Efficient Simulation and Analysis of Gas Networks with H_2 Injection

Gefördert durch:

Bundesministerium für Wirtschaft und Energie

Fraunhofer SCAI

Efficient Simulation and Analysis of Gas Networks with H_2 Injection

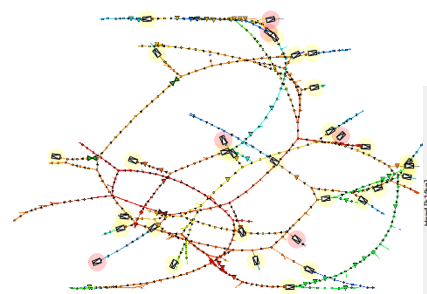
<u>Tanja Clees</u>, Anton Baldin, Kläre Cassirer, Bernhard Klaaßen,

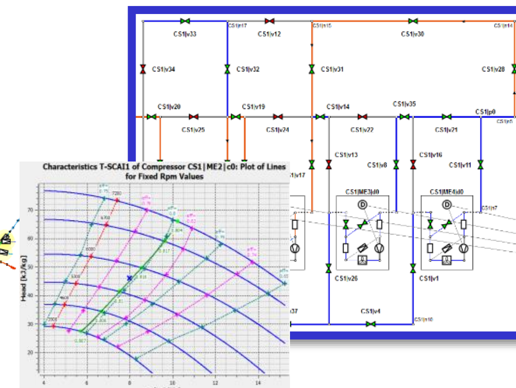
Lialia Nikitina, Igor Nikitin, Sabine Pott, et al.

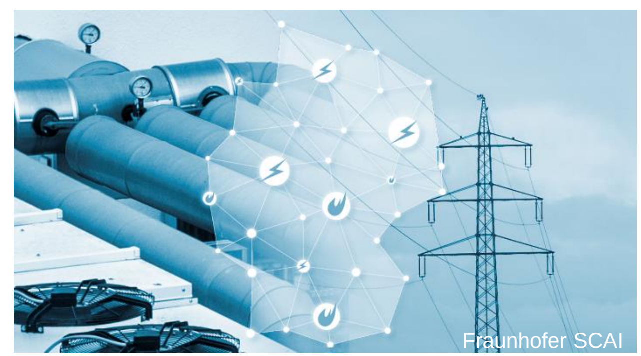
Fraunhofer SCAI

53757 Sankt Augustin, Germany

tanja.clees@scai.fraunhofer.de







Math Energy

Gefördert durch:

Bundesministerium für Wirtschaft und Energie

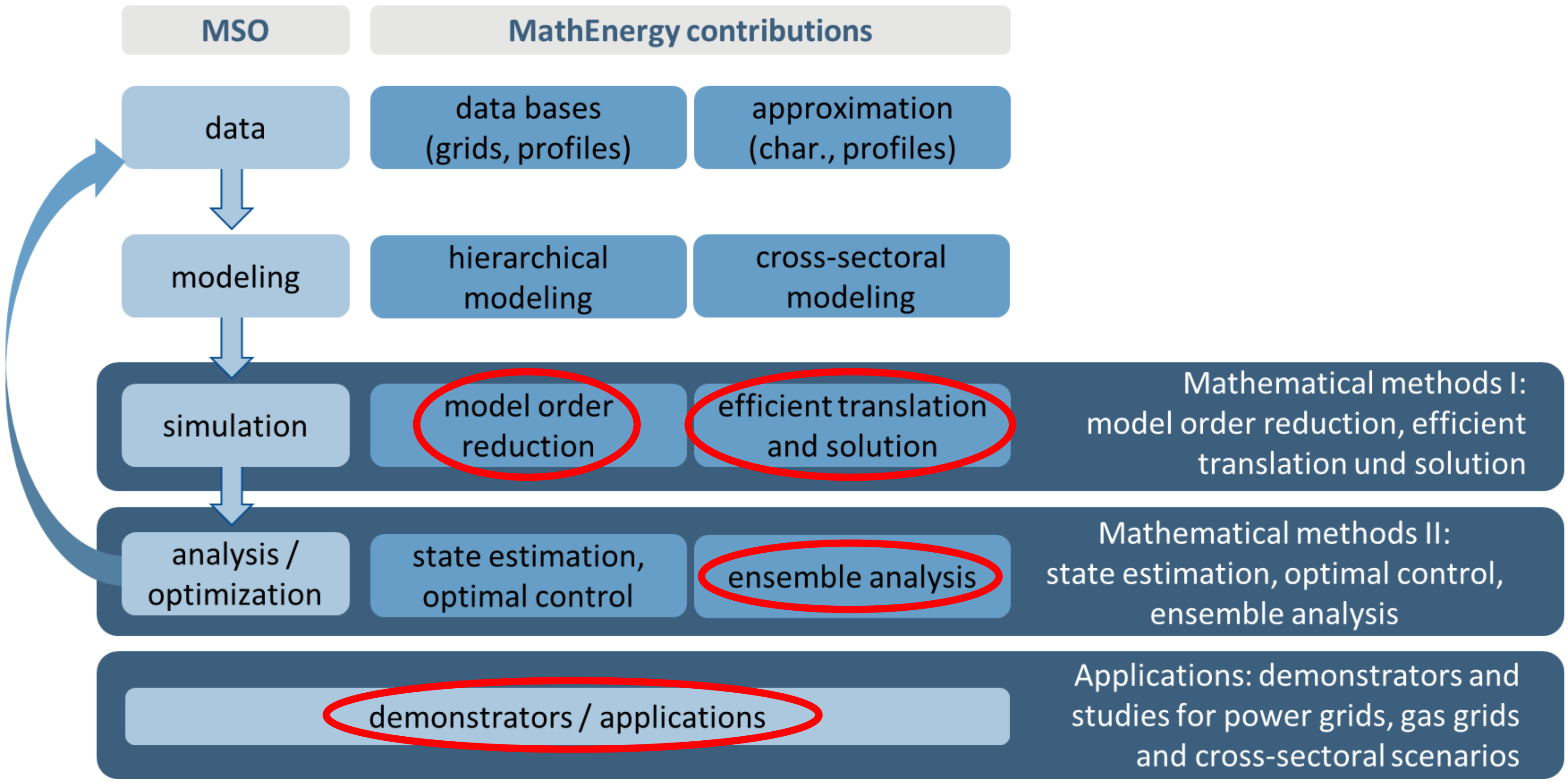
Fraunhofer SCAI

Introduction

- For transforming current energy infrastructure, pipeline systems for natural gas have to be converted for transporting (synthetic gases containing) H_2.
- Intense planning and optimization based on simulations needed.
- Since known simulation tools were designed for natural gas primarily, they are expected to be not accurate enough for scenarios with H_2 fractions above 10%.
- An efficient method for simulating transport of gases from renewable resources as well as impacts of H_2 injection into gas networks is developed.
- This includes a concept for setting up scenarios for analysis of impacts to long-distance gas networks for a country based on transient estimates for wind excess power, at least per federal state of the country considered.
- The method employs transient non-isothermal Euler equations with GERG-2008, the most recent gas law allowing for H_2 fractions up to 100%, and an approach for shifting compressor characteristics according to gas composition.

Gefördert durch:
Bundesministerium für Wirtschaft und Energie

Key Aspects of this Contribution



Gefördert durch:
Bundesministerium für Wirtschaft und Energie

Fraunhofer SCAI

Gas Laws and „Official“ Range of Applicability

- The ideal gas law reads $p = R_s \rho T$ with $R_s = R/M$ being the specific, R the universal gas constant, p pressure, ρ density, T temperature, M molar mass.
- To describe real gases, a compressibility factor $z = p/(R_s \rho T)$ is introduced in order to model deviations from an ideal gas.
- Typical, accurate gas laws used in simulators for natural gases are AGA8-DC92 ("DC92") and GERG-2008 ("GERG"), which is the most recent EOS.
- Only GERG can be used for higher H_2 fractions:

Gas law	Pressure (MPa)	Temperature (K)		Methane mole fraction (%)		H_2 mole fraction	
	max	min	max	min	max	min	max
DC92	12	263	338	70	100	0	10
DC92-wide	65	225	350	50	100	0	10
GERG	35	90	450	0	100	0	100

Gefördert durch:

Bundesministerium für Wirtschaft und Energie

Gas Compositions Considered, Including Biogases of Different Flavor and Industrial Hydrogen

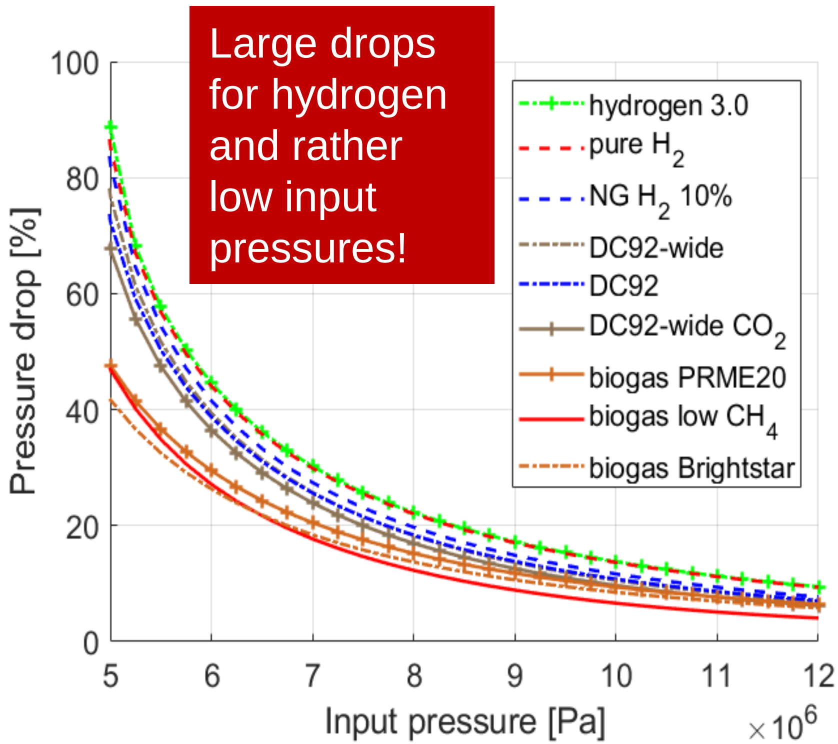
Abbreviation used here	Molar mass [g/mol]	z_G [-]	z_D [-]	$\left\| 1 - \frac{z_D}{z_G} \right\|$ [%]	CH_4 [%]	H_2 [%]	CO_2 [%]	CO [%]	N_2 [%]	Others [%]
biogas PRME20	20.05	0.968555	0.933968	3.571	0	**43**	22	29	3	3
biogas Brightstar	19.02	0.966751	0.944623	2.289	15	**40**	20	24	1	0
biogas low CH_4	31.47	0.716752	0.7214	0.648	40	**0**	51.5	0	5	3.5
DC92-wide with CO_2	24.43	0.793816	0.797345	0.445	50	**10**	30	0	0	10
DC92-wide	20.04	0.805976	0.806773	0.099	50	**10**	0	0	10	30
DC92	18.84	0.84529	0.84594	0.077	70	**10**	10	0	0	10
m30h to m90h	6.22 to 14.64	1.019 to 0.896	1.019 to 0.896	0.023 - 0.030	30 – 90	**70 – 10**	0	0	0	0
pure H_2	2.04	1.04303	1.04319	0.015	0	**100**	0	0	0	0
hydrogen 3.0	2.03	1.04302	1.04316	0.013	0	**99.935**	0	0	0.05	0.015
m10h	3.42	1.03773	1.03763	0.010	10	**90**	0	0	0	0
m20h	4.82	1.02974	1.02982	0.008	20	**80**	0	0	0	0
methane	16.04	0.861734	0.861689	0.005	100	**0**	0	0	0	0
NG H_2 10%	16.47	0.868365	0.8684	0.004	79.601	**10**	2.09	0	0.69	7.619

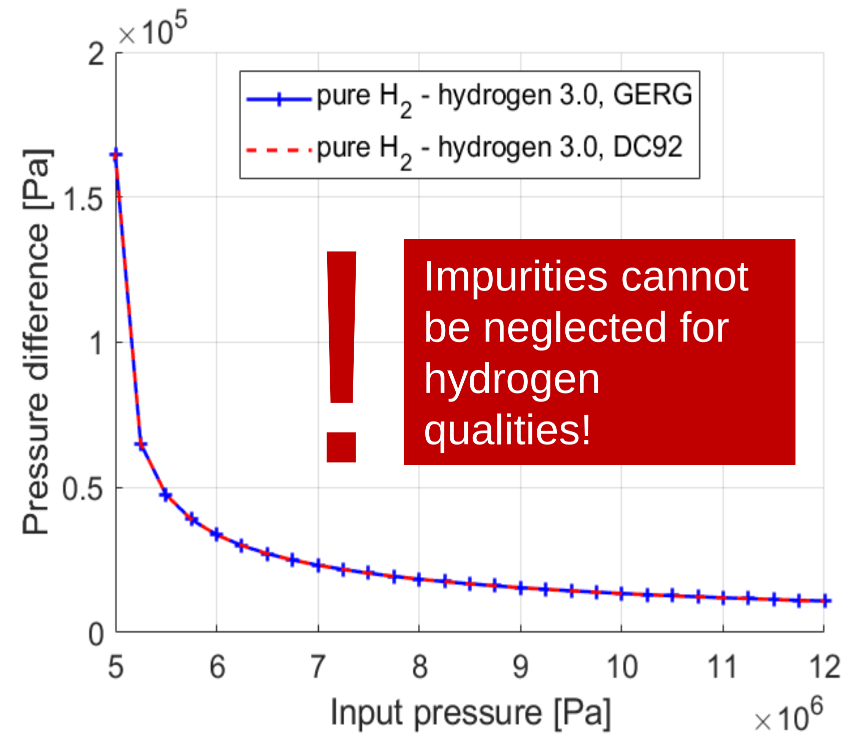
Gefördert durch:
Bundesministerium für Wirtschaft und Energie

Fraunhofer SCAI

Pressure Drops and Pressure Differences for a Simple Pipe Demonstrator of 100 km Length

- At demand node: (left) Pressure drops for biogas, hydrogen and DC(-wide) blends (GERG), (right) pressure difference between two hydrogen qualities

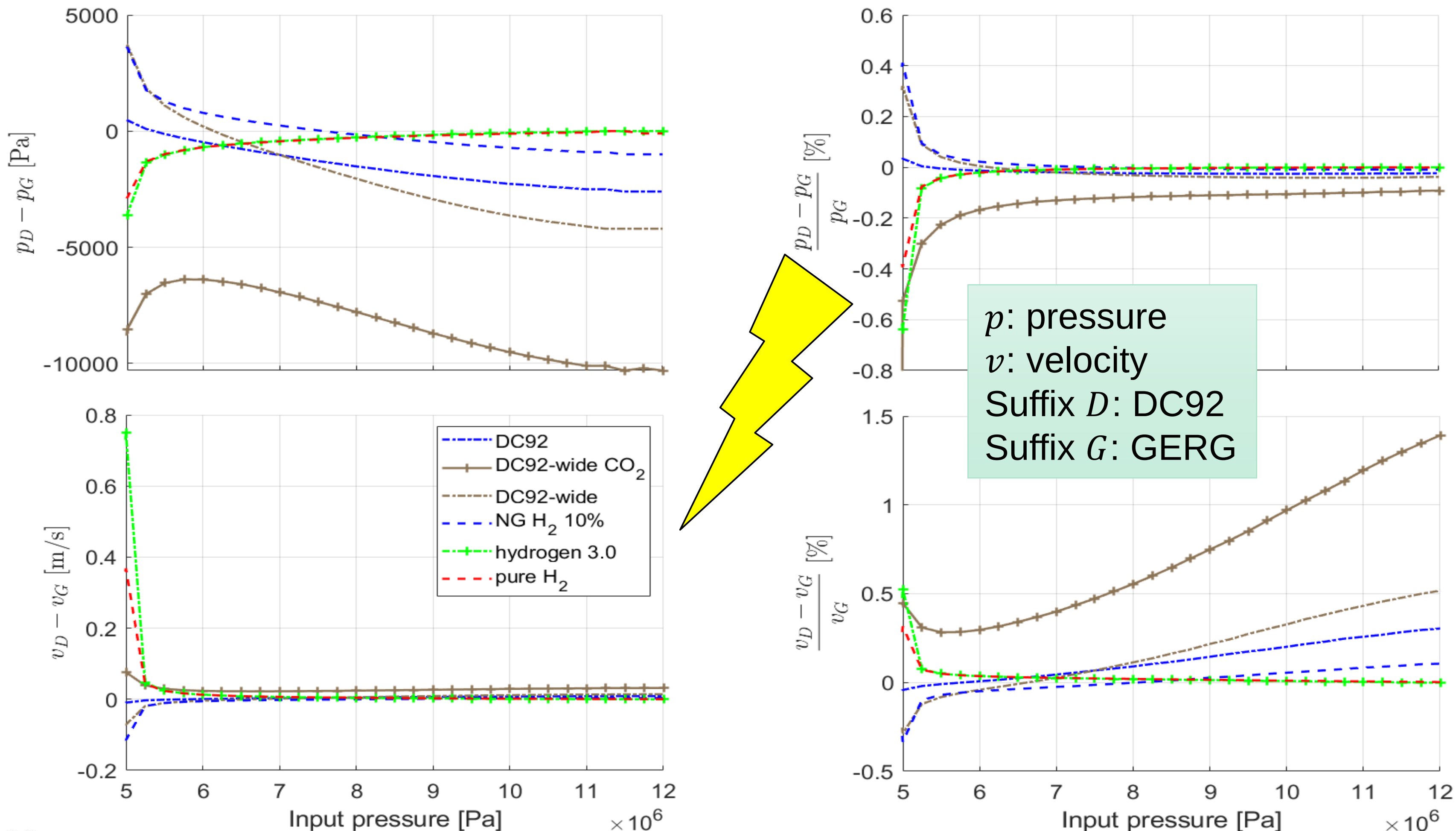




Gefördert durch:

Bundesministerium für Wirtschaft und Energie

Pipe Demonstrator: Differences of GERG and DC92 for DC92(-wide) gases and Hydrogen at Demand Node



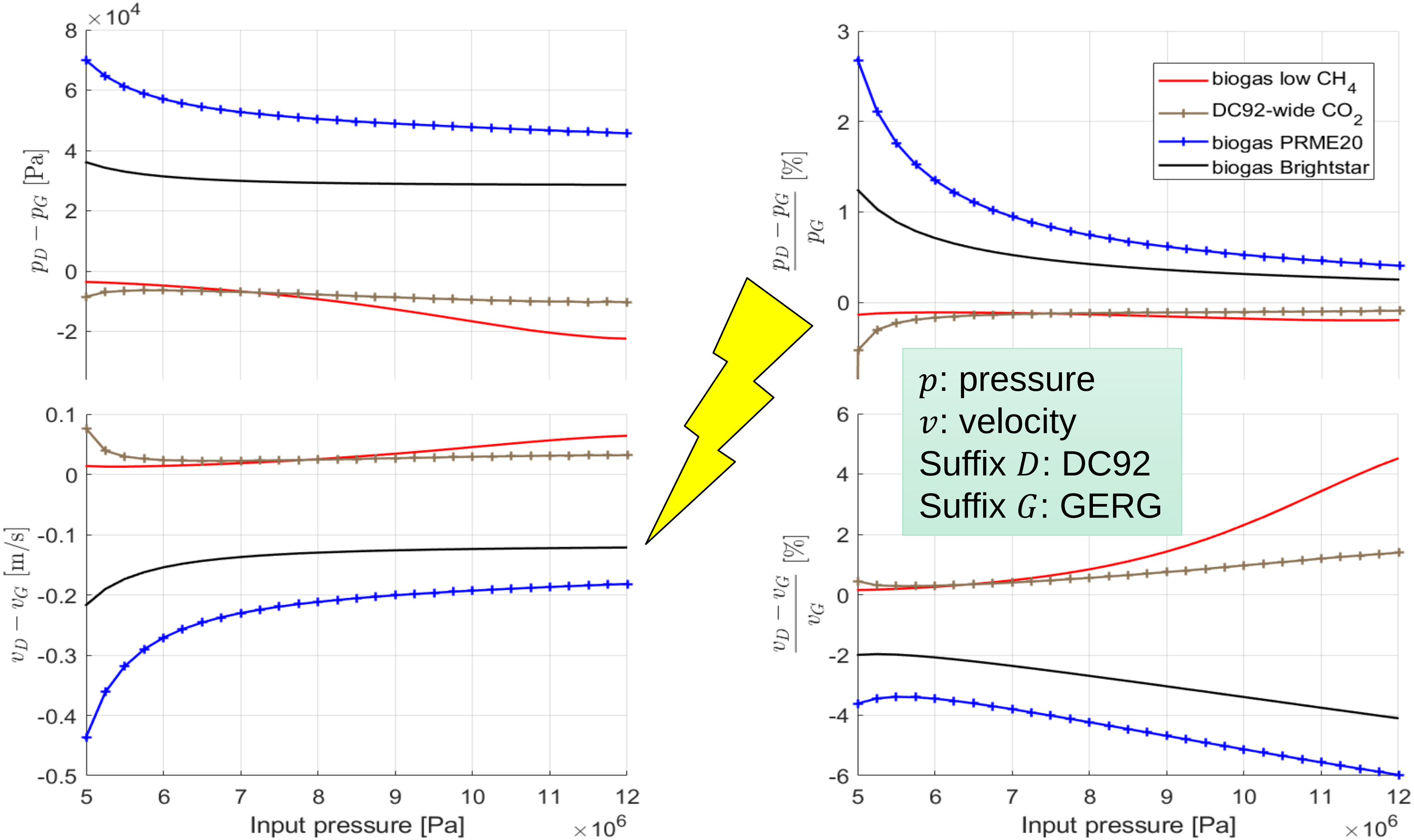
p: pressure
v: velocity
Suffix D: DC92
Suffix G: GERG

Gefördert durch:

Bundesministerium für Wirtschaft und Energie

Fraunhofer SCAI

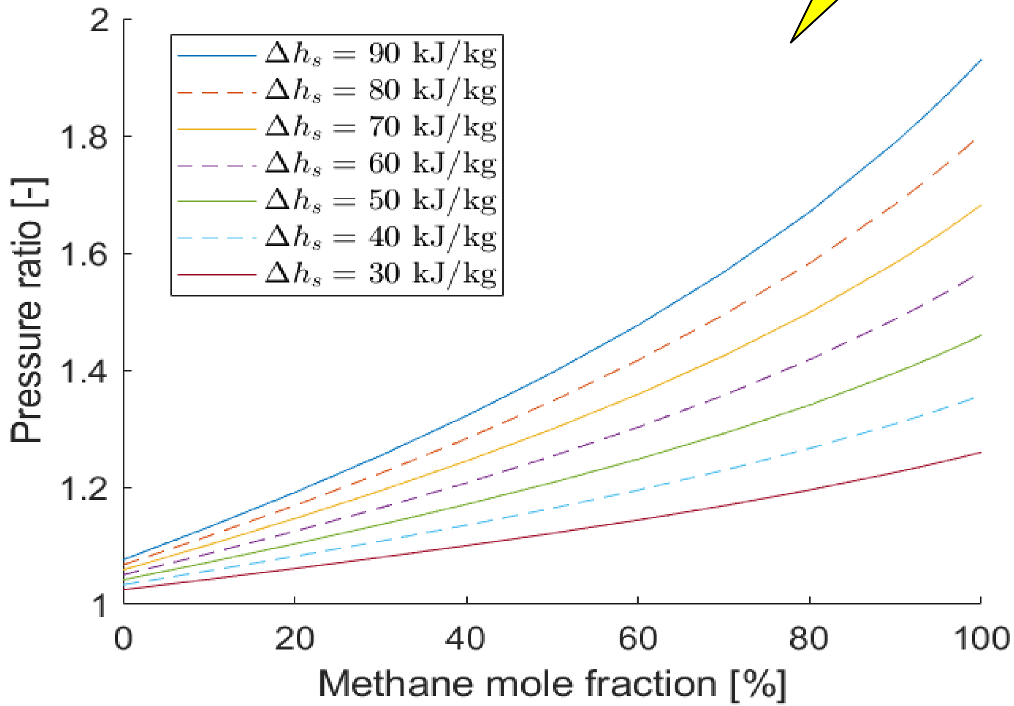
Pipe Demonstrator: Differences of GERG and DC92 for non-DC92 gases Including Biogases at Demand Node



Gefördert durch:

Compressor Map Shifting – Exemplary Results: Pressure Ratios for Methane-Hydrogen Compositions

- Pressure ratios of a compression process with Δh_s ranging from 30 to 90 kJ/kg versus methane mole fraction (GERG):
- Pressure ratios for H_2 are between 1.025 and 1.075 only!



- As a guideline:

For a compressor with a maximal pressure rate of 1.4 for natural gas (1.7 for methane), this is reduced to approx. 1.04 (1.08) for H_2.

Gefördert durch:
Bundesministerium für Wirtschaft und Energie

Method for Analysis of Hydrogen Injection into a Long-Distance Gas Transport Network

Phase 1: Setup

a) gas network, including existing supply nodes

b) scenario data – in particular, estimate PtG power profiles per state:

   a) From public data, obtain fraction of produced from installed onshore wind power

   b) From public data, estimate load profiles: It is assumed here that wind power which is currently not directly used by customers shall be converted to gas. Average hourly power demand profiles are assembled for households and businesses, and characteristic load profiles for weekdays, Saturdays, Sundays in summer and winter.

   c) From public data, obtain state-specific data:

$$P_{wind.installed}, P_{PtG.installed}, P_{PtG.max}, n_{population}, P_{base}$$

   d) Based on data above, perform estimation of PtG power profiles

c) locations of H_2 injection nodes and their connection to the network

Gefördert durch:

Bundesministerium für Wirtschaft und Energie

Fraunhofer SCAI

Method for Analysis of Hydrogen Injection into a Long-Distance Gas Transport Network

Phase 2: Simulation-Based Analysis

a) steady-state scenario(s):

- At least one basic scenario with injections corresponding to already known PtG projects should be analyzed.
- Balancing these PtG injections to the demands given reveals amounts of gas from non-renewable resources still needed.
- The simulation results show local distributions of gas from renewable vs. non-renewable resources, and performance of compressor stations, in particular.
- Compressor characteristics are shifted during simulation and have to be analyzed in order to assess whether all installed machine units have a sufficient performance.

b) transient case(s), particularly using the PtG power profiles per state

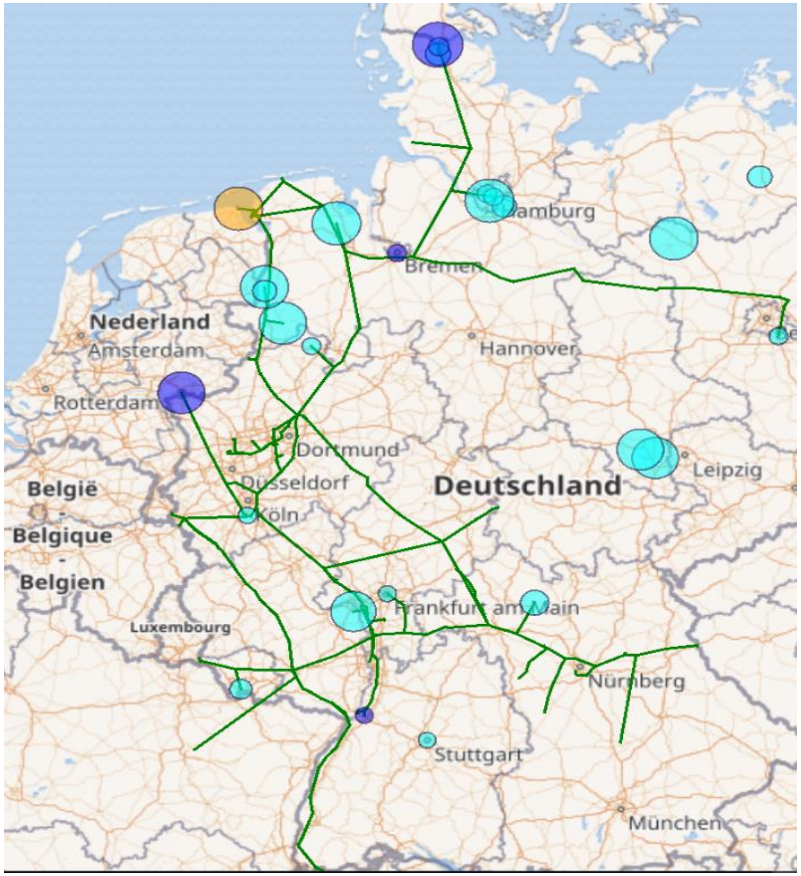
c) transition to a network with gas from 100% renewable resources

Gefördert durch:

Bundesministerium für Wirtschaft und Energie

Exemplary Application – partDE-Hy Demonstrator

- partDE-Hy network on Open Street Map (left) and in MYNTS (right)



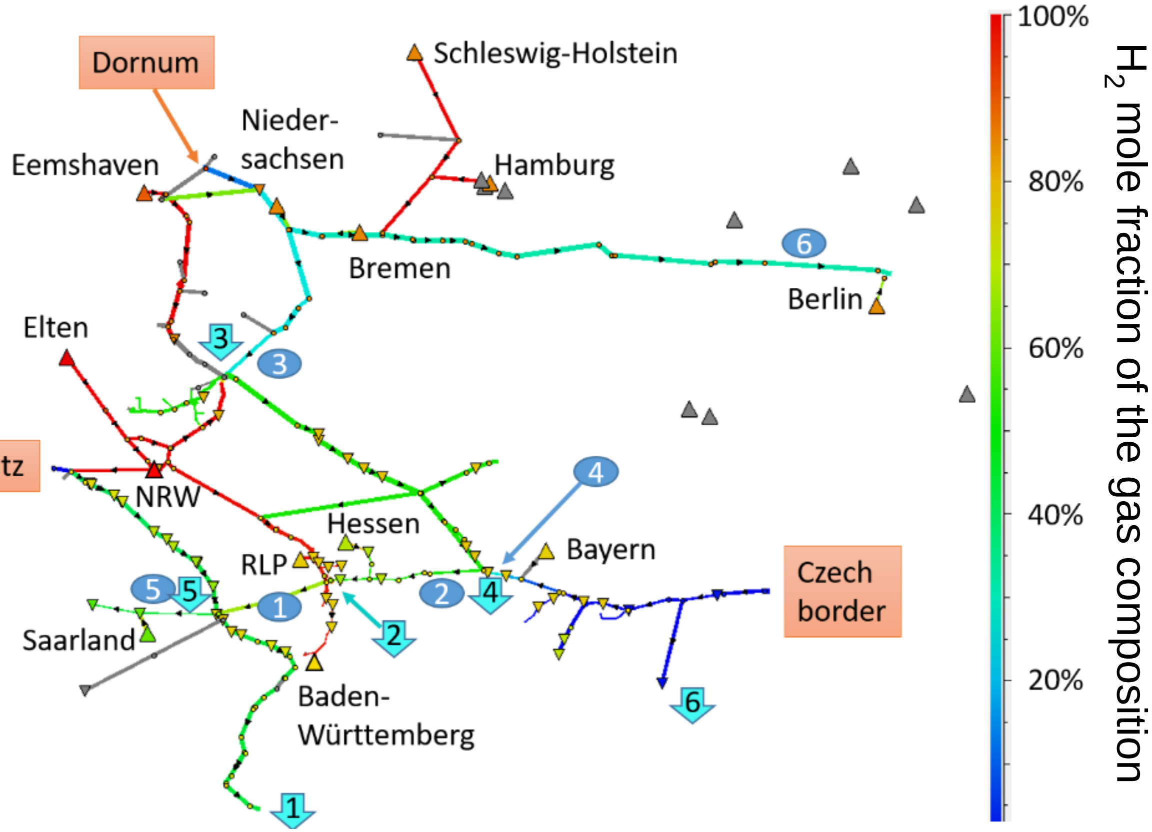
Gefördert durch:

Bundesministerium
für Wirtschaft
und Energie

Fraunhofer
SCAI

MYNTS Simulation Model of partDE-Hy v.2.0

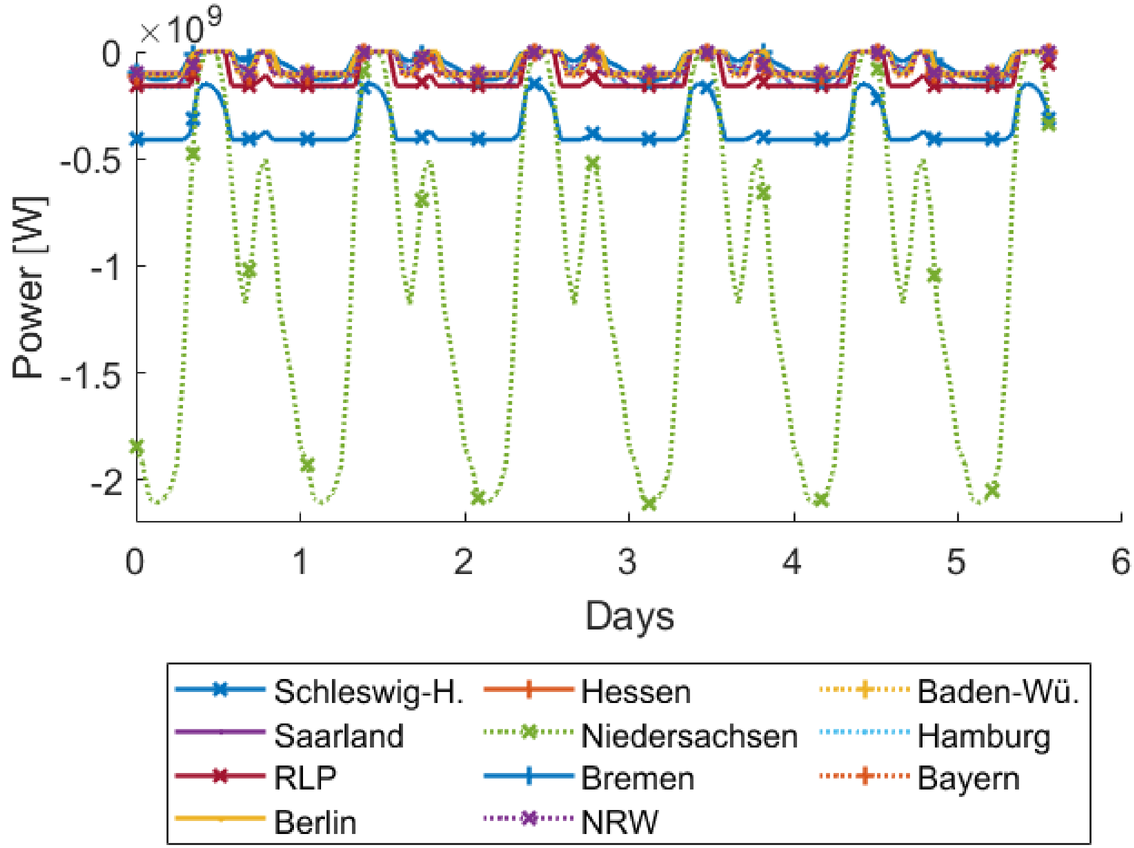
- injection nodes (orange triangles)
- pressure supplies (orange)
- demands (cyan) selected for analysis
- edges (blue) selected for analysis
- and steady-state simulation result with GERG showing hydrogen mole fractions (edge-color)



Gefördert durch:

partDE-Hy – Injection Profiles

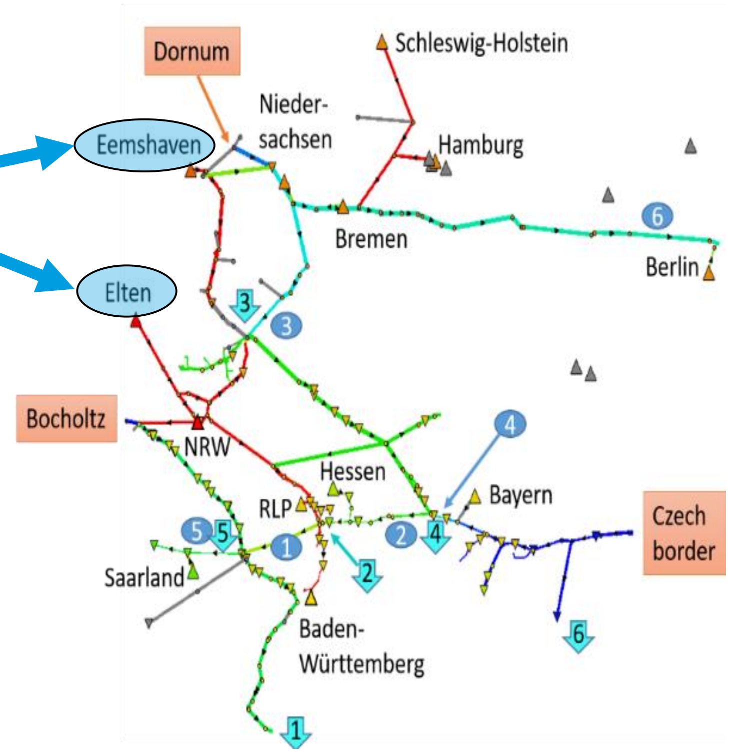
- P_PtG injection profiles (average wind power, Saturdays in winter)
- y-axis: power value [MW] at given node (inputs are negative)
- Schleswig-H. = Schleswig-Holstein
- Baden-Wü. = Baden-Württemberg
- NRW = Nordrhein-Westfalen
- RLP = Rheinland-Pfalz



Gefördert durch:

partDE-Hy – Scenarios Considered Here

- Base scenario (S-BA)
  - low to moderate injection mainly from two realistic locations (NL)
  - used to assess amount of natural gas still needed in the near future
- Scenario with more hydrogen (S-HY)
  - moderate to high injection with a prospective, still realistic magnitude (in the future) and direction, i.e. mainly from North to South
  - used to assess amount of natural gas still needed in the future (mid-term)

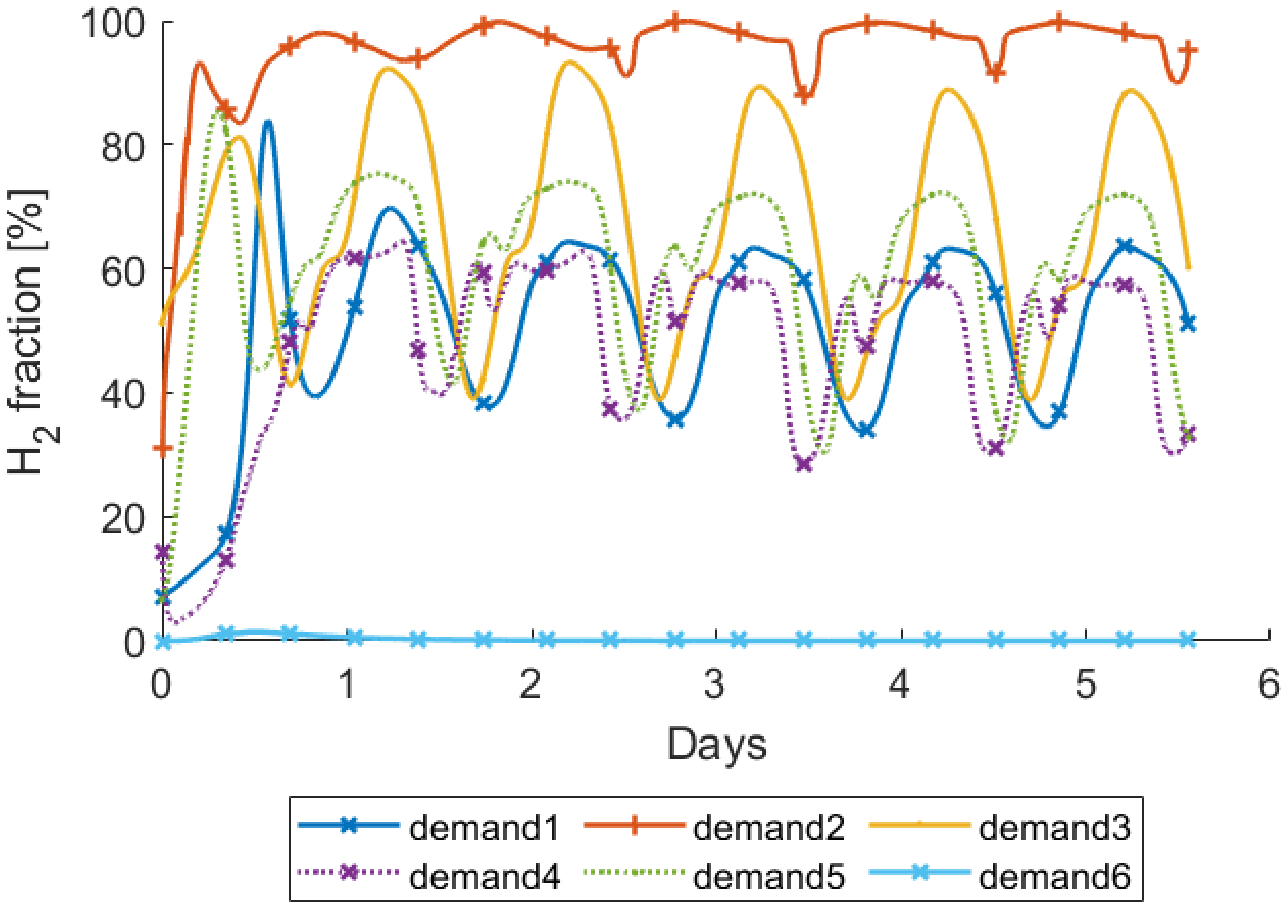


Gefördert durch:
Bundesministerium
für Wirtschaft
und Energie

Results for partDE-Hy –
Locally Quite Different Gas Compositions

- Results for transient S-HY scenario with GERG:

  H_2 fraction at demands



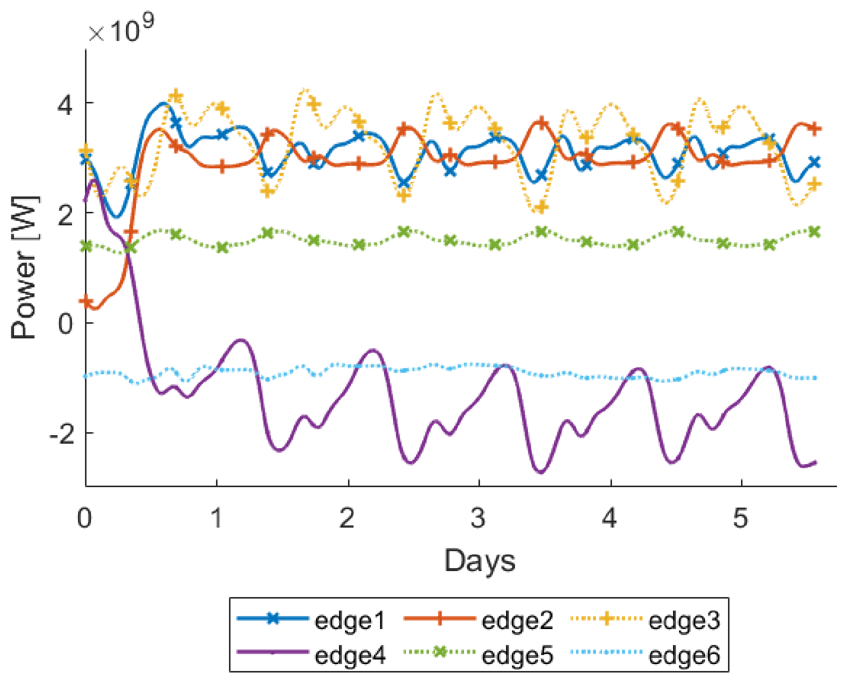
Gefördert durch:

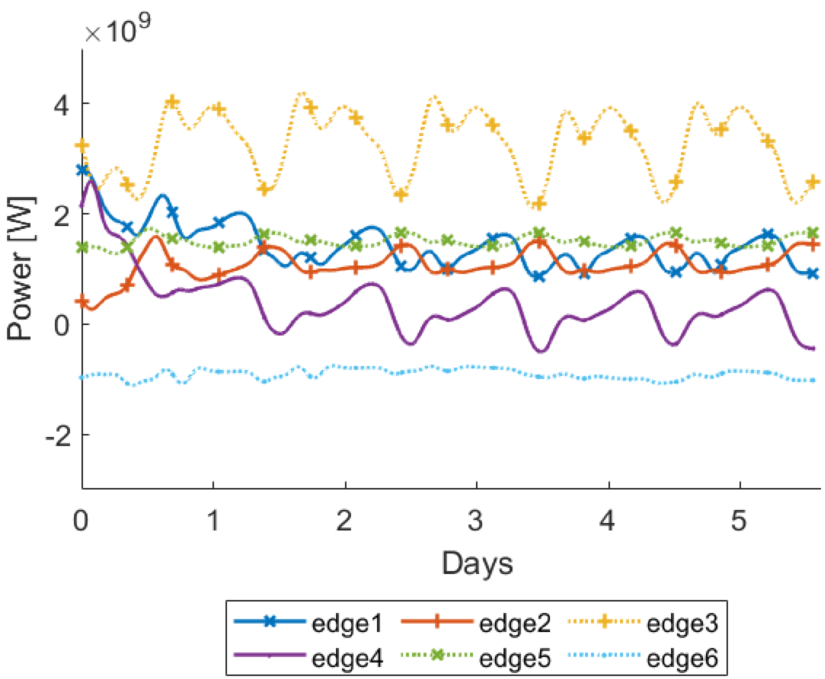
Bundesministerium für Wirtschaft und Energie

Fraunhofer SCAI

Results for partDE-Hy – Comparison of Gas Laws

- Simulation results with GERG (left) and DC92 (right) for the transient scenario chosen (average wind power, Saturday in winter)
- y-axis: power flow at given edge; negative sign means flow in opposite direction to the fixed “standard” flow direction of the edge.





Gefördert durch:
Bundesministerium für Wirtschaft und Energie

Fraunhofer SCAI

Conclusion

- An efficient method for simulating transport of gases from renewable resources as well as impacts of H_2 injection into gas networks was developed.
- A novel set of realistic long-distance gas transport scenarios (partDE-Hy) for a decisive part of Germany with H_2 injection nodes based on a study of wind power and power-to-gas plants as well as a simple pipeline model for testing biogas, syngas, natural gas and hydrogen qualities were developed.
- For both models, GERG is more accurate; for the simple pipeline model with 100 km length, GERG and DC92 can differ up to 2.8% in P and 6% in v
- Simulation with GERG at least as fast as with DC92 → GERG should be used!
- For H_2 and realistic scenarios, compressors' $P_{ratio} \in [1.025 ; 1.075]$ only.
- Results for partDE-Hy indicate that with larger H_2 injections, considerable flow shifts and locally quite different gas compositions over Germany can be expected, and a pure H_2 network would need large additional injections, favorably from the northwestern part of Europe.

Gefördert durch:

Bundesministerium für Wirtschaft und Energie

References

1. Clees, Tanja ; Baldin, Anton ; Klaassen, Bernhard ; Nikitina, Lialia ; Nikitin, Igor ; Spelten, Philipp: Efficient method for simulation of long distance gas transport networks with large amounts of hydrogen injection. Energy Conversion and Management. Accepted for publication.
2. Clees, Tanja ; Baldin, Anton ; Klaassen, Bernhard ; Nikitina, Lialia ; Nikitin, Igor ; Spelten, Philipp: Efficient Modeling and Simulation of Long-Distance Gas Transport Networks with Large Amounts of Hydrogen Injection. In: Procs. 15th SDEWES Conference, (online) Sep 1-5 2020, Cologne, Germany.
3. Clees, T., Baldin, A., Benner, P., Grundel, S., Himpe, C., Klaassen, B., Küsters, F., Marheineke, N., Nikitina, L., Nikitin, I., Pade, J., Stahl, N., Strohm, C., Tischendorf, C. and Wirsen, A., MathEnergy – Mathematical Key Technologies for Evolving Energy Grids. In: S. Goettlich, M. Herty and A. Milde, Eds., Mathematical Modeling, Simulation and Optimization for Power Engineering and Management, Mathematics in Industry 34, Springer, Heidelberg, ISBN 978-3-03062731-7

Gefördert durch:

Bundesministerium für Wirtschaft und Energie

Thanks for Your Attention

www.mathenergy.de

tanja.clees@scai.fraunhofer.de

Gefördert durch:

Bundesministerium für Wirtschaft und Energie

Fraunhofer SCAI