

Coupling power-plant and reservoir models: A workflow for integrated surface–subsurface applications

Firdovsi Gasanzade¹ and Francesco Witte²

¹ *Kiel University*

² *Researcher at German Aerospace Center. Developing TESPpy as independent researcher.*

Integrated assessment: requirements and drivers

Subsurface reservoir facility:

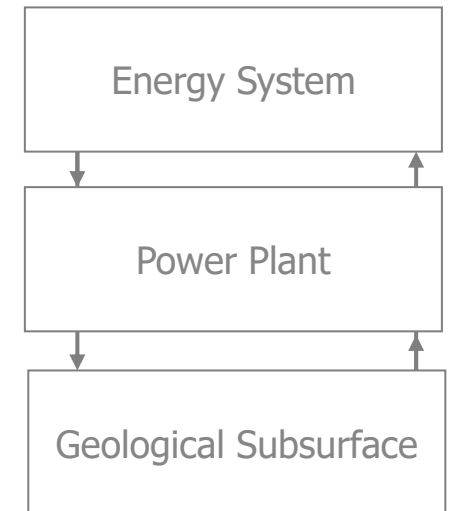
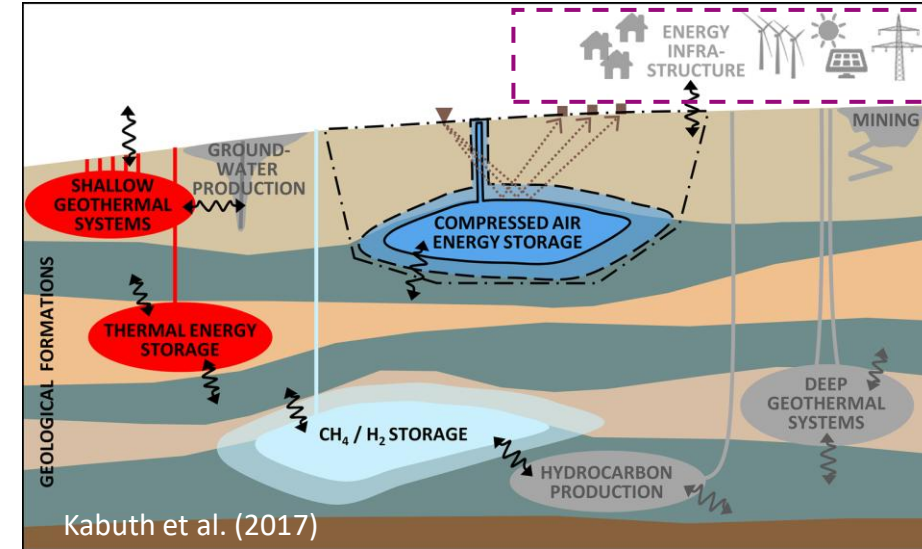
- > All subsurface systems are **inherently coupled** with the surface infrastructure
- > New energy applications CAES, H₂ storage, CCUS
- > Heat storage topics: Geothermal, ATEs
- > Conventional resource exploration...
- > Reservoirs as **dynamic buffers**: shift from steady-state extraction to cyclic, demand-driven loading/unloading

Surface power plant facility:

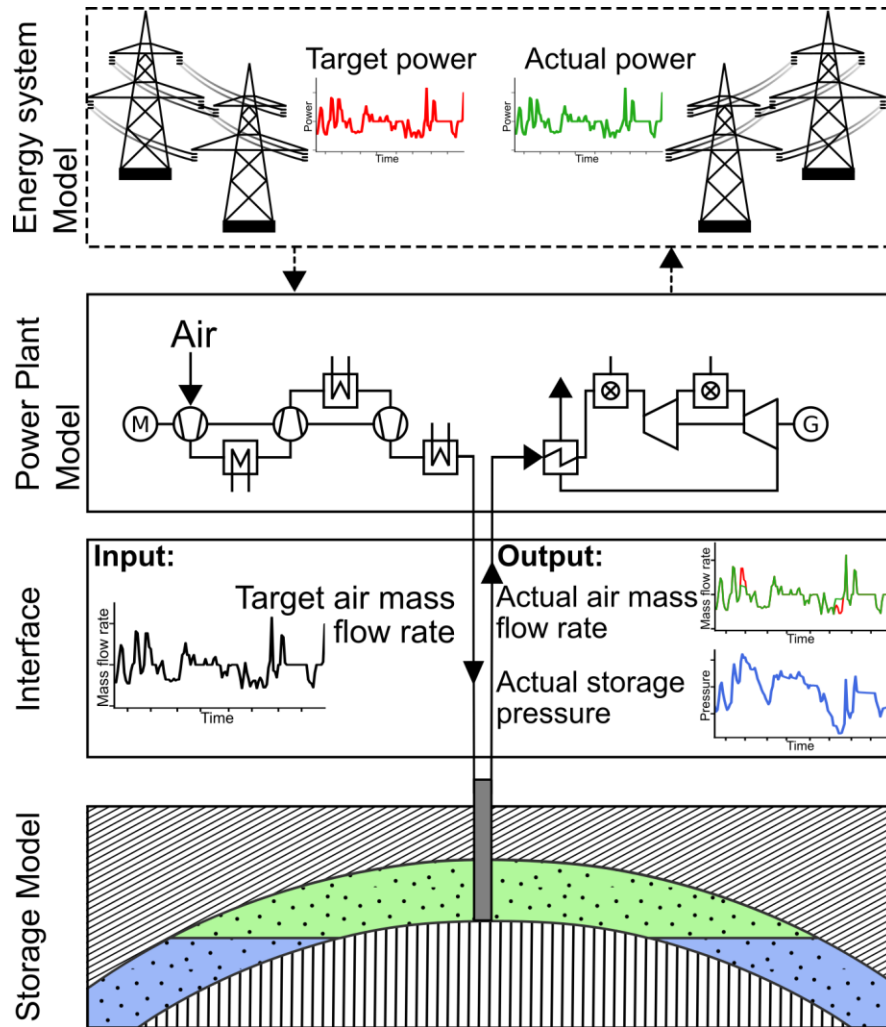
- > Traditional decoupled simulations fail to account for the **dynamic feedback loop** between surface plant thermodynamics and subsurface processes

Subsurface-Surface dynamics:

- > Integrated modelling approach is essential for feasibility assessment and to optimise performance and/or prevent interference
- > Optimal energy infrastructure design requires a transition from single-asset analysis to integrated, multi-use basin management to maximise total power output and storage capacity



How we do assessment?



after Pfeiffer et al. (2021)

> Energy system level

- Defines macro-scale boundary conditions
- Managed via load profiles: **charge, discharge or shut-in**

> Site-specific power plant level

- Thermodynamic process layer with constraints defined in the JSON configuration. Components are linked via a topological network to simulate plant logic

> Interface layer

- Data translation bridge utilizing Python interface for iterative model coupling
- Facilitates time-step-wise exchange of reservoir pressure and mass flow rates

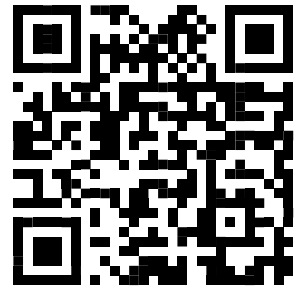
> Geological storage

- Agnostic to subsurface application (CAES, H2, CCUS etc.), depending on simulator flexibility
- Technical constraints are enforced through both the OPM Flow input deck and the JSON control file

Power plant layer: TESPpy



tespy ['tɛs.paɪ]
open energy modelling framework



[Link to GitHub](#)

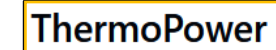
> Features

- Component based steady-state simulation
- Equation oriented solver
- Design and part load simulation
- Library of standard and specialized components
- Heat pumps, ORC plants, combined cycle, ...

> Users

- Academia and research, e.g. Fraunhofer, German Aerospace Center, TU Munich, TU Berlin, Flensburg University, KTH Stockholm, ETH Zürich, ...
- Industry, e.g. heat pump or ORC power plant manufacturers, consultancies, start-ups, ...

Other simulators in (thermal) energy engineering



Power plant layer: Modeling concept

> Components

- Power and heat transfer
- Pressure change
- Efficiency
- Complex parameters, e.g. EN12900 polynomials

> Connections

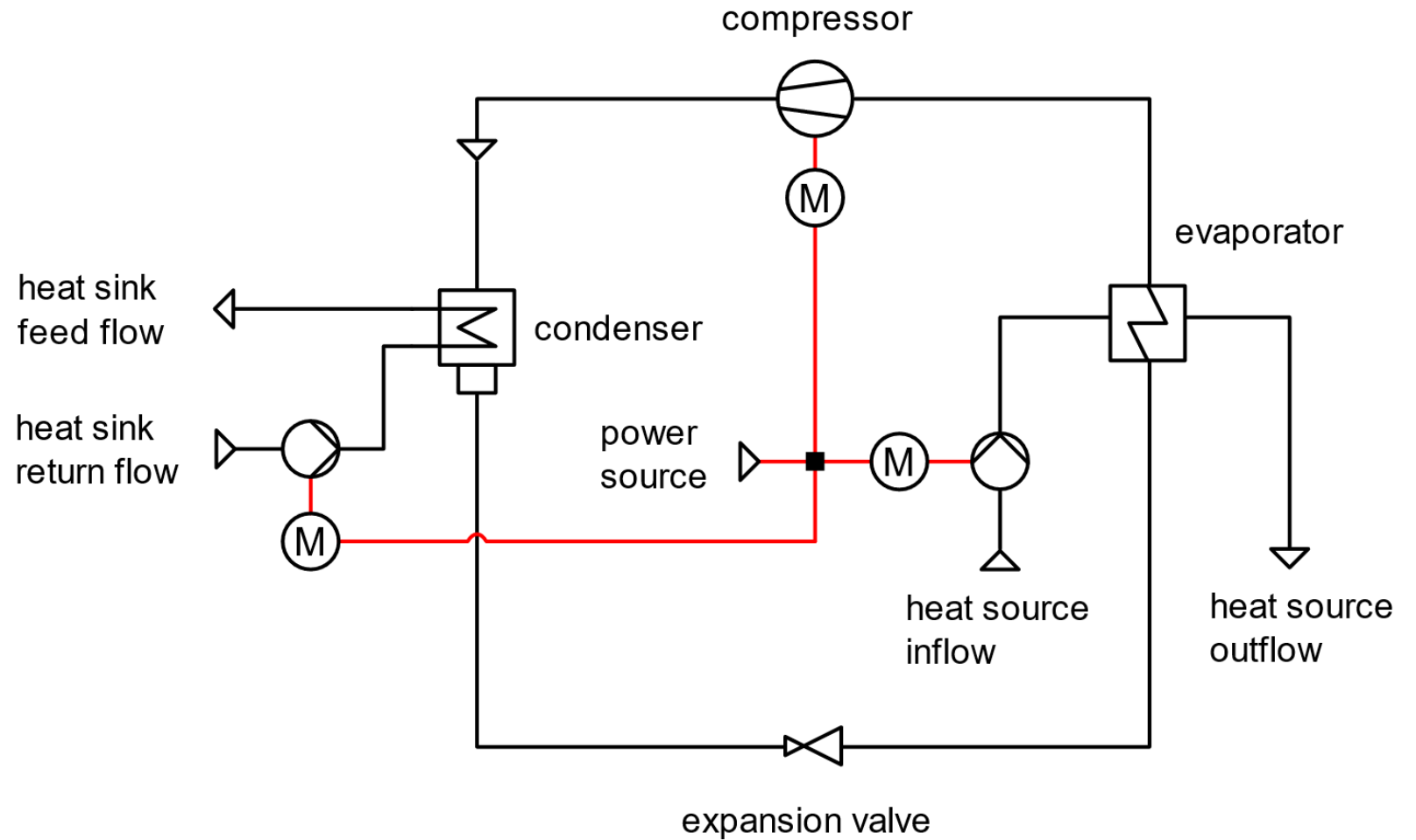
- **Mass flow, pressure enthalpy**
- Fluid composition
- Temperature, quality, ...

> More Components

- Power
- Efficiency

> PowerConnections

- **Power**



Power plant layer: Modeling concept

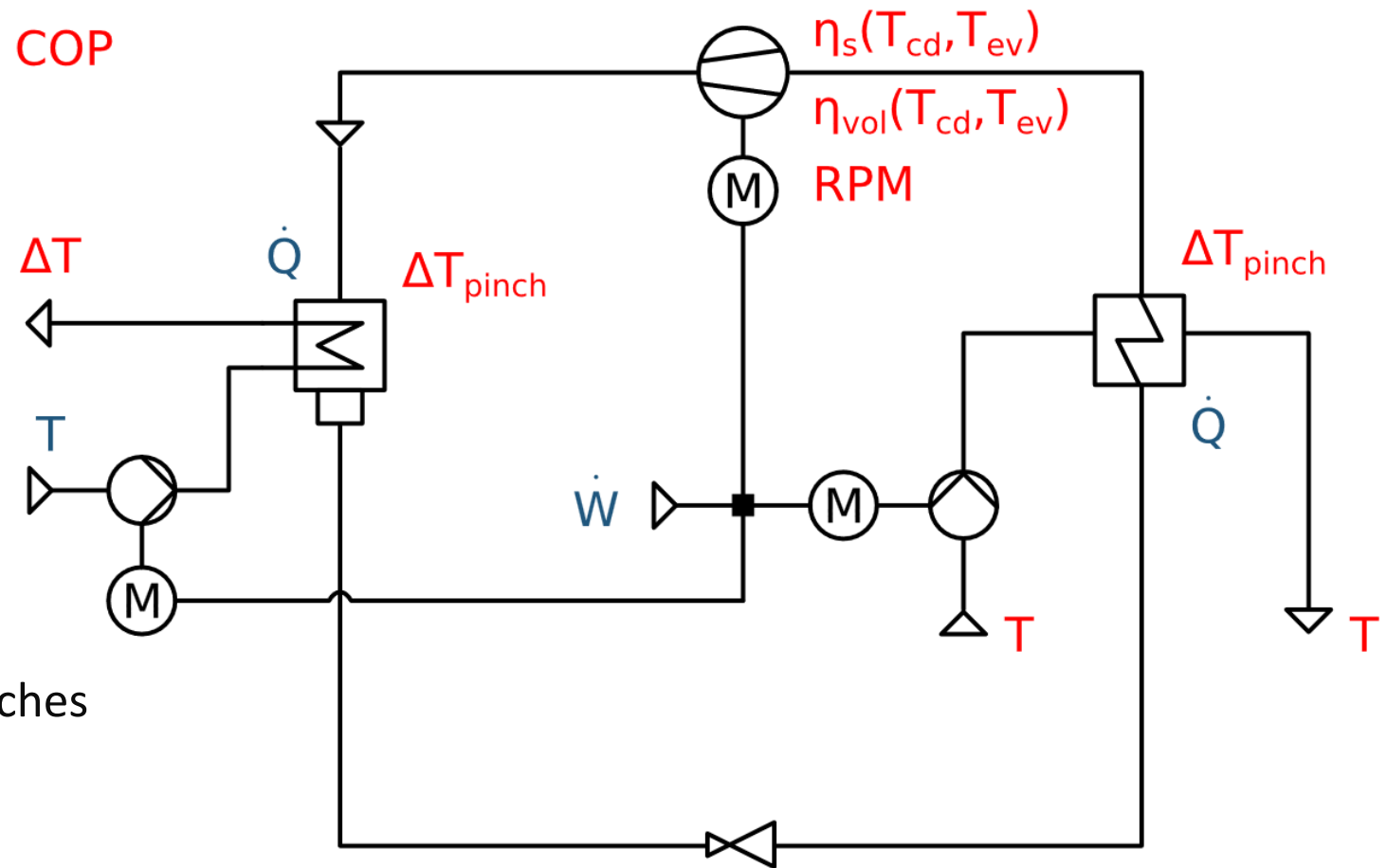
> Inputs and results are interchangeable without changing the setup!

> Inputs

> Results

> High degree of freedom is a challenge for numerical robustness in model coupling

> Development goal: unify approaches



Interface level: Iterative coupling algorithm

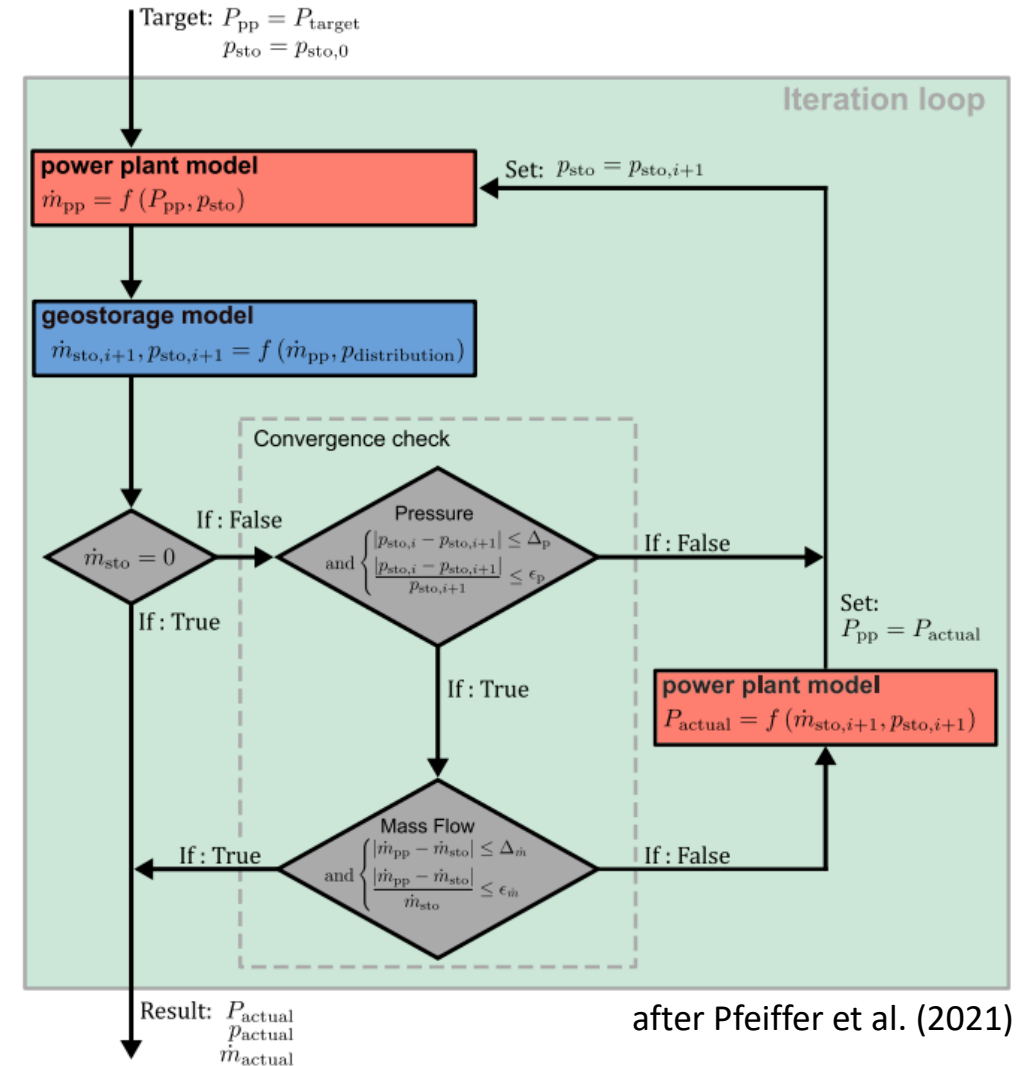
> **Initialisation:** system enters the loop with **Power** and initial **reservoir state**

> **Bi-Directional Communication:**

- Convergence Criterion 1 (Pressure)
- Convergence Criterion 2 (Mass Flow)
- Power Correction

> **Validated output**

- Terminated results represent a thermodynamically and geologically consistent operating point



Geological storage level: OPM Flow

> Static sections

- The **geological baseline** is defined in *RUNSPEC, GRID, EDIT, PROPS, REGIONS*: these remain constant during the coupling loop
- SUMMARY: Provides essential .RSM data for **iterative state-updates** in the coupling loop

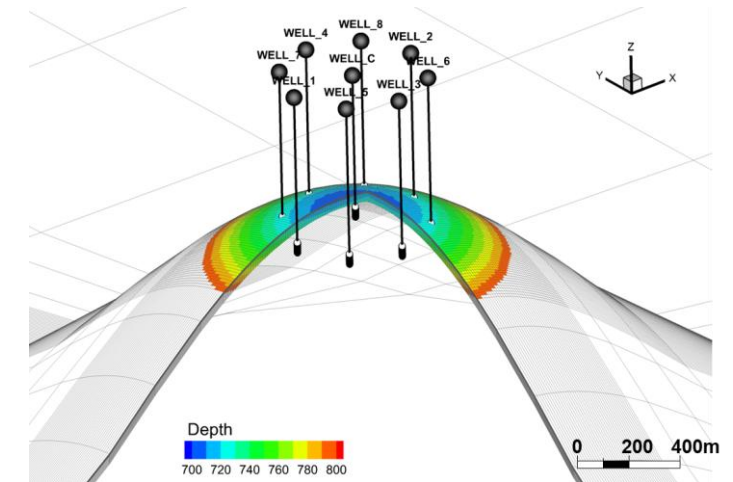
> Dynamic sections

- SOLUTION: establishes initial gas/air-in-place mass (cushion gas). Utilises restart files to resume simulation
- SCHEDULE: the core of the operation-splitting approach. The coupling interface dynamically updates *WCONINJE* and *WCONPROD* keywords based on target mass flow rates derived from surface plant demand
- Operational limits: hard-coded BHP constraints in JSON-based file

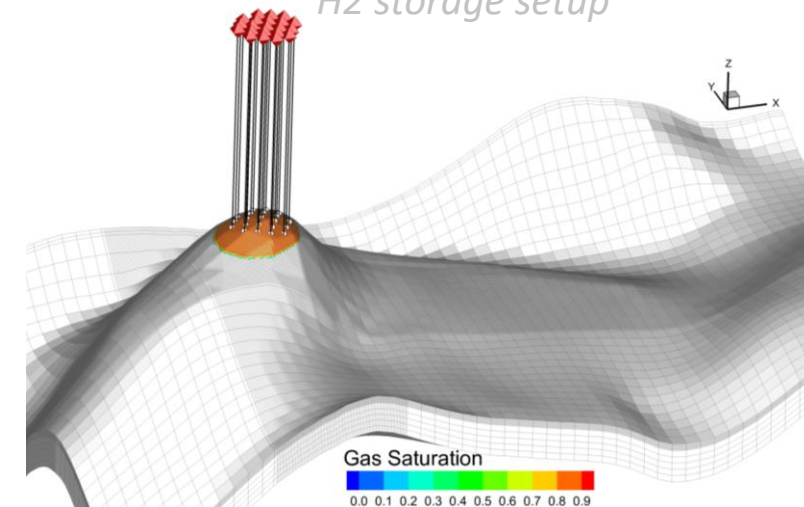
> Execution & Control:

- JSON-based configuration: centralised management of simulator paths, well metadata (depths/BHP limits), and parallelisation settings (opm flags)
- *SAVE/LOAD*: this is a bottleneck, but commercial simulators support it. For high-frequency scenario modelling, this reduces runtime significantly.

Compressed air energy storage

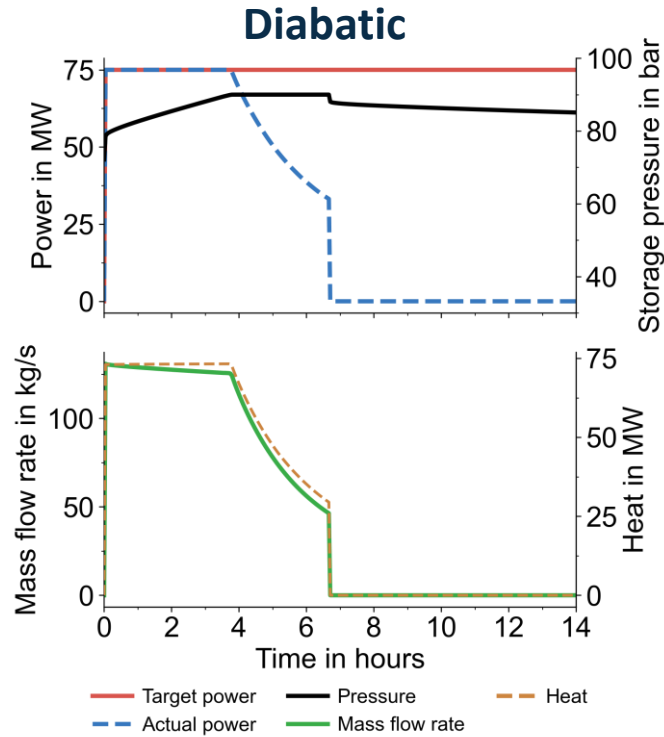


H2 storage setup



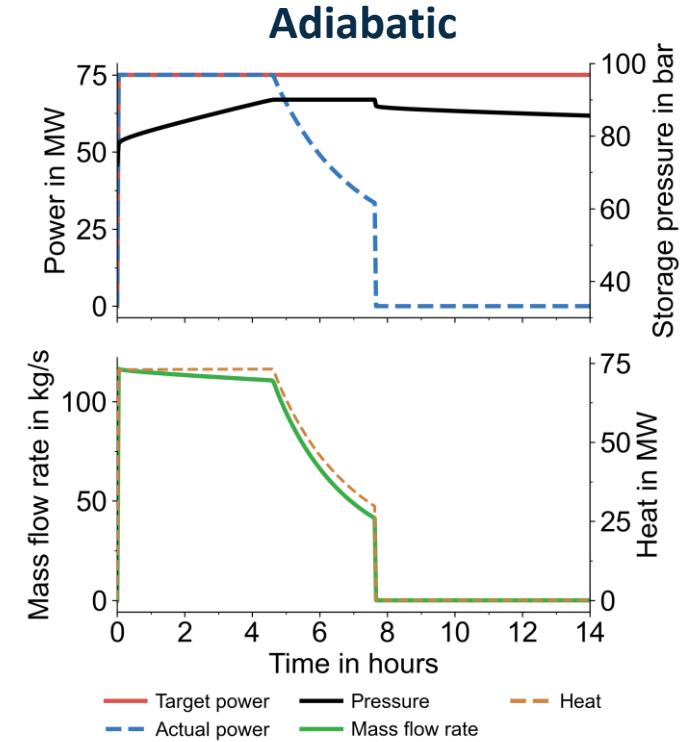
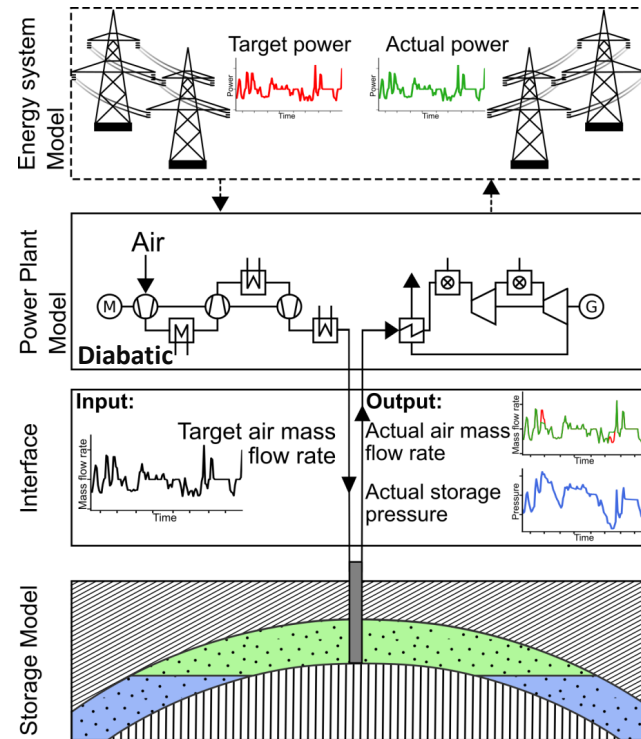
Testcase: Compressed air energy storage

Continuous charging



> Operational phases:

1. Normal operation
2. Geostorage limitation
3. Power plant limitation: Facility shut-in

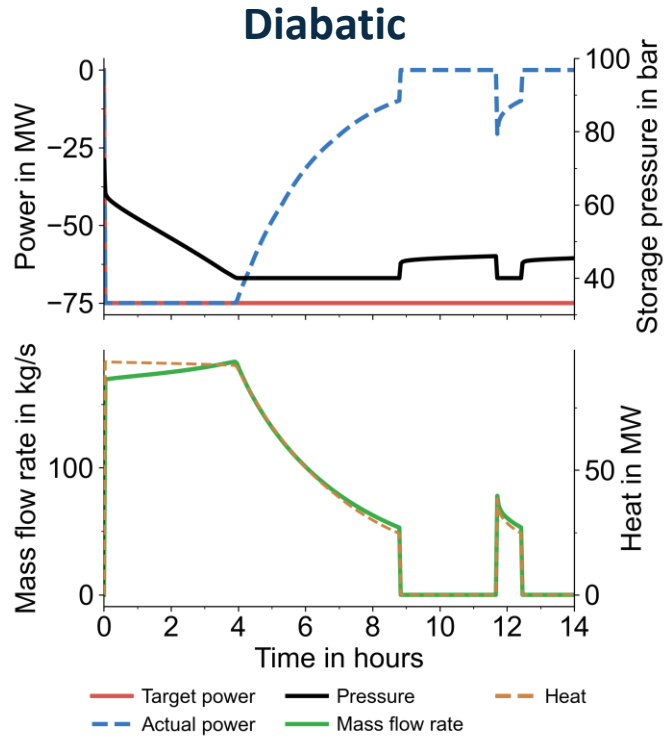


> Operational phases:

1. Normal operation
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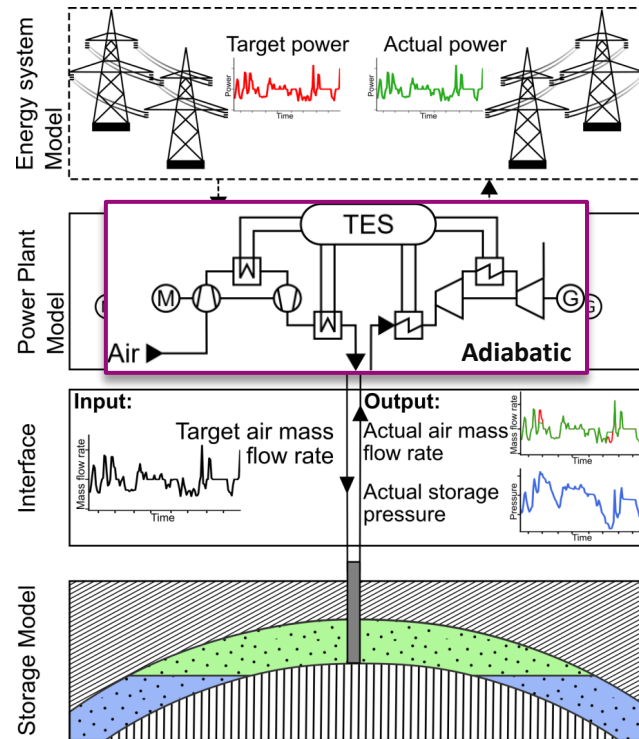
Testcase: Compressed air energy storage

Continuous discharging

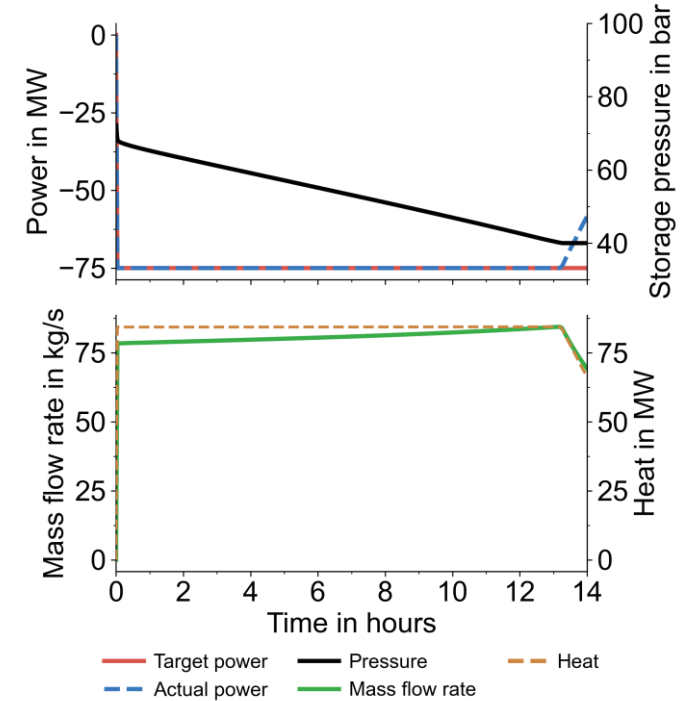


> Operational phases:

1. Normal operation
2. Geostorage limitation
3. Facility shut-in
4. Geostorage limitation



Adiabatic

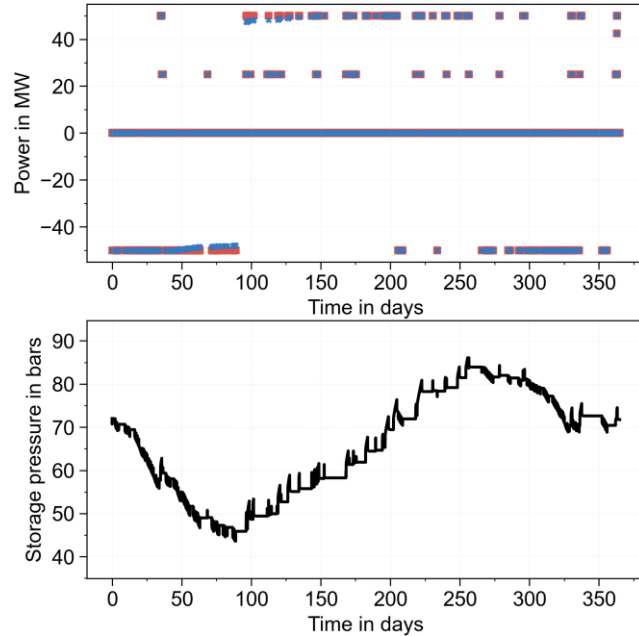


> Operational phases:

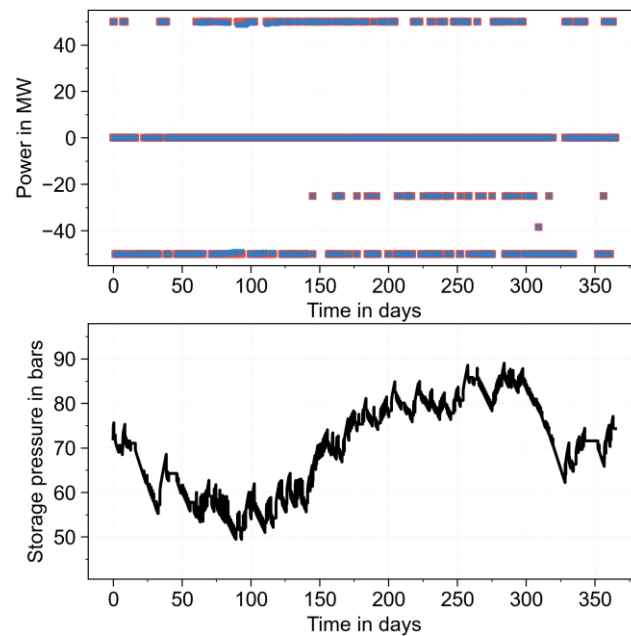
1. Normal operation
2. Geostorage limitation

Scenario simulations

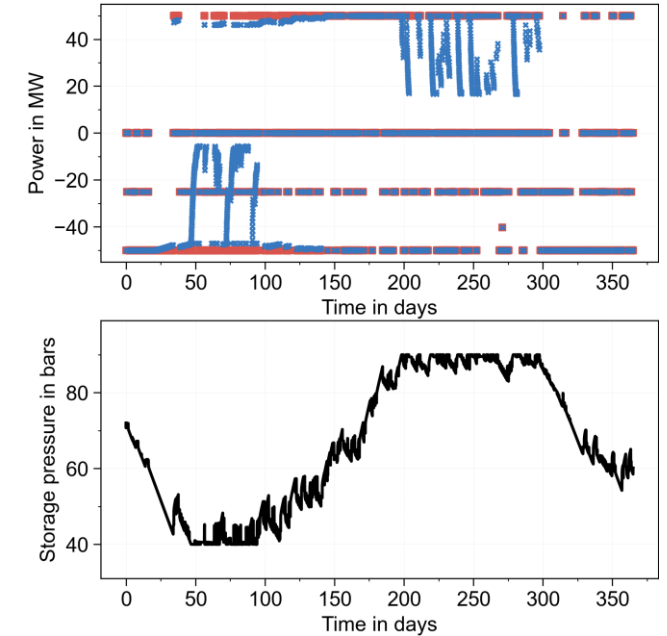
Scenario 2030



Scenario 2040



Scenario 2050



> Annual operational scenarios

- Constraint detection: Identifies power curtailment in the 2050 scenario where subsurface limits override surface demand (blue/red deviations).
- Operational limits: Maintained a strict 40-90 bar pressure envelope despite high-frequency operational ramp rates.
- Captures sub-daily cycling superimposed on seasonal reservoir pressure and cushion gas evolution.
- Annual simulations with hourly coupling resolution completed in 6-10 hours.

Summary

- > Assessment tool is developed and tested, integrated OPM Flow–TESPy modelling identifies operational power curtailments and pressure violations that decoupled simulations overlook.
- > Operational validation: the iterative coupling loop ensures thermodynamic **consistency** between surface **plant demand and subsurface** geological limits.
- > Computational feasibility: annual simulations at hourly resolution complete within 6-10 hours, enabling **high-frequency scenario assessments**.
- > The modular Python interface is **fluid-agnostic**; it supports CAES, H2 or CCUS workflows with minimal configuration changes (maybe even geothermal plants).

Thank you for your attention!

Francesco Witte

- Developing TESPpy as independent researcher and contractor
- Researcher at German Aerospace Center
- tespy@witte.sh

Firdovsi Gasanzade

- Kiel University
- firdovsi.gasanzade@ifg.uni-kiel.de