OPTIMISATION OF A MULTI-ENERGY SYSTEM WITH HYDROGEN PRODUCER AND CONSUMER

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CLIMATE CHANGE IS FORCING THE WORLD TO SPEED UP EFFORTS FOR DRASTIC GLOBAL CO2 EMISSION REDUCTION

The effects of climate change can today be seen globally. Record floods, forest fires and droughts are in the news almost every week.

Now governments have set ambitious CO2 reduction targets – some of which already need to be fulfilled within the next decade.

The technology race has begun – but how can companies decide on the best system architecture with so many options for clean energy production, conversion and storage available?

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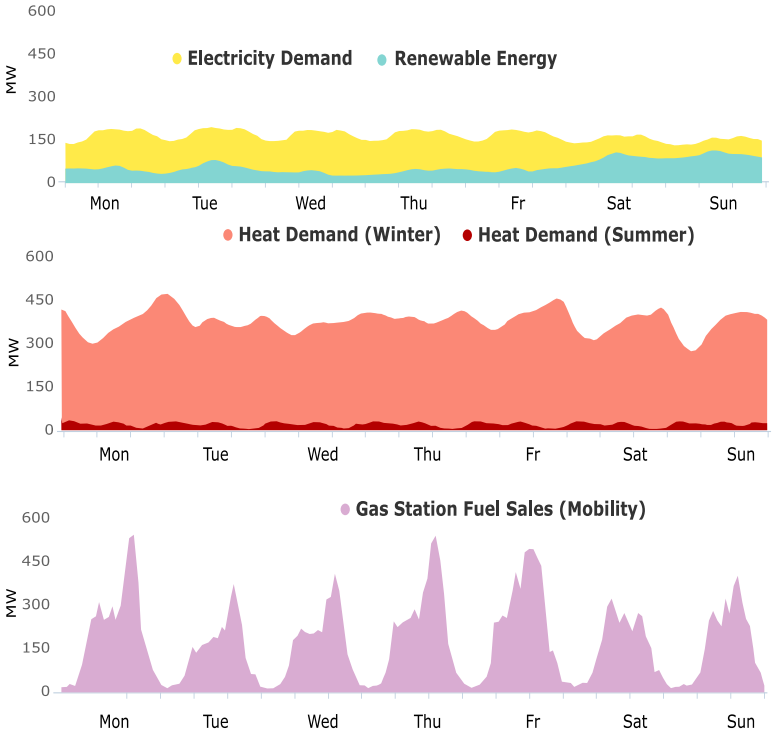
WHY SECTOR COUPLING?

Past Energy Market in northern European city (2015)



- Traditional market for electricity, heat and mobility
- Relatively simple technology
- Little interaction between the different supply sectors
- Reliable, cheap and convenient
- But: High amount of greenhouse gas emissions and consumption of resources
- **Future: Increasing (fluctuating) renewable energy and elimination of fossil-based energy sources makes use of novel energy storage solutions essential - but which one is right for my infrastructure?**

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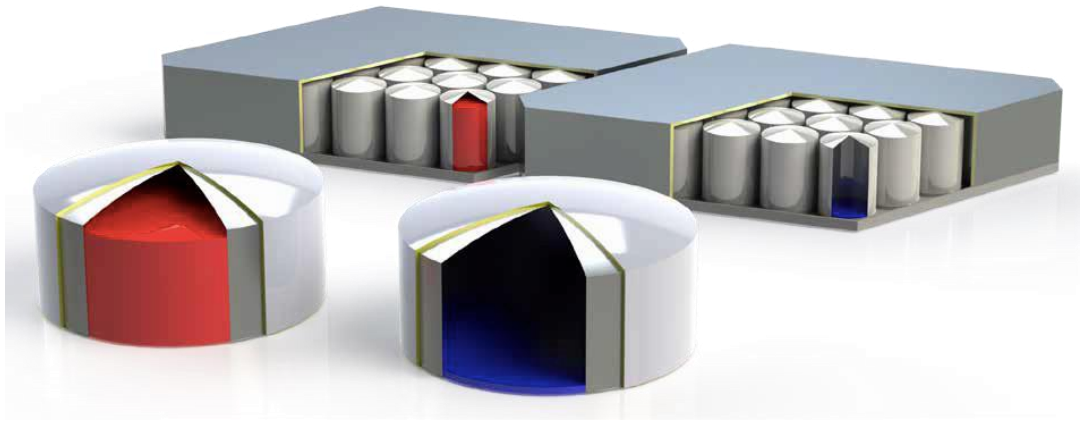
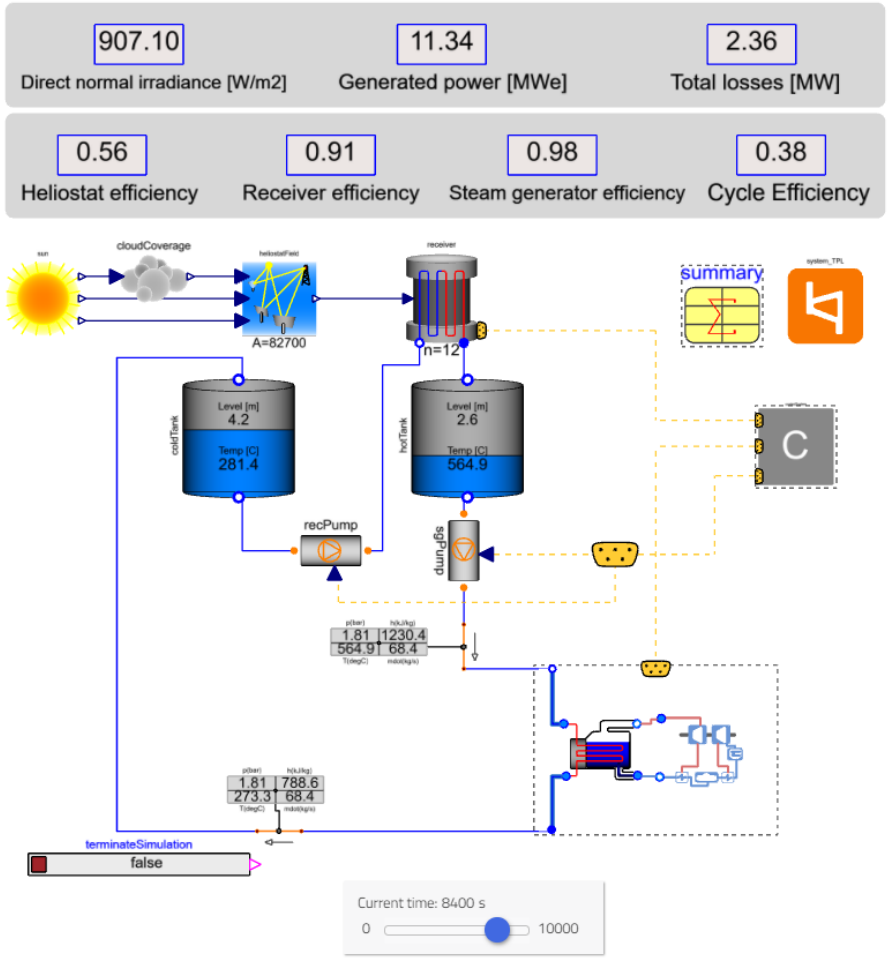
TECHNOLOGY OPTIONS FOR ENERGY STORAGE WITH KPI

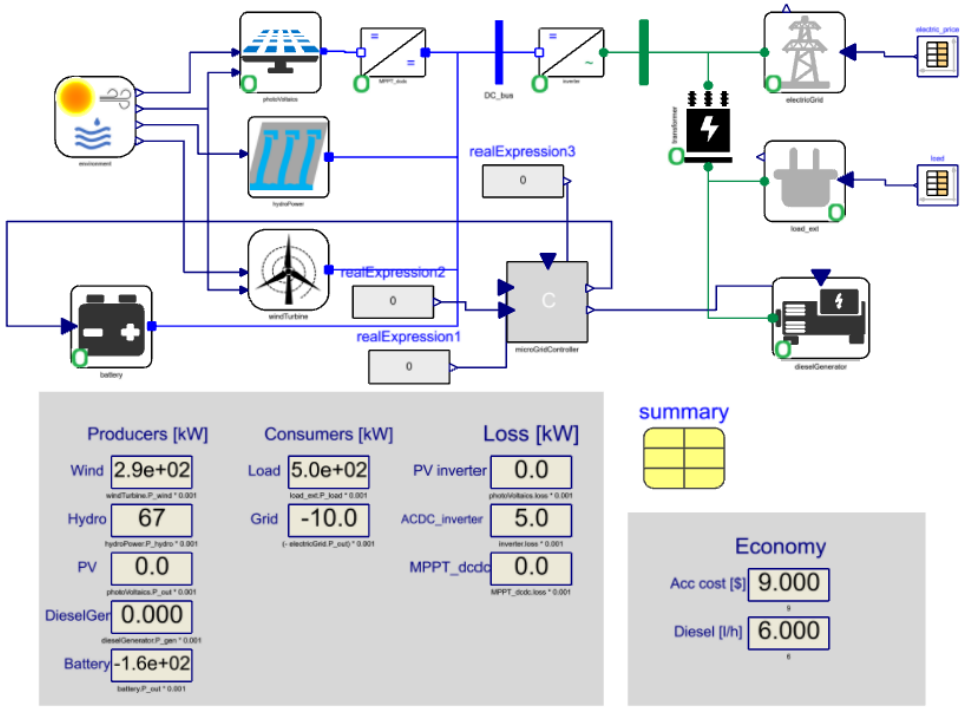
- TES:
  - Efficiency: medium
  - Cost: low
  - Capacity: large
  - Sector-Coupling: Electricity, Heat





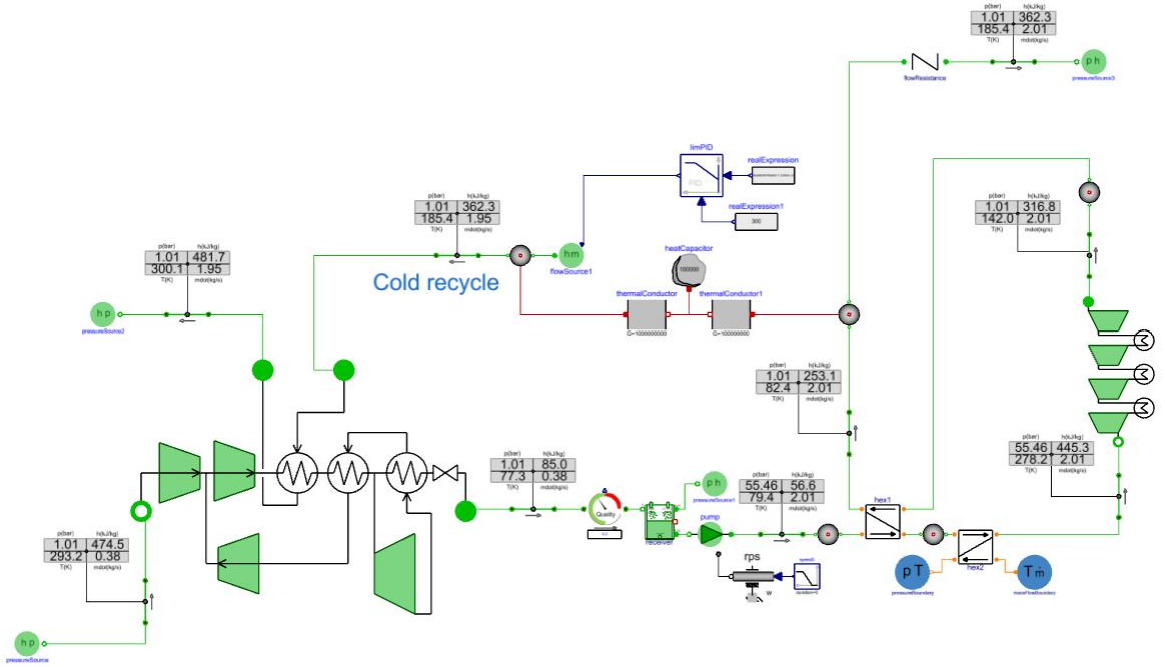
TECHNOLOGY OPTIONS FOR ENERGY STORAGE WITH KPI

- Conventional Battery:
  - Efficiency: high
  - Cost: medium
  - Capacity: small
  - Sector-Coupling: Electricity + Mobility



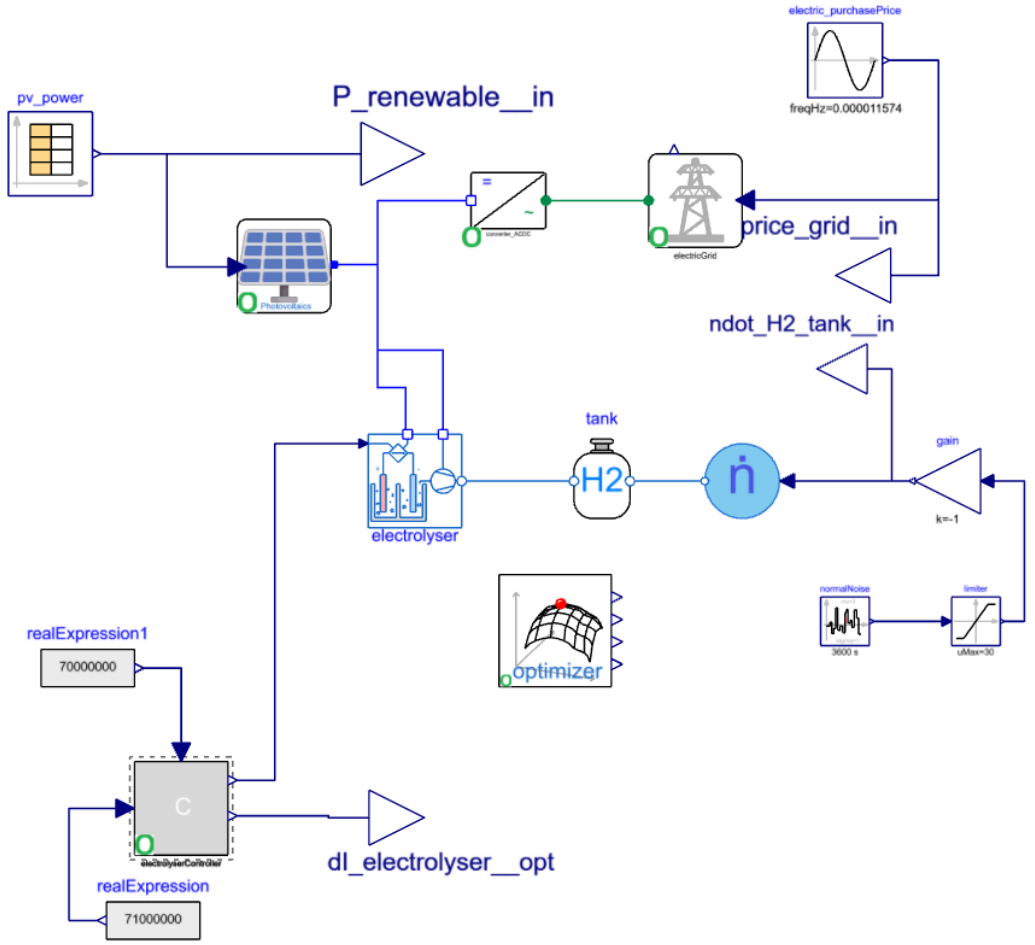
TECHNOLOGY OPTIONS FOR ENERGY STORAGE WITH KPI

- LAES:
  - Efficiency: high
  - Cost: high
  - Capacity: medium
  - Sector-Coupling: Electricity, Cooling



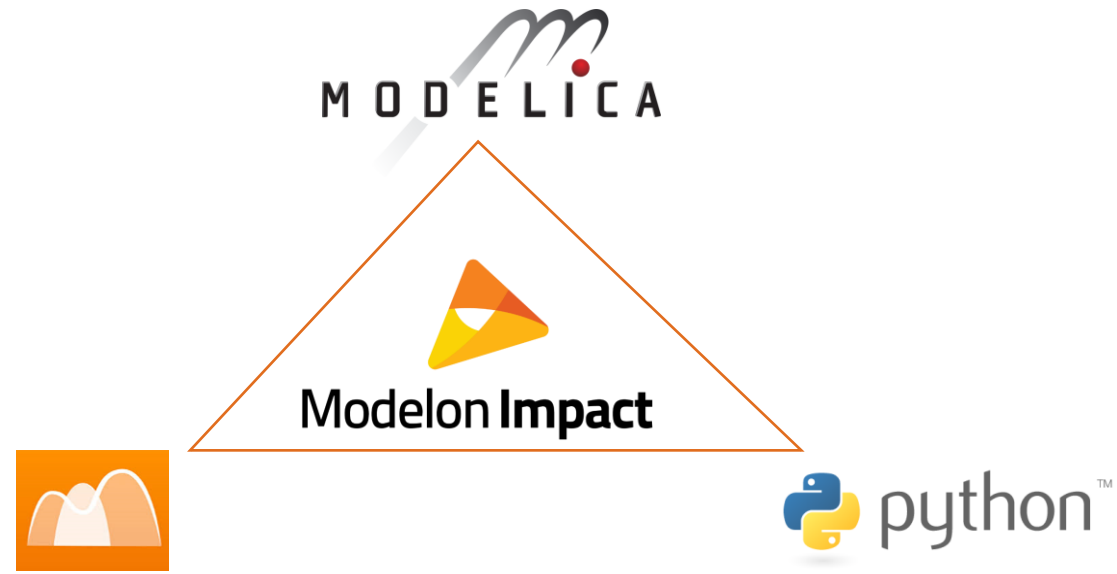
TECHNOLOGY OPTIONS FOR ENERGY STORAGE WITH KPI

- Hydrogen production and storage:
  - Efficiency: medium
  - Cost: high
  - Capacity: large
  - Sector-Coupling: Electricity, Mobility, Heat



PROPOSED APPROACH

Challenge: complex components in complex system → Dynamic optimisation for design and operation



1. Write models in Modelica
2. Add optimization information in Optimica
   - A small extension of Modelica for optimization
   - Allows to add optimization information:
   - Cost function
   - Additional constraints
   - Parameters to optimize – including time horizon length
   - Initial guesses
3. Work with optimization problems from Python

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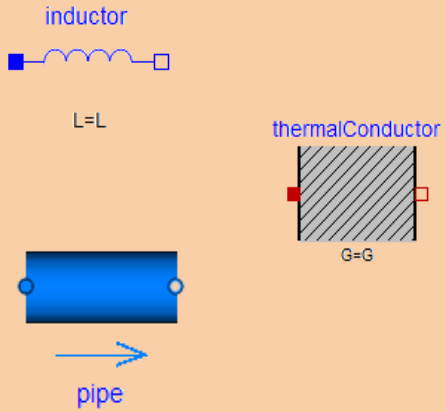
KEY MODELICA CONCEPTS

https://modelica.org/

Physical modeling language

- Physics-based equation modeling
- Connectors pass physical information
- Coverage of all physical domains
- Accurate bookkeeping of variable types and units

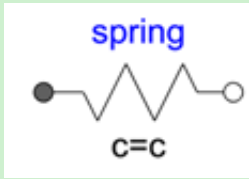


An equivalent graphical and code interface

- Build systems rapidly from graphical components (through drag & drop or templates)
- Look at the code and change to your needs
- Documentation embedded in models

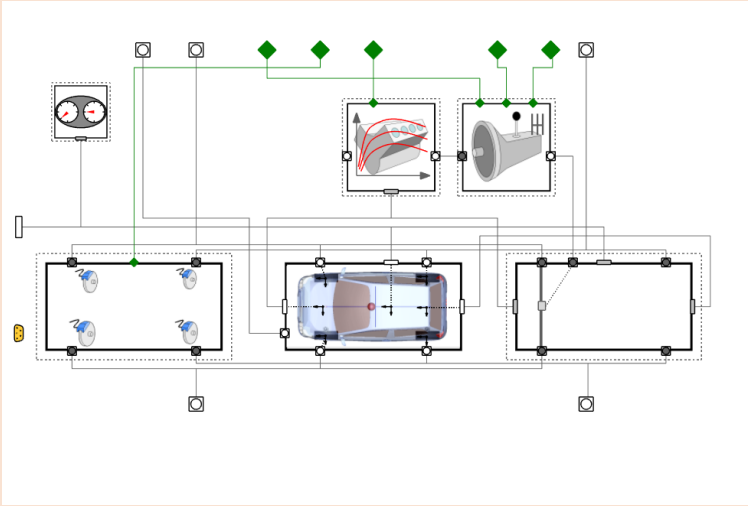
```
model Spring "Linear 1D rotational spring"
  extends Modelica.Mechanics.Rotational.Interfaces.PartialCompliant;
  parameter SI.RotationalSpringConstant c(final min=0, start=1.0e5)
    "Spring constant";
  parameter SI.Angle phi_rel0=0 "Unstretched spring angle";

equation
  tau = c*(phi_rel - phi_rel0);
  annotation (
    Documentation(info="<html>
```



Efficient modeling

- Separation of models and algorithms
- A-causality
- **Architecture based modelling** for handing different levels of fidelity and variants.



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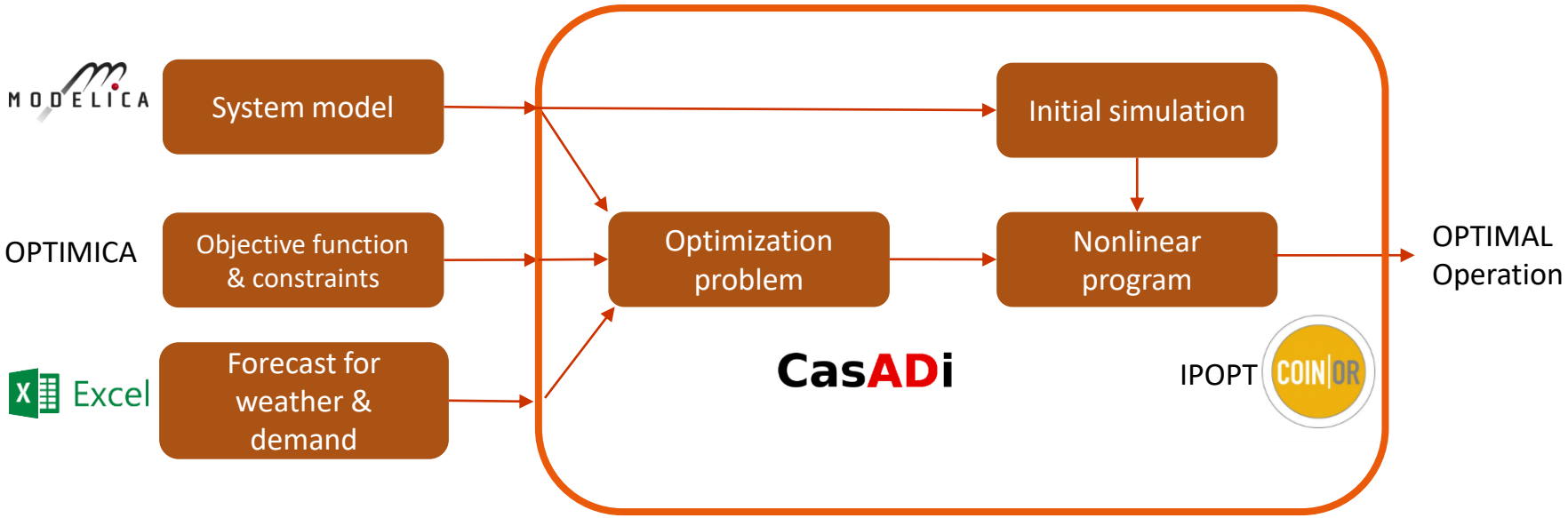
DYNAMIC OPTIMIZATION APPROACH



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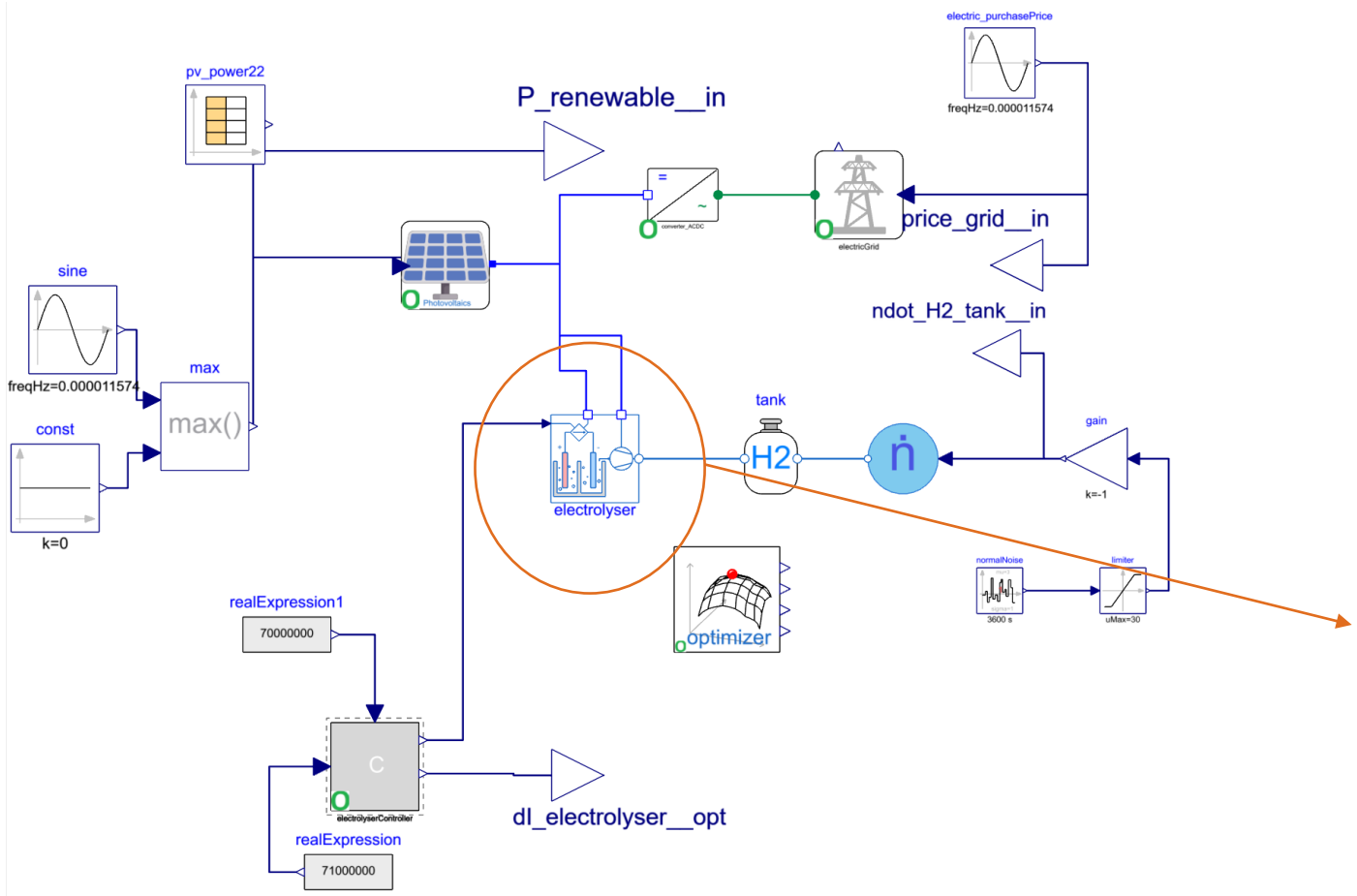
MULTI-ENERGY SYSTEM MODEL FOR USE-CASE



- Including Renewables, Grid, Hydrogen Electrolyzer, Hydrogen Storage, Consumption
- Optimal operation and general design
- Variable renewable input, electricity price, hydrogen demand
- Goal: economic dispatch
- Missing: Low-Fidelity Electrolyser model

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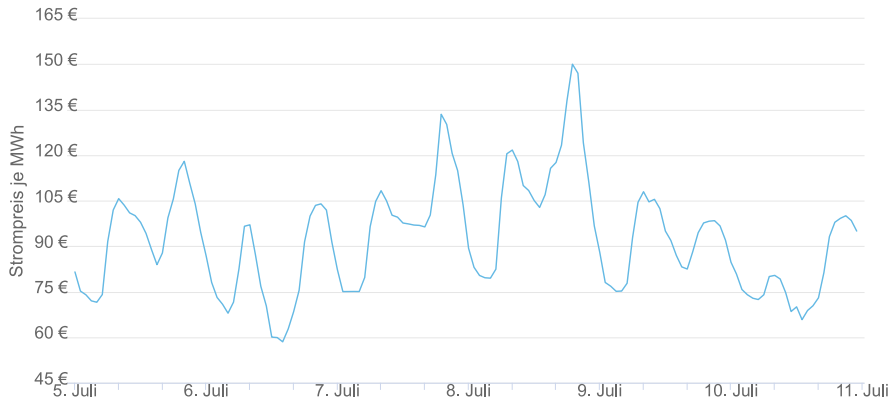
USE-CASE FOR HYDROGEN – OVERVIEW

- Electricity grid connection with fixed or variable electricity price (Germany, July 2021)



- Different types of renewables
  A. Wind, Load profile: long-term fluctuations
  B. Solar, Load profile: periodic
  C. Biomass, Load profile: constant
- Prescribed hydrogen consumers demand (e.g. for mobility, process or heat):
  - 118 MWh with a fixed demand curve
  - Pressurized Hydrogen storage tank, 50m3, maximum pressure 810bar
- Question: how does the type of RES affect the profitability (OPEX) of the sector coupled hydrogen system?

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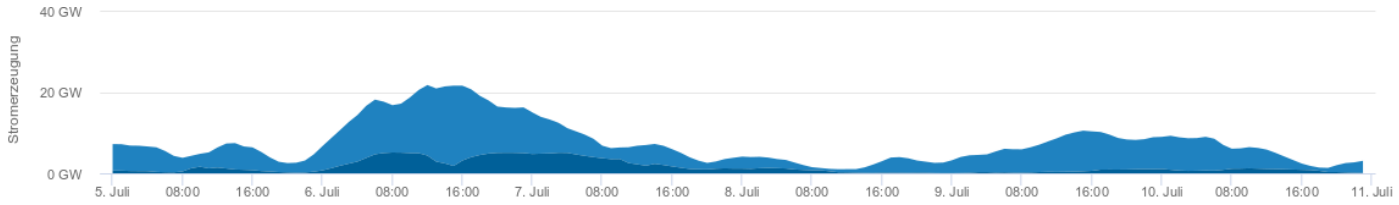
CHARACTERISTICS OF DIFFERENT RENEWABLES

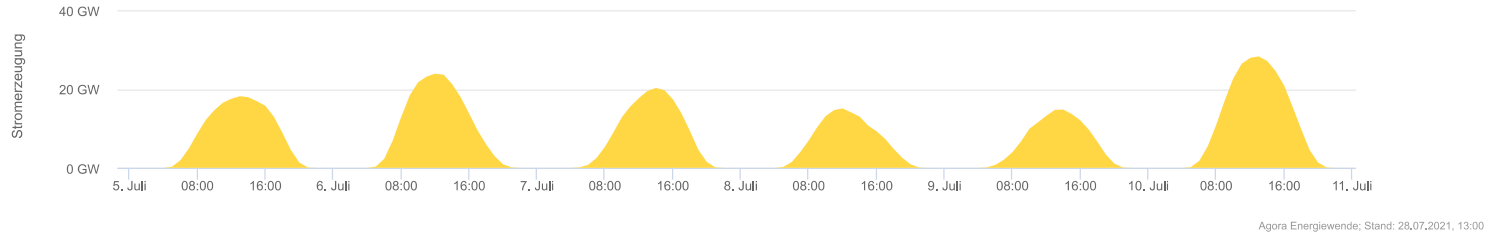
- System 1: RES from Wind



Wind profile:
- Intermittent
- Irregular
- Longer high and low periods (up to 2 weeks)
- Seasonal

*Data from Germany, July 2021, scaled to total energy of 56 MWh

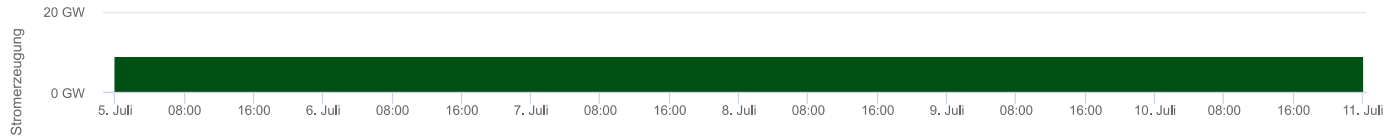
- System 2: RES from Solar



Solar profile:
- Regular
- 24h period
- Seasonal

*Data from Germany, July 2021, scaled to total energy of 56 MWh

- System 3: RES from Biomass



Typical biomass profile:
- Constant

*Data assumed to be constant, scaled to total energy of 56 MWh

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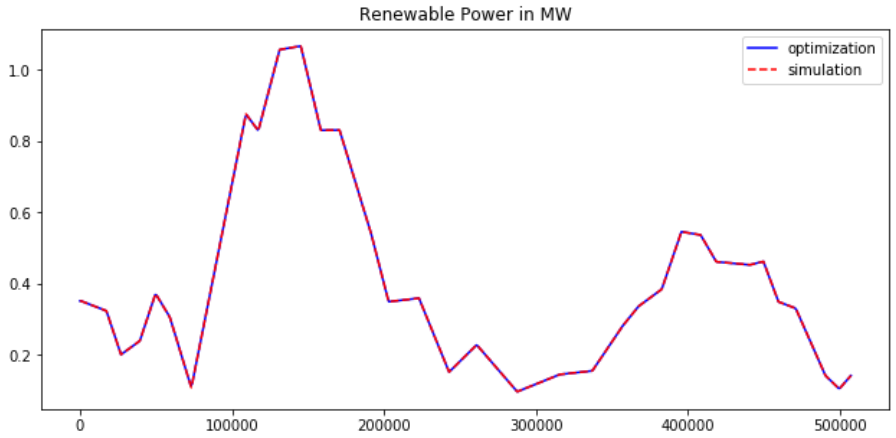
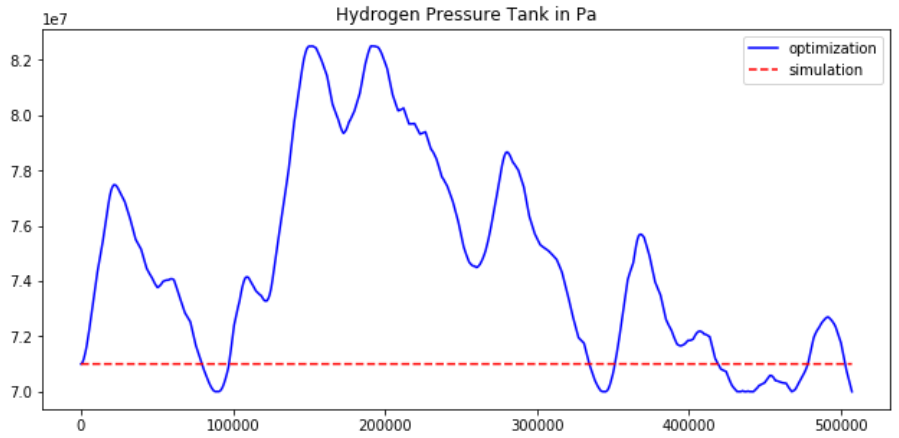
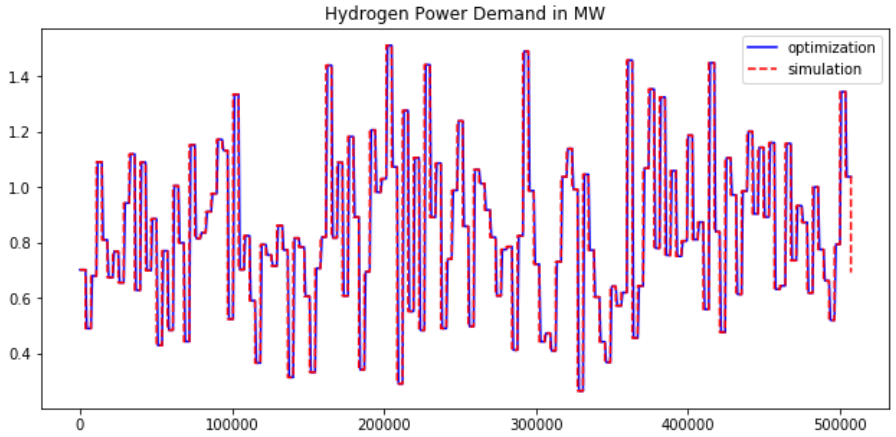
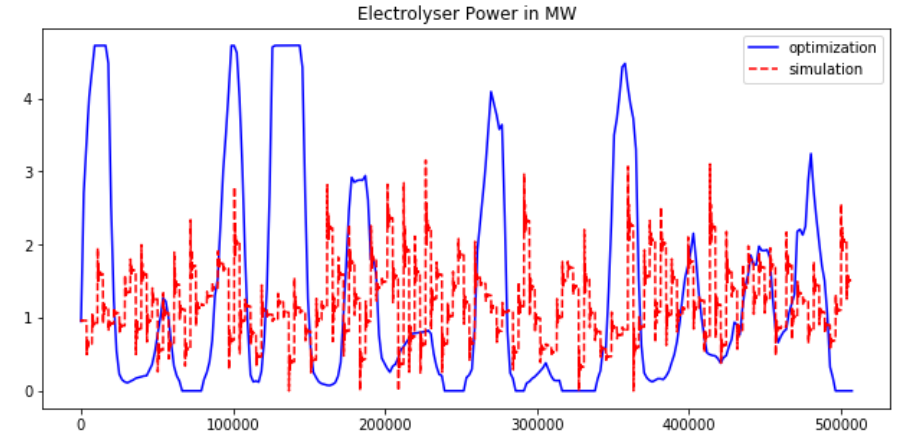
RESULTS – WIND SYSTEM









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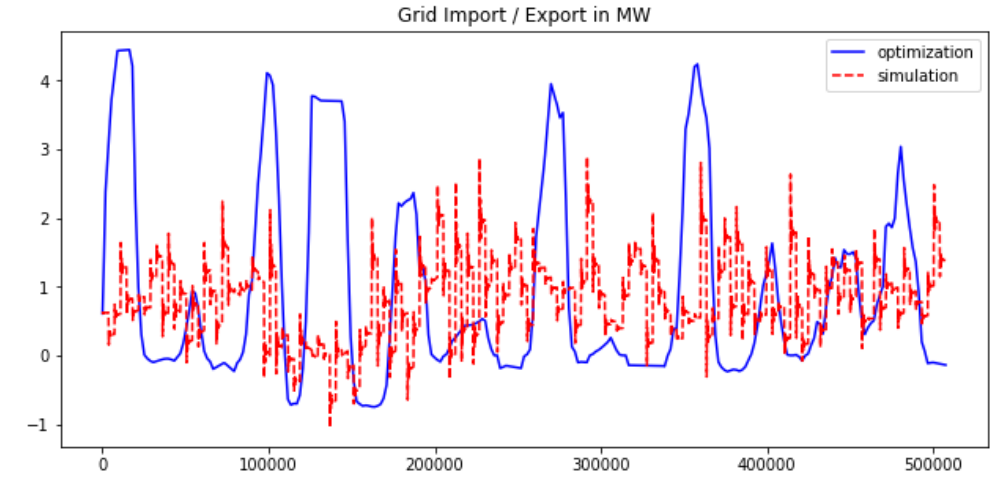
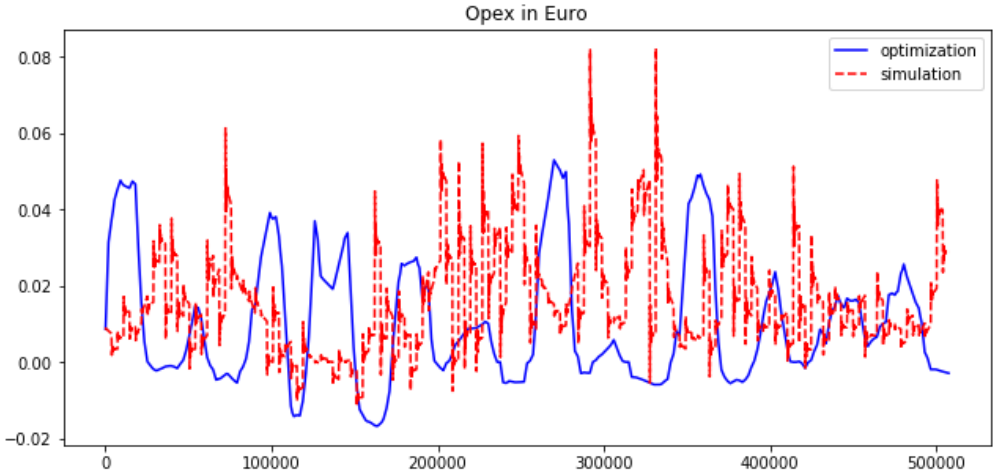
RESULTS – WIND SYSTEM





- Characteristics of wind profile requires full storage usage for an optimal operation.
- OPEX:
  - Simulation: 7947 €
  - Optimization: 5108 €

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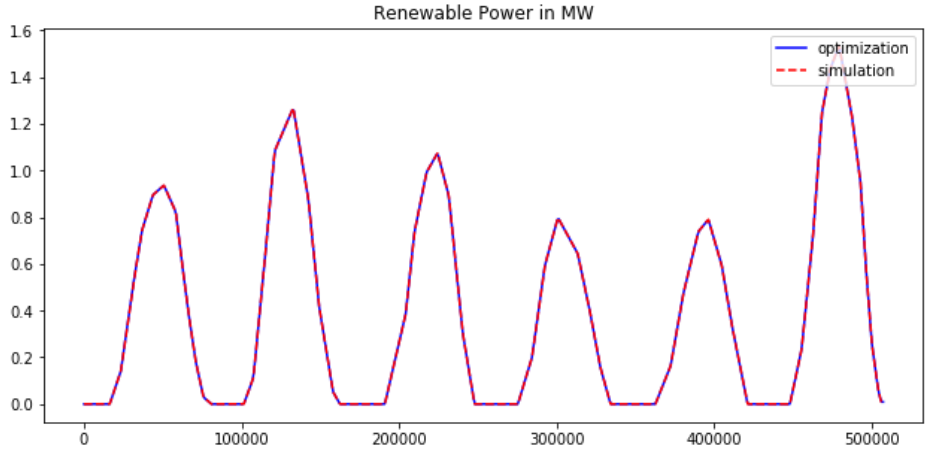
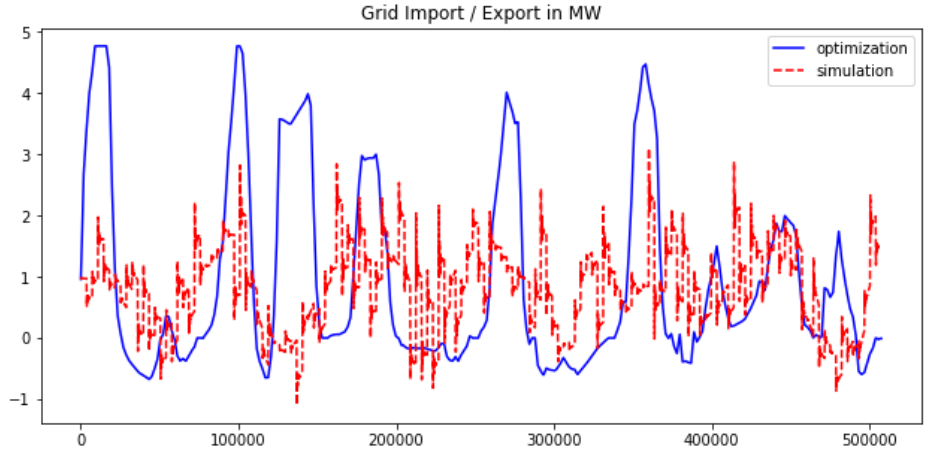
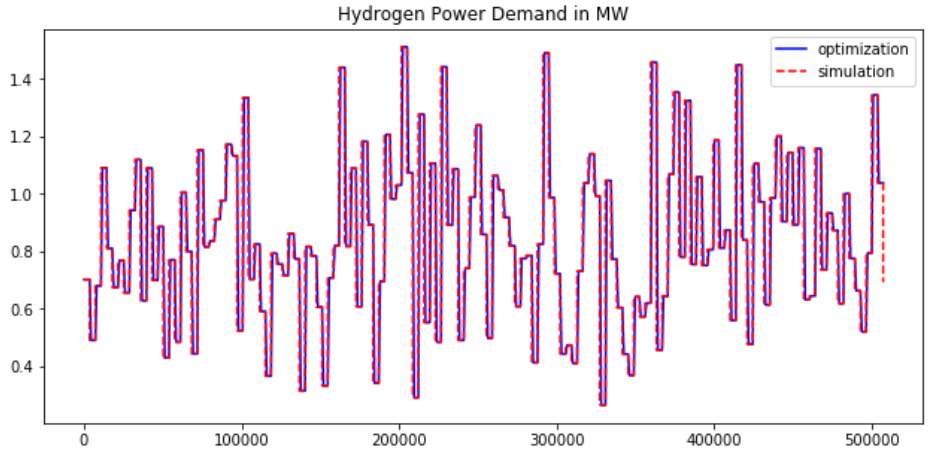
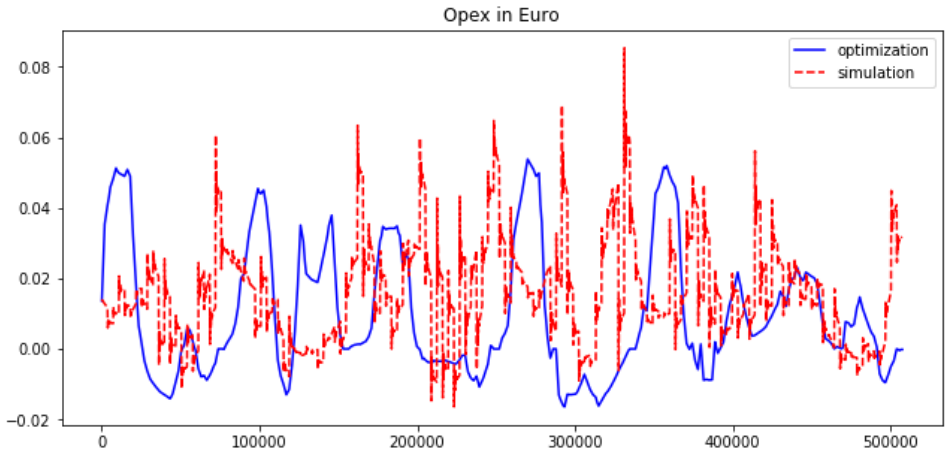
RESULTS –SOLAR SYSTEM









- Characteristics of solar profile requires partial storage usage for an optimal operation. Smaller storage compared to wind system can be installed.
- OPEX:
  - Simulation: 7773 €
  - Optimization: 4952 €

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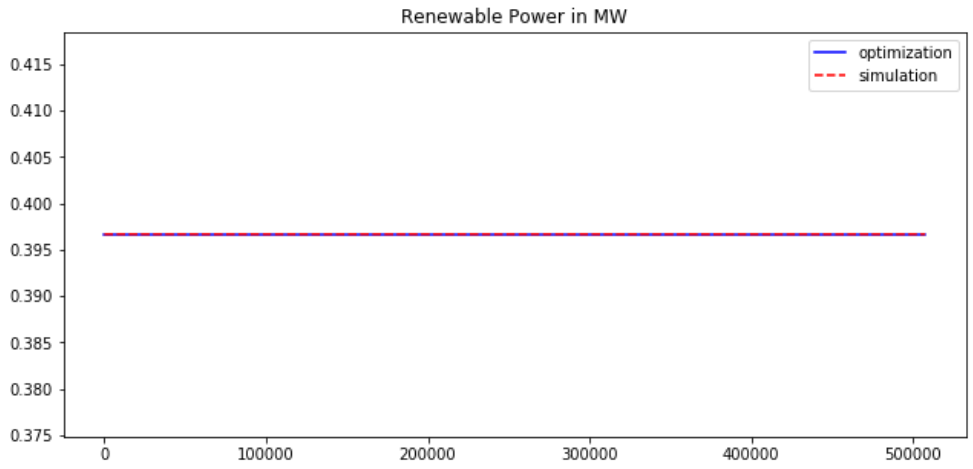
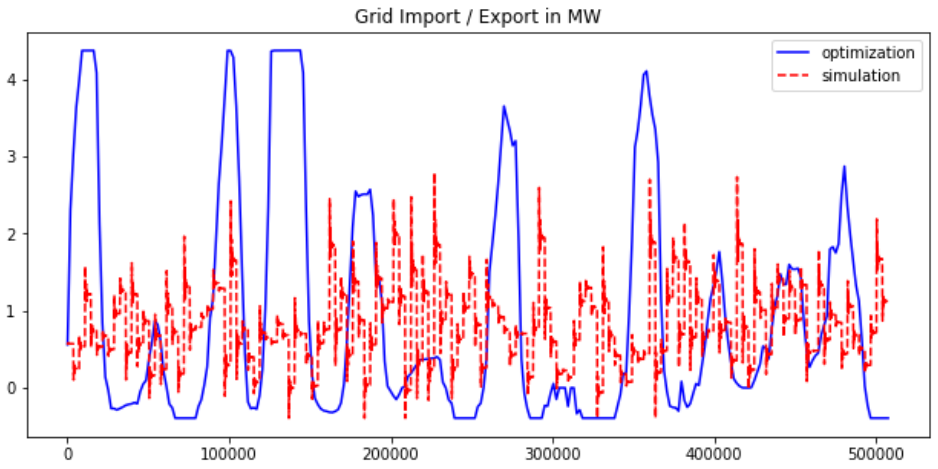
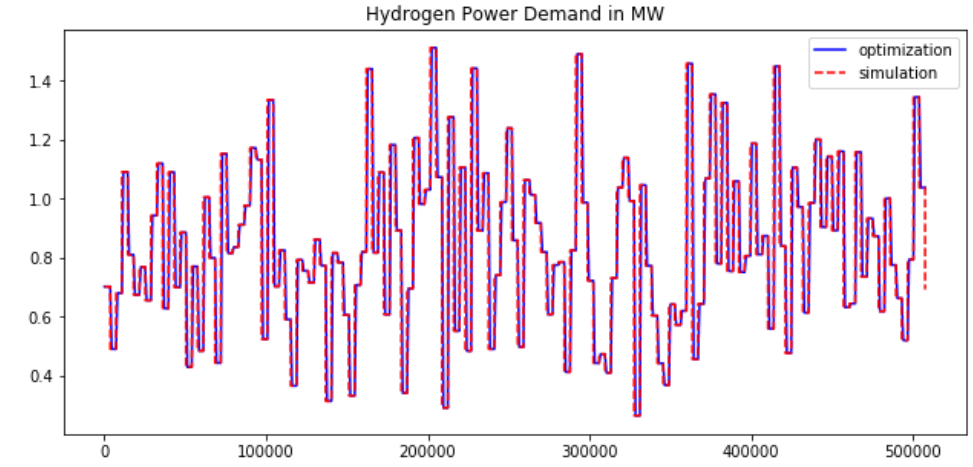
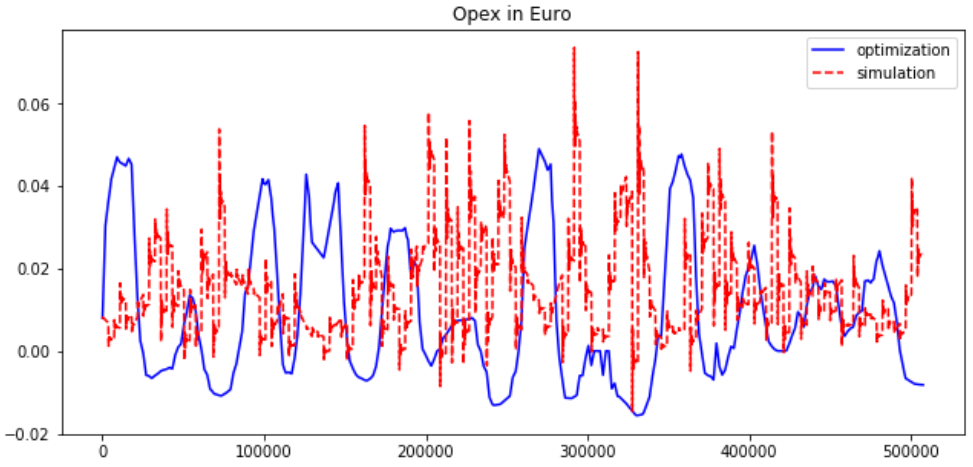
RESULTS – BIOMASS SYSTEM









- Characteristics of biomass profile requires partial storage usage for an optimal operation. Smaller storage compared to wind and solar system can be installed.
- OPEX:
  - Simulation: 7501 €
  - Optimization: 4676 €

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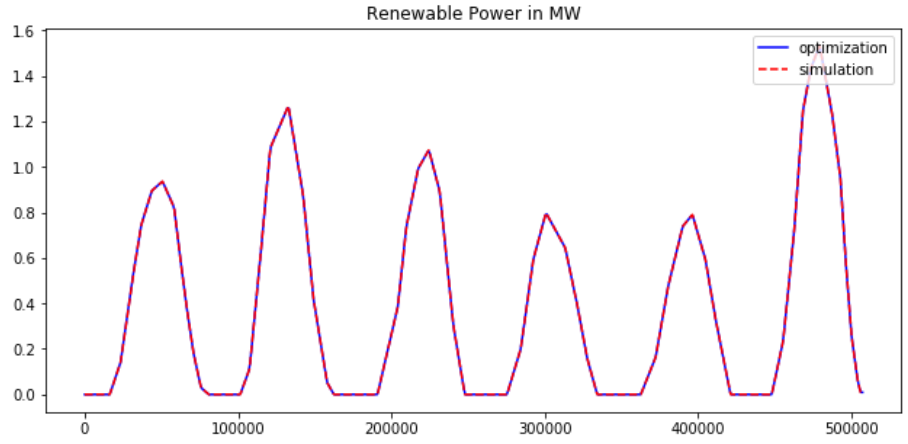
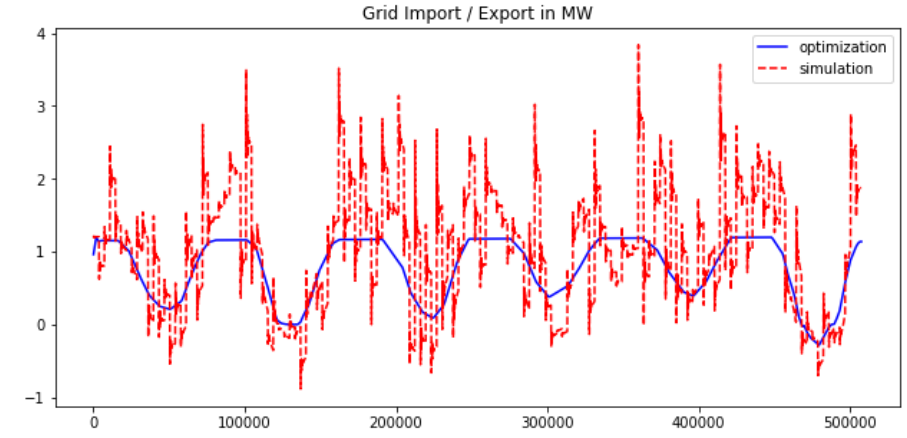
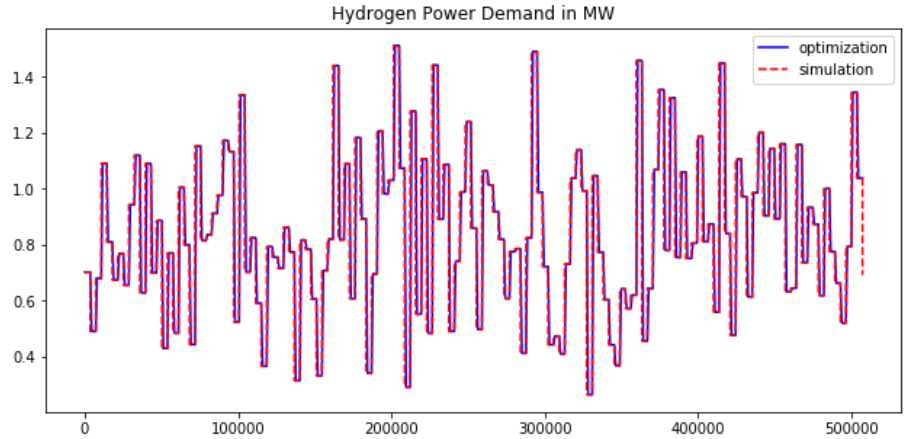
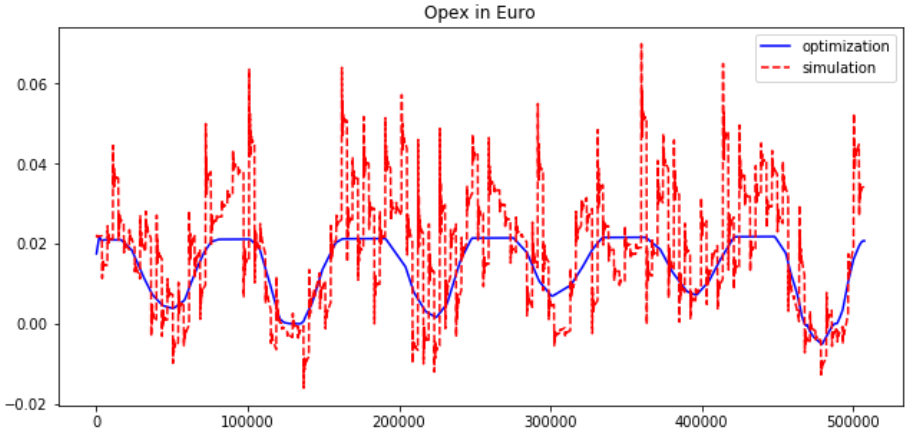
RESULTS –SOLAR SYSTEM, CONSTANT PRICE (AV. PRICE)









- OPEX:
  - Simulation: 9293€
  - Optimization: 7171 €

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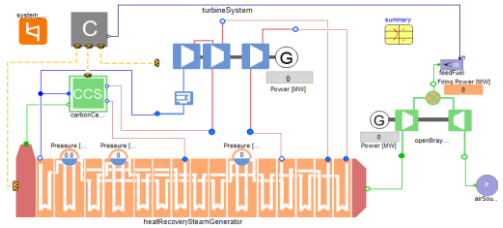
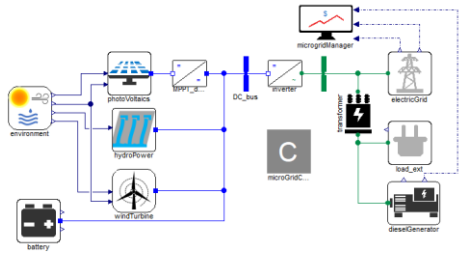
SUMMARY

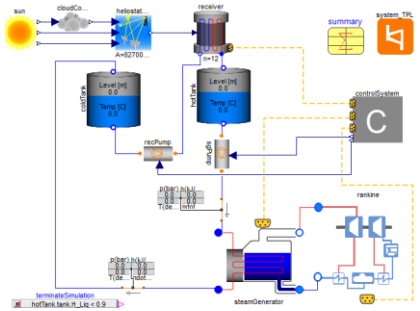
- Future energy system requires coordination of complex technology – for design as well as operation.
- Hydrogen technology can play a major role as it can be used both for sector coupling and storage.
- Modelica as an open standard high-level programming language allows fast model development for innovative technology
- Integration with Optimica and Casadi allows dynamic optimization for both operation and design problems.

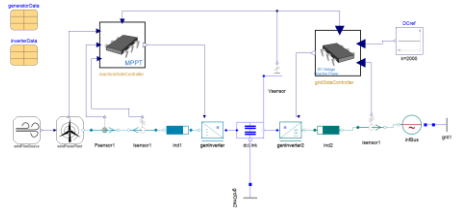
THANK YOU

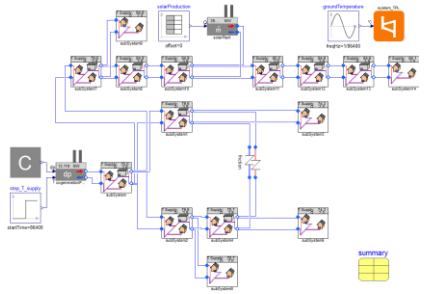
EXAMPLE APPLICATIONS ADDRESSED WITH SYSTEM SIMULATION IN OPEN STANDARD SOFTWARE











Power plant

- Thermal power plants
- Steam, CO2 & ORC cycles
- Control & plant design
- Flexibility analysis
- Carbon capture
- Hydrogen gas-turbine retrofit

Renewable

- Biomass
- Hydropower
- Solar – PV & CSP
- Wind power
- Fuel cell – PEM & SOFC
- Renewable integration

Storage

- Battery incl. aging
- Liquid Air Energy Storage
- Electro-thermal storage
- Hydrogen
- Molten salt
- Water accumulator

Electric grid

- Transmission & distribution
- Transient & fault analysis
- Microgrid design
- Grid synchronization
- Energy management
- Transport electrification

District energy

- Heating & cooling networks
- Cogeneration plant
- Heat pump & chiller
- Production planning
- Distributed production
- Prosumer

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