Integration of Renewable Gases into the Gas Market: A Nonlinear Optimization Approach

Supported by:
Federal Ministry for Economic Affairs and Energy
on the basis of a decision by the German Bundestag

Sebastian Kolb, Marius Dillig, Jürgen Karl

Chair of Energy Process Engineering (EVT), Friedrich-Alexander Universität Erlangen-Nürnberg, Fürther Str. 244f, 90429 Nürnberg

Motivation

In 2016, about 50% of the German heat demand was covered by natural gas. Only approx. 13% of the overall heat was provided by renewable energies [1]. This leads to high dependencies on natural gas and uncertainties regarding future security of supply and prices. In order to reduce those issues, numerous technologies aim to produce substitutes for natural gas from renewable energies:

- Biomethane through the treatment of biogas
- Substitute Natural Gas (SNG) by methanation of synthesis gas from thermo-chemical conversion of ligneous biomass
- Hydrogen production by use of renewable electricity (Power-to-Hydrogen, PtH) as well as its conversion to synthetic natural gas (Power-to-Methane, PtM).

The project "SustainableGas" aims to simulate possible market scenarios for the integration of those renewable gases into the German gas market until the year 2050. In order to be able to take into account scenario-based changes in supply and demand structures as well as the fluctuating nature of PtG production, an optimization model for the dynamic calculation of gas prizes and storage operations was developed and implemented.

Modelling Approach

The model combines Agent-Based System Dynamics simulation with nonlinear optimization (figure 1). By changing exogenous market conditions as well as shares of renewable gas technologies, different scenarios and their impacts on the German gas market can be evaluated dynamically.

Detailed models of different PtM-, PtH-, Biomethane- and SNG-plants in the multimethod modelling software AnyLogic generate hourly values for productivity and prices based on market and weather conditions for each plant built in the scenario. The performance data are gathered as monthly cumulative density distributions and transferred to a nonlinear optimization equilibrium model after each simulation year. The optimization model maximizes the consumer surplus (CS) – which is defined as the difference between Willingness to Pay (WTP) and costs (C) – by varying monthly gas prices and storage operations considering supply and demand:

$$\max_{\Delta P_m, St_m}\left(\sum_{i=1}^{12} CS_{(i)}\right) = \max_{\Delta P_m, St_m}\left(\sum_{i=1}^{12}\left(WTP_{(i)} - C_{(i)}\right)\right)$$

This enables to model a gas operator, which mimics the real gas market behavior and compensates seasonal differences in demand and prices by strategically storing and releasing gas.

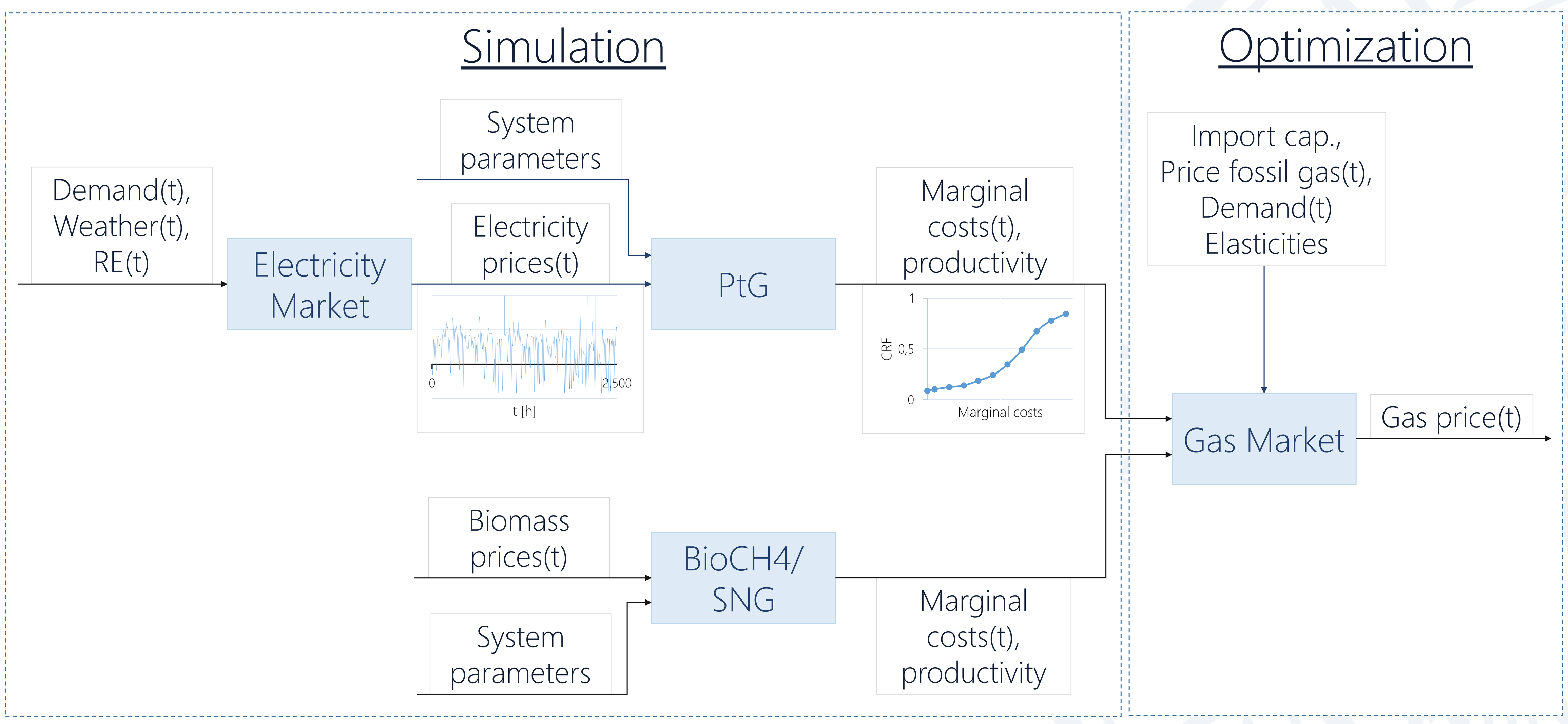

Figure 1: Flow sheet of the gas market model

First Results

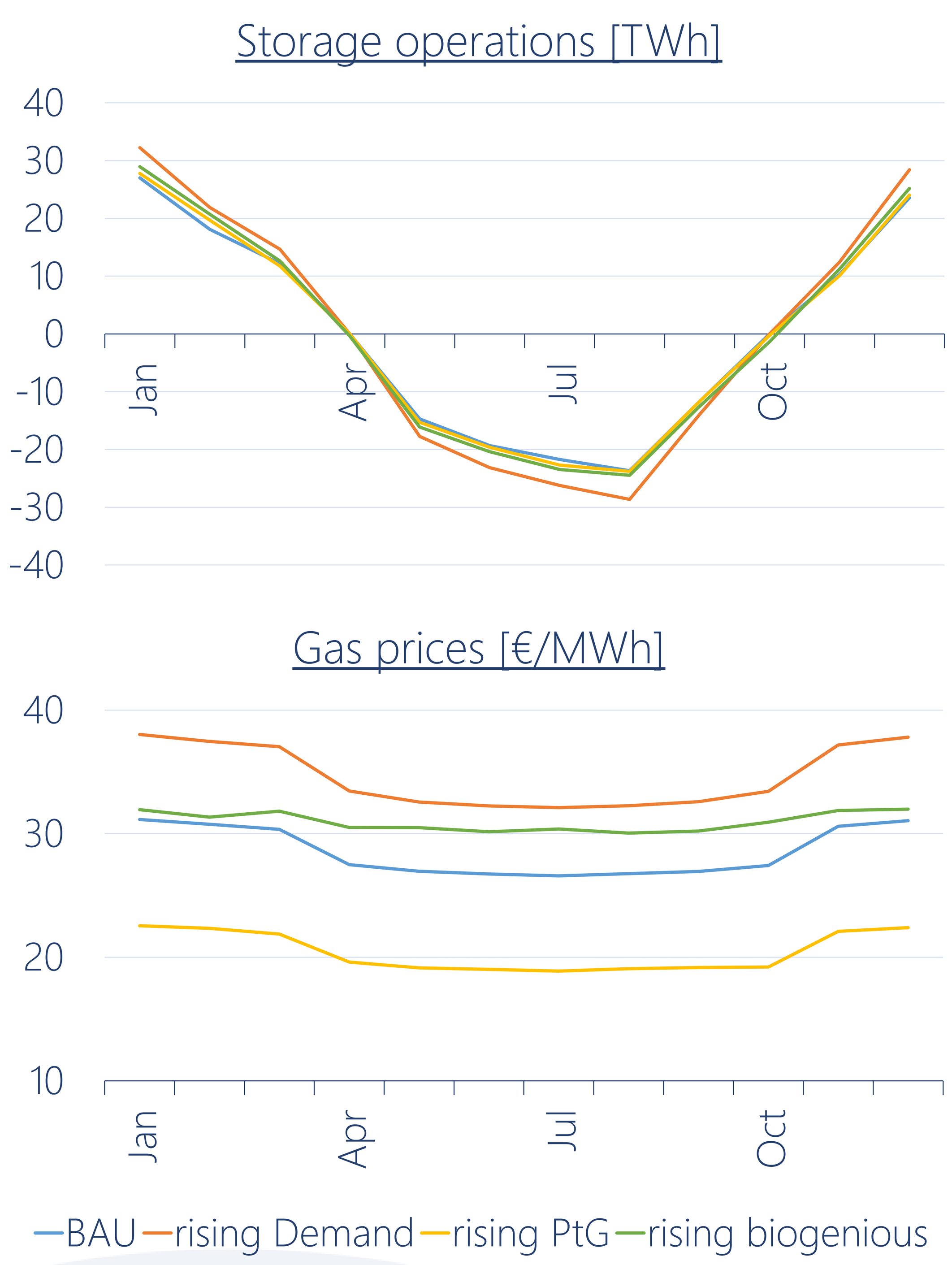

Figure 2: Storage operations and gas prices in different scenarios

Comparisons of the optimization model with historic values showed a high degree of consistency. When changing different input parameters, the model is able to return the corresponding ideal gas prices and storage operations (figure 2). Rising demands for example lead to more storage operations and higher gas prices. A higher share of continuously feeding biogenous gases results in a smoothing of the price curve, whereas more PtG has the potential to reduce gas prices. From a microeconomic perspective such low prices indeed won't allow profitable operation of the PtG-plants.

In the next step, this model can be combined with scenarios for the development of renewable gases or an optimized expansion planning to dynamically simulate future scenarios for the German gas market. The future scenarios will in particular consider environmental impacts and public acceptance indicators provided by project partners from social and environmental sciences.

[1] Federal Ministry for Economic Affairs and Energy, Energy Data, www.bmwi.de

Sebastian Kolb, M.Sc.
+49 (0)911/5302-9028
sebastian.kolb@fau.de

Lehrstuhl für Energieverfahrenstechnik
Prof. Dr.-Ing. Jürgen Karl