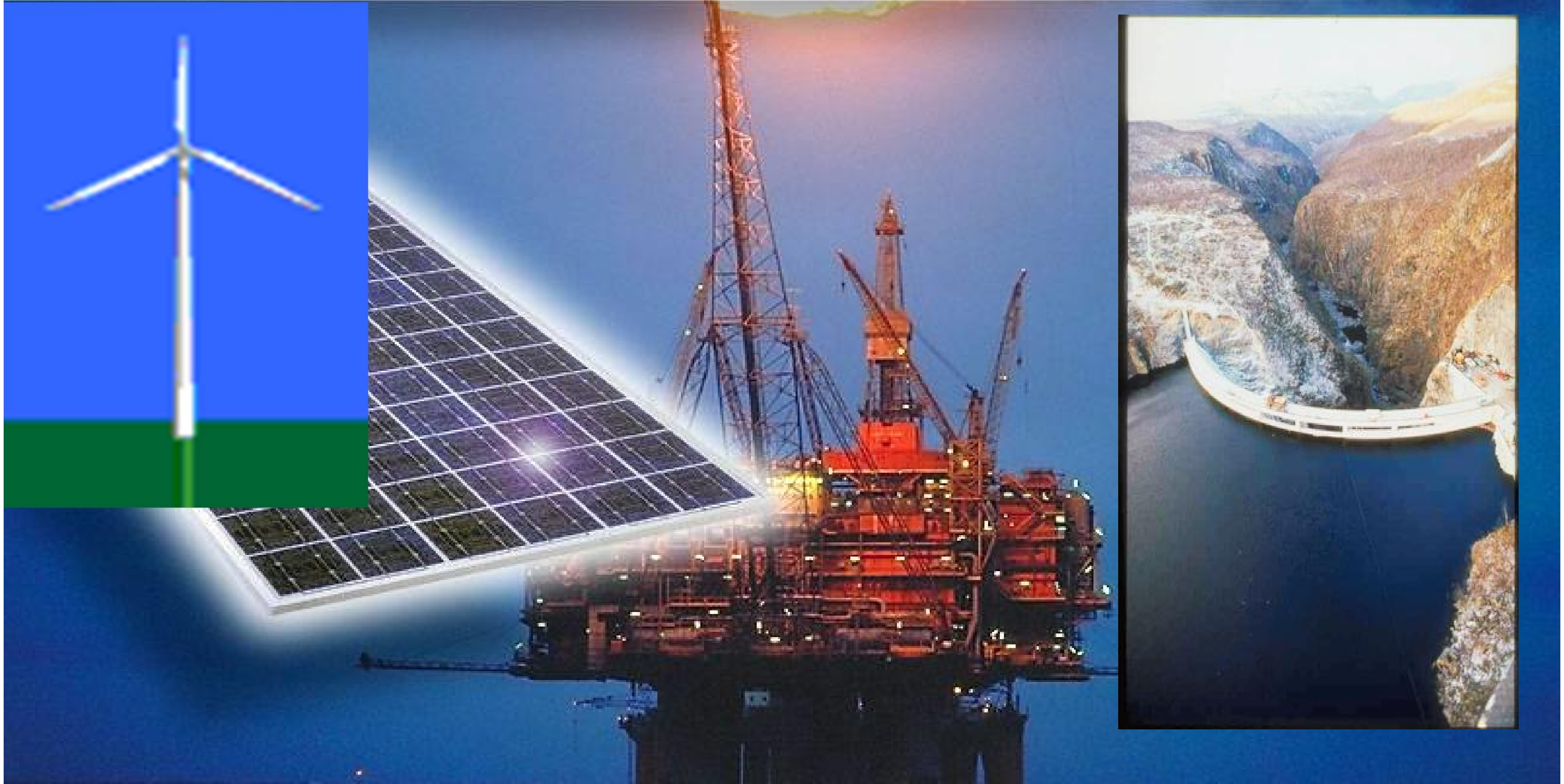


Less requirements to the methods used

Linearization

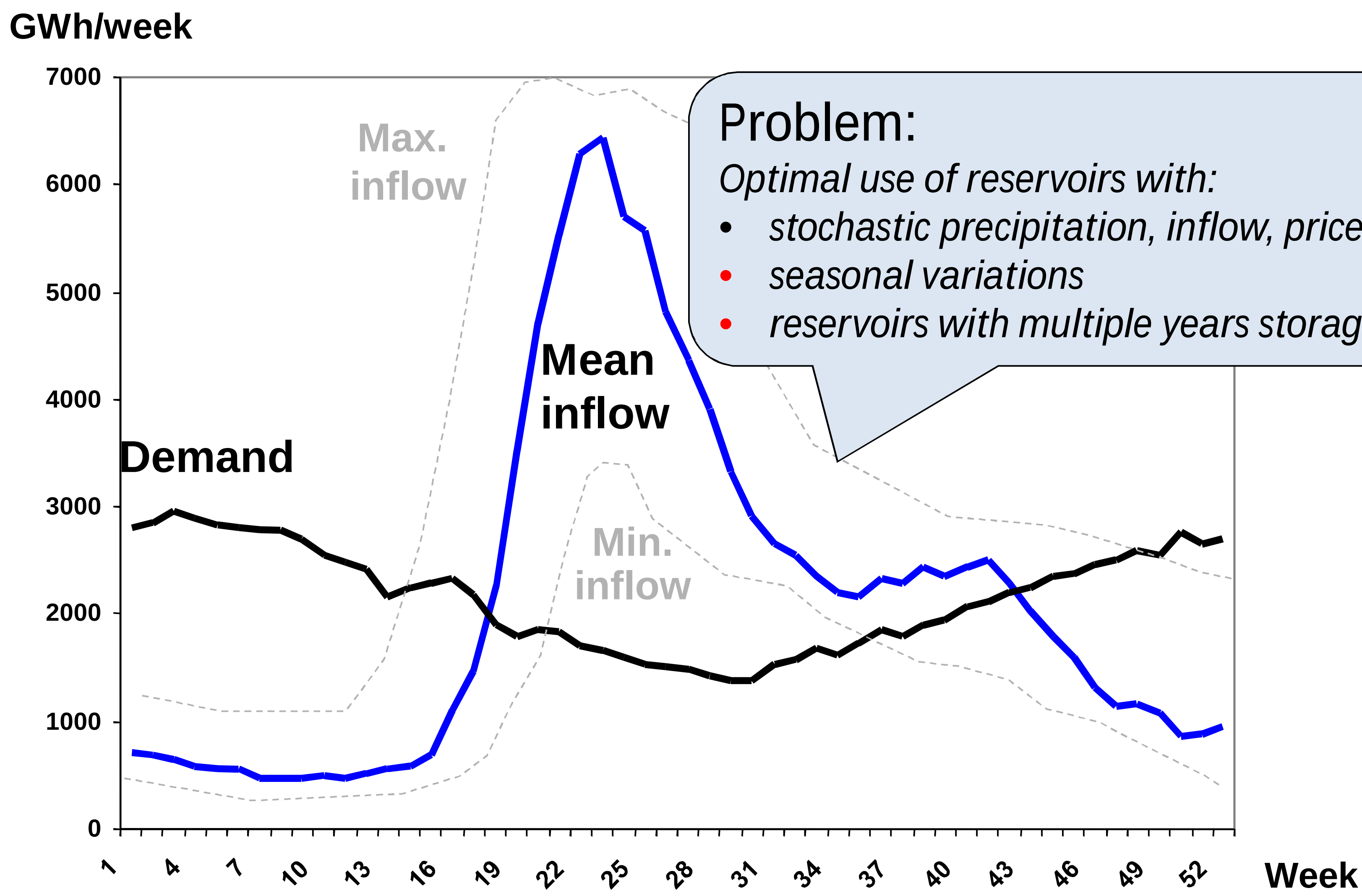


Norway - an energy nation…….



3 generations of energy development: Hydro Power, Petroleum, Renewables

Resource – demand profiles

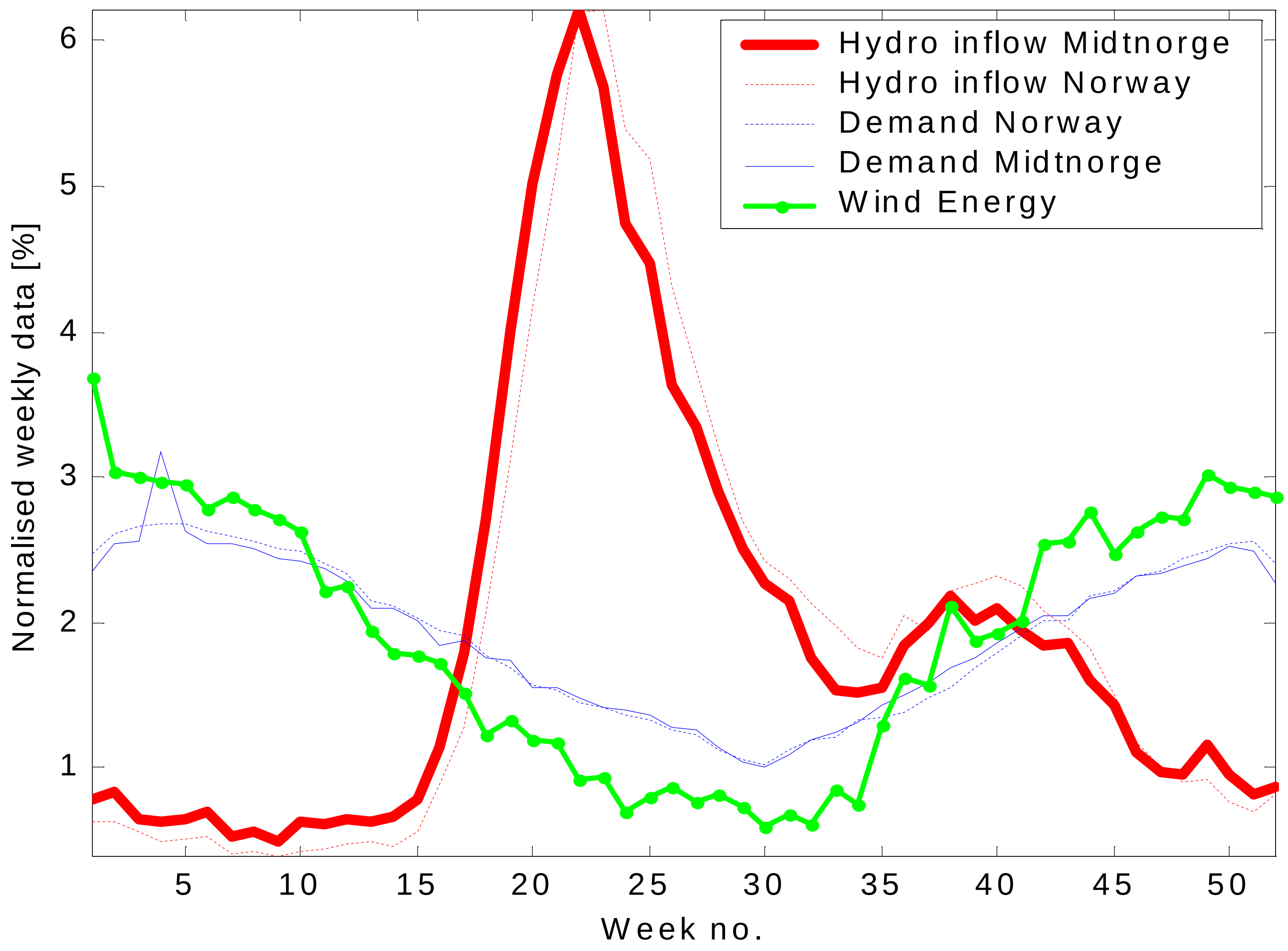


Problem:

Optimal use of reservoirs with:

- *stochastic precipitation, inflow, prices*
- *seasonal variations*
- *reservoirs with multiple years storage*

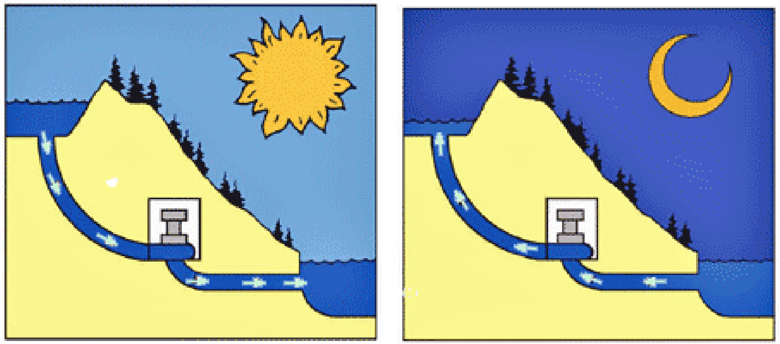
Complementarity: Wind Power / Hydro vs. Demand



Norwegian hydropower for balancing

- The reservoirs are natural lakes
  - Multi-year reservoirs
  - Largest lake stores 8 TWh
  - Total 84 TWh reservior capacity

- Balancing capacity estimates 2030
  - 29 GW installed at present
  - + 10 GW with larger tunnels and generators
  - + 20 GW pumped storage
  - 30 GW total new capacity
    - Within todays environmental limits
  - Requires more transmission capacity



Courtesy: Birger Mo / CEDREN

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Price difference between Norway and Germany – average week