Demonstration of Spine modelling tools through selected case studies

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9 September 2021
Spine project

- SPINE - Open source toolbox for modelling integrated energy systems
  
  - Project funded under the European Union’s Horizon 2020 research and innovation programme under grant agreement N. 774629
  
  - October 2017 – September 2021

http://www.spine-model.org/
https://github.com/Spine-project
Spine Webinars

**SpineOpt**
A flexible energy system modelling framework in Julia
7 Sep, 2021, 14:00-15:30 CEST

**Spine Toolbox**
Data, workflow and scenario management for modelling
8 Sep, 2021, 17:00-18:30 CEST

**Case Studies**
Demonstration of Spine modelling tools through selected case studies
9 Sep, 2021, 14:00-16:00 CEST

**SpineInterface**
Quickly and easily creating new optimization models in Julia
10 Sep, 2021, 14:00-15:30 CEST

In collaboration with

[EEERA](https://www.eera-station.eu/)
JP on Energy System Integration

In collaboration with

[GLOBAL PST CONSORTIUM](https://www.globalpstconsortium.eu/)

Register via [http://www.spine-model.org/spine_webinar.htm#2](http://www.spine-model.org/spine_webinar.htm#2)
Recordings will be available afterwards
Some housekeeping

- Webinar is being recorded and made available afterwards (link will be emailed)
- All your webcams are off and microphones are muted
- Questions can be raised during the presentations in the chat
  - Dependent on the question, these will be answered in the chat, or alternatively, during the Q&A afterwards
- During Q&A, you can “raise your hand”, then we will unmute you to raise your question, or alternatively, you can use the chat

Presenters: Manuel (KTH), Topi (VTT), and Maren (KUL)
Agenda

- 14:05 - Introduction to Spine
- 14:15 - Hydro
- 14:30 - Building heating
- 14:45 - Break
- 15:00 - Gas grid
- 15:15 - Stochastic
- 15:30 - Power grid investments
- 15:45 - Q&A
Introduction to Spine: System overview

**Spine Toolbox**
An application to manage data, scenarios and workflows for modelling and simulation (GUI)

**SpineOpt**
A highly adaptable model generator for multi-energy systems
Introduction to Spine: Spine Toolbox

Data Connection
Data in external format (e.g., CSV, Excel, Gdx, SQL)

Importer
Converts data from external format into Spine

Data Store
Data in Spine format

Tool
A model that receives some input and produces some output

e.g. SpineOpt

Data Store
(Output)

Exporter
Converts data from Spine into external format
Introduction to Spine: SpineOpt

Model
- holds general information about the optimization problem

Temporal block
- defines the model’s temporal resolution(s)

Stochastic structure
- defines the sequence(s) of the stochastic scenario(s)

Stochastic scenario
- defines the stochastic properties of a scenario

Node
- balances energy flows; may also represent a storage technology

Commodity
- (optional) used to assign a tradable good to energy flows e.g., electricity, heat, oil, gas, water, etc.

Connection
- represents transport flows between different nodes

Unit
- represents arbitrary conversion processes to and from nodes
Introduction to Spine: Live demo

**Power plant A**
capacity: 100 MWh
cost: 25 euro/fuel unit
generates 0.7 MWh of electricity per unit of fuel

**Power plant B**
capacity: 200 MWh
cost: 50 euro/fuel unit
generates 0.8 MWh of electricity per unit of fuel

**Fuel**
Infinite supply

**Demand**
150 MWh
Hydro: Objective

Model one week of operation of the Skellefte river in the Swedish hydropower system.
Hydro: Inputs and assumptions

What we know

❖ For each of the 15 stations
  ➢ Capacity of the turbine
  ➢ Conversion ratio from water to electricity
  ➢ Initial, final, and maximum reservoir level
  ➢ Minimum water discharge and spillage per hour
  ➢ Downstream station and time to reach it, both for spillage and discharge branches
  ➢ Local inflow per hour
  ➢ Average water discharge per hour
❖ Electricity prices during the week

What we assume

❖ The system is operated to maximize profit from electricity production over the week
❖ All power plants have been discharging the average amount of water before the beginning of the week
Hydro: Implementation

Entrance to the station

Entrance to the downstream station

Spilled water

Connection delay

Fixed connection flow

Unit capacity

Has state (reservoir)

Fix node state (fixed reservoir levels)

Demand (negative local inflow)

Discharged water

Electricity

Vom cost (negative electricity price)

Fix ratio out in unit flow (conversion ratio)

Connection delay

Fix connection flow (fixed water discharge)
Hydro: Results*

a) Electricity production over the week.

b) Reservoir levels for the three largest stations.

Hydro: Live demo
Building heating: Motivation

- Heating and cooling of the built environment accounts for almost 40% of the final energy demand in the EU.
  - Electrification of heating/cooling has a lot of demand response potential!
- **Objective:** Demonstrate that flexible heating/cooling demand can be co-optimized alongside the power and district heating systems using SpineOpt.
Building heating: Modelled system

- A very simple model of the Finnish power/district heating systems.
- A simple model of the heating/cooling demand of the electrically heated Finnish detached housing stock.
- One year long rolling horizon optimization with an hourly time resolution.
Building heating: Implementation

- Spine Toolbox workflows were implemented for both SpineOpt and Backbone for comparing the results.
Building heating: Buildings-only results

- Performance of the SpineOpt model for the electrically heated Finnish detached housing stock practically identical to our previous simulations with Backbone.

Electricity consumption of modelled space heating equipment in Northern Finland in MW

![Unit input comparison graph]

NMAE=7.411255721432752e-5

![Model cumulative objective comparison graph]

NMAE=7.651645212441854e-5
Building heating: Combined model results

- Performance diverges somewhat for the full-year co-optimization with the power and district heating systems.
  - However, impact on the objective function value is minor.
Building heating: Conclusions

- SpineOpt can handle simple lumped-capacitance thermal models of buildings.
- **Heating and cooling sector can be co-optimized with the power system!**
Break time!
Gas Grid: Motivation and Objective

**Motivation**
- Increasing shares of variable renewable energy sources
- Gas plants useful as flexibility options to ensure system reliability
- Ability to study cross-sectoral interactions
- Analyse the potential of the linepacks, i.e. storage ability of pipelines

**Goal of this Case study**
1. Co-optimize the operation of the power and gas dispatch including DC power flow equations and pressure-driven gas transfer
2. Validate and compare results
Gas Grid: Modelled system

Scope

- 24 hours of operation of a co-optimized power and gas system
- 12 natural gas nodes, 24 electricity nodes
- Reference:


# Gas Grid: Input data & Assumptions

## Gas system input

Gas pipelines:
- Initial linepack
- Compression factor

Gas nodes:
- Min-/max pressure
- Demand

## Assumptions
- Isothermal gas flow
- Constant compression factor of compressor stations
- Outer approximation of Weymouth equation (describes the pressure dependent steady-state gasflow) around fixed pressure points

## Gas-fired power plants:

**Units**
- Capacity
- Conversion factor Gas/Electricity

## Electricity system input

Transmission lines:
- Capacity
- Min/max voltage angle
- Line susceptance

**Units:**
- Capacity
- Wind availability factor
- Fuel costs

Electricity nodes:
- Electricity demand

## Assumptions
- Lossless DC model
Gas Grid: Implementation

Gas network
Gas Grid: Implementation

Gas network

Electricity network
Gas Grid: Implementation

Gas network  Gas-fired power plants  Electricity network
Gas Grid: Results and Conclusion

1. Co-optimize the operation of the power and gas dispatch including DC power flow equations and pressure-driven gas transfer

1. Validate and compare results
   - In comparison to the literature, objective function values coincide and the linepack flexibility is reproducible
Stochastic: Motivation

SpineOpt can handle different stochastic structures on different parts of the model, so let’s try and use that!

Simple two-stage stochastic problem:

- A company owns four hydro power plants and trades electricity on the market
- Electricity prices are uncertain, but 4 scenarios are equally probable
- The company has a very accurate forecast of the electricity prices for the next 6 hours
- The company is offered a bilateral contract to sell a fixed amount of electricity during hours 2 to 5
- Objective: maximize the income of sold electricity plus the value of stored water
  - In the first stage, decide whether to accept or reject the bilateral contract
  - In the second stage, determine trades and operation of the power plants
# Stochastic: Inputs

![Power plant locations](image)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Hour</th>
<th>Future</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>2</td>
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<td>430</td>
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<tr>
<td>4</td>
<td>407</td>
<td>641</td>
</tr>
</tbody>
</table>

Forecast of electricity prices (*/MWh)
Stochastic: Implementation
Stochastic: Implementation
Stochastic: Implementation
Stochastic: Implementation
Stochastic: Implementation
Stochastic: Results

- Fallet reservoir level
- Forsen reservoir level
Stochastic: Results

Strömen reservoir level

Selle reservoir level
Stochastic: Live demo
Power grid investments: Motivation

Build a long-term power grid investment model of the Nordic system that captures as much operational detail as possible, while remaining computationally tractable.

- Take data from the N490 model of the Nordic synchronous power grid system (Norway, Sweden, Denmark, and Finland).
- Use parallel scenario execution in Spine Toolbox.
- Use Benders’ decomposition to solve the optimisation problem in SpineOpt.
Power grid investments: Implementation

- Run SpineOpt with N490 data to compute line flows
- Compare line flows with line capacities to assess congestion
- Select most congested lines as candidates for investment
- Run SpineOpt again to determine investment decisions
Power grid investments: Implementation

- **Import N490 data into a SpineOpt DB (including the template)**
- **Run SpineOpt with operation & investment data**
- **Import N490 data (with line capacities), wind scenarios, and candidate lines into a SpineOpt DB**
- **Use results from operation run to select candidate lines**
Power grid investments: Results

The N490 model ported into Spine, with nodes in blue, generating units in red, and connections in green.*

* Not the actual node geographical locations
Power grid investments: Results

The N490 model with candidate connections in dark yellow, computed as the 100 most “congested” connections from the operation run.
Power grid investments: Results

The N490 model with the 14 invested connections in pink, as determined by the investment run. The model converges after two Benders iterations, about 6 hours of wall time.
Power grid investments: Conclusions and future work

Conclusions
▪ Spine Toolbox and SpineOpt can be effectively used to model long-term investment problems with high operational detail
▪ Benders’ decomposition and parallel scenario execution help to improve tractability

Future work
▪ Improve methodology to select candidate lines
▪ Use representative periods
▪ Model hydro generators more accurately
▪ Combine with hydropower model
▪ Consider investment costs and lifetime
Question time?
This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N. 774629.