Alternative fuels

High-fidelity modeling for sector coupling and flexibility assessment in planning and operation: a case study of hydrogen generation site

Work package 3

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1 INTRODUCTION AND OBJECTIVES

This work deals with cost-effective generation of hydrogen and flexibility provision from hydrogen generation sites. The following research questions were addressed:

Q1 – does the adoption of high-fidelity models affect the identified optimal design?

Q2 – how much can waste heat recovery reduce the levelised cost of hydrogen?

Q3 – how much flexibility can an hydrogen generation site provide?

2 CONTRIBUTIONS TO PATHFDNR

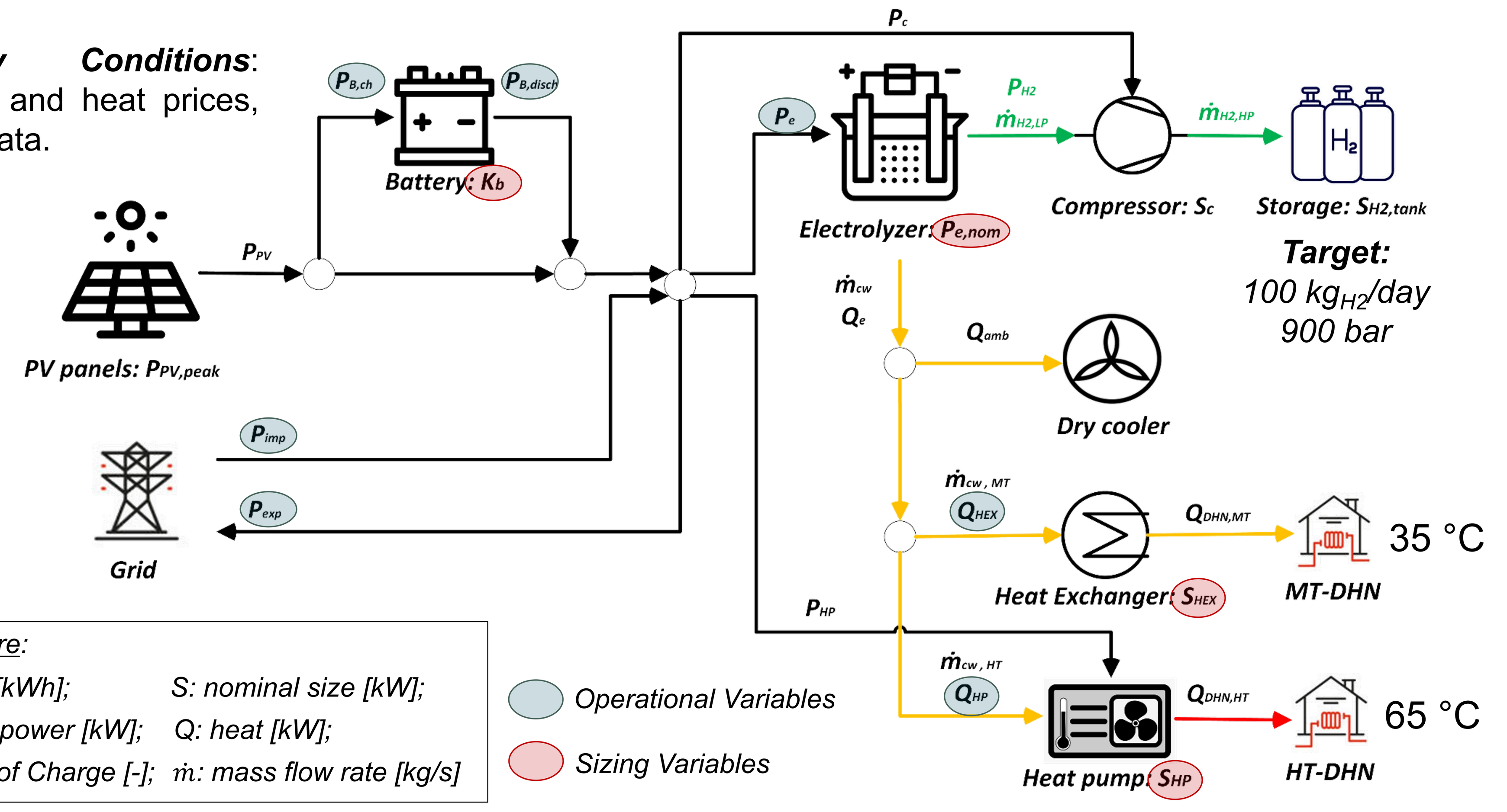
C1 – planning phase: under the hypothesis of perfect predictions, development of a numerical tool for the optimal sizing and operation of hydrogen generation sites and study of the impact of modelling level of fidelity;

C2 – planning phase: assessment of the economical benefits from sector coupling between hydrogen generation sites and district heating networks;

C3 – operational phase: quantification of flexibility provision from the operation of an hydrogen generation site and development of flexible control strategies;

3 METHODOLOGY – ENERGY SYSTEM AND NUMERICAL TOOLS

Boundary Conditions: Electricity and heat prices, weather data.



Nomenclature:
C: capacity [kWh]; S: nominal size [kW];
P: electrical power [kW]; Q: heat [kW];
SOC: State of Charge [-]; $\dot{m}$: mass flow rate [kg/s]

Planning phase: perfect forecasts.

Mixed integer linear programming (**MILP**) for the minimization of the levelised cost of hydrogen with the key components sizes and operational variables as design variables;
A desired hydrogen production of 100 kg/day is targeted;
Use of high-fidelity models from manufactures and literature [1];

Analysis of the operation of a representative case study

Operational phase: case study of MOVE [2].

MOVE is a refuelling station for hydrogen vehicles with a PEM electrolyser of 186 kW.
MILP for operational cost minimization with PWA functions calibrated over historical data;
Quantification of flexibility through flexibility envelope [3].

4 PLANNING PHASE – OPTIMAL DESIGN

4.1 Use of high-fidelity models

The optimal sizes are compared for different modelling level of fidelity for the electrolyzer efficiency, η_e,with the symbol *n* indicating the number of breakpoints for the PWA approximation.

The optimal configuration converges for *n≥4*. However, near optimal sizing is obtained already for n=2.

Optimal components' sizes and capacities for increasing modelling fidelity

# break points	$P_{PV,peak}$ [kW]	S_e [kW]	S_{HP} [kW]	S_{HEX} [kW]	K_b [kWh]	LCOH [CHF/kg]
Const	+0%	-9.95%	-9.35%	+0 %	+0 %	+3.53%
n = 2	+0%	-0.94%	-0.27%	+ 0 %	+ 0 %	+1.69%
n = 4	1500	411	103	0	0	10.65
n = 10	+0%	+0.12%	-0.06%	+ 0 %	+ 0 %	-0.22%

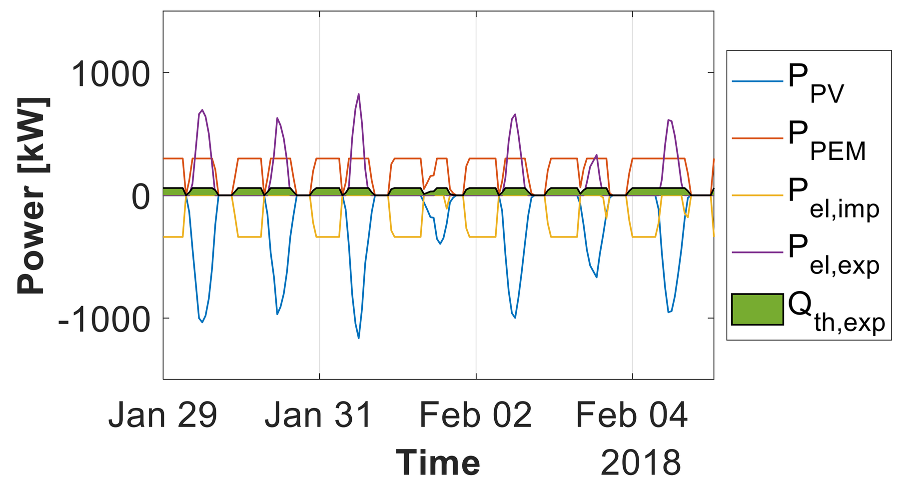
4.2 Benefits from sector coupling

A final LCOH=10.65 CHF/kg is predicted;

The waste heat recovery (WHR) ensure a LCOH reduction of 6.0% compared to solutions without WHR.

During winter season, heat is always injected in the HT-DHN (65 °C) when the electrolyzer is operating (figure on the right);

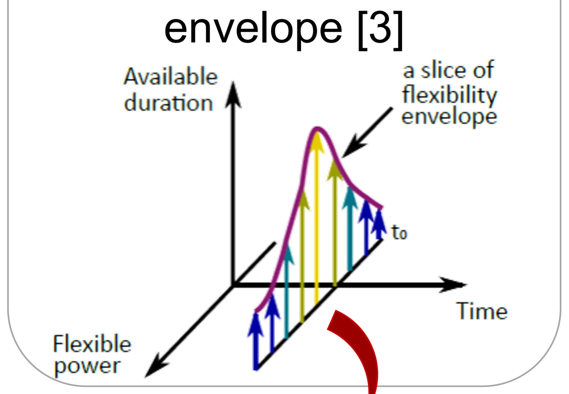
Operational patter in a selected week

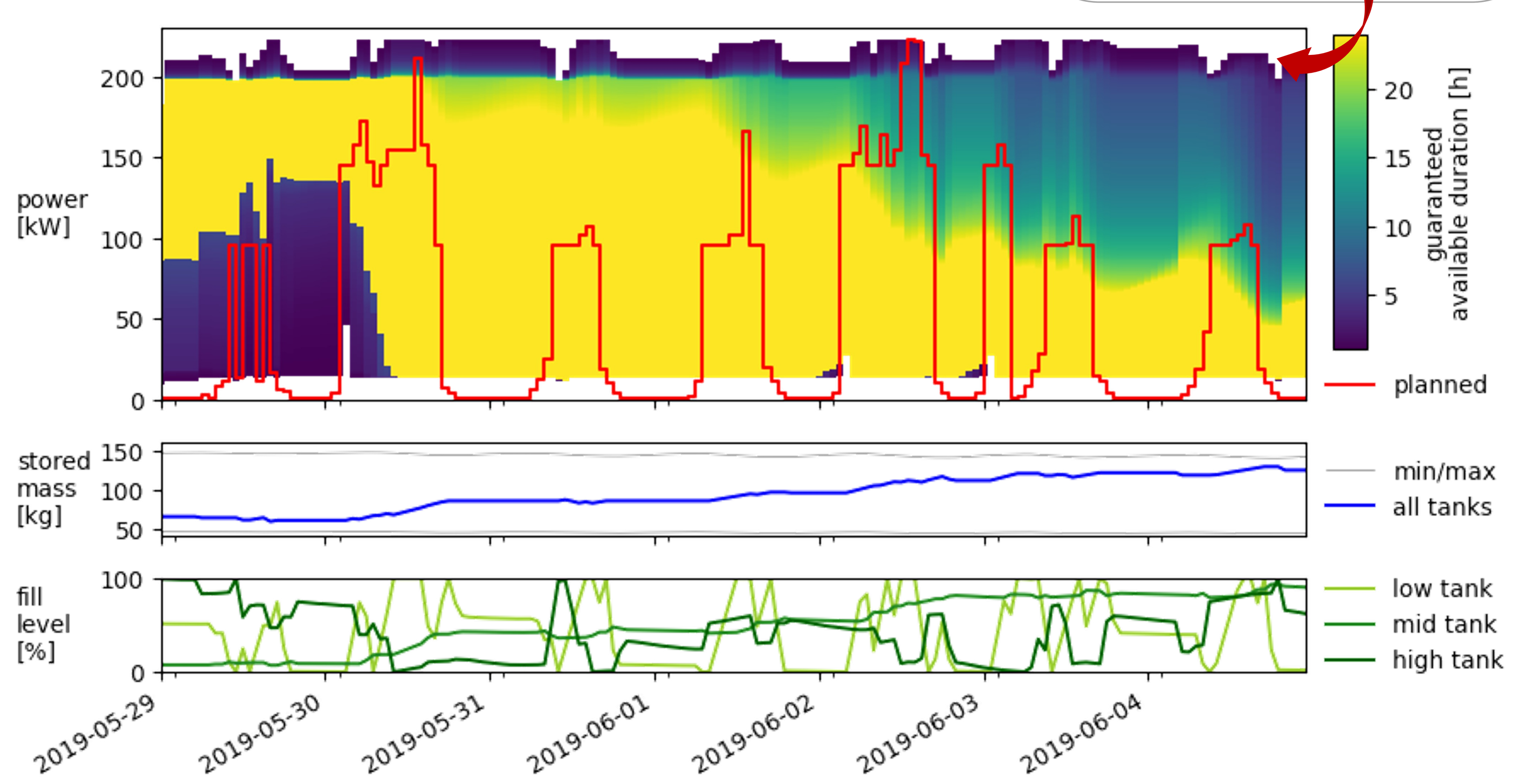


5 OPERATIONAL PHASE – FLEXIBILITY PROVISION

When high fill level are measured in the storage tanks, the **maximum power can be provided for short times**;
The lower power bound has very **sharp drops** in guaranteed duration when going from one power level to the next. This is due to the non-convex energy bounds;

The concept of flexibility envelope [3]





REFERENCES

1 Gabrielli et al., Electrochemical conversion technologies for optimal design of decentralized multi-energy systems: Modeling framework and technology assessment, 2018
2 MOVE – mobility of the future, https://www.empa.ch/web/move
3 Gasser et al., Predictive energy management of residential buildings while self-reporting flexibility envelope, 2021

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ACKNOWLEDGMENTS

This work was performed by the PATHFNDR consortium, which is sponsored by the Swiss Federal Office of Energy's SWEET programme.