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The future electric power system: Impact of Power-to-Gas by interacting with other renewable energy components

Editha Kötter [a,*], Ludwig Schneider [a], Frank Sehnke [b], Kay Ohnmeiss [b], Ramona Schröer [c,1]

[a] RLI – Reiner Lemoine Institut gGmbH, Ostendstraße 25, 12459 Berlin, Germany
[b] ZSW – Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg, Industriestraße 6, 70565 Stuttgart, Germany
[c] juwi international GmbH, Energie-Allee 1, 55286 Wörrstadt, Germany

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ABSTRACT

The storage of fluctuating energy production is a major challenge on the pathway to a fully renewable electricity supply. This paper investigates the impact of the storage technology Power-to-Gas (PtG) in the implementation of the Energiewende. A detailed cost optimisation model based on data from an existing system in an actual German region describes the optimal composition and application of energy supply technologies. The electricity demand of the region can be covered with 100% renewable energy (RE) at a levelised cost of electricity (LCOE) of 11 ct/kW h_{el}. A 100% RE supply is possible with or without PtG. However, long-term energy storage system such as PtG reduce the LCOE of the energy system significantly. We conclude that the capital expenditures (CAPEX) of PtG must at least reach values below 2500 €/kW_{el} to compete with short-term solutions such as Li-ion batteries. Beside PtG this investigation identifies several system components with extensive impact on LCOE and demand of long-term energy storage, such as Power to Heat (PtH), wind turbine technology and hydropower. The combination of such influences increases the impact of each of them on the LCOE. Several energy system components can positively influence the implementation of the Energiewende, PtG is one of them.

1. Introduction

Storage of renewable energy (RE) will pose a decisive challenge on the pathway to a fully renewable energy supply. Power-to-Gas (PtG), a technology that takes surpluses of RE and produces synthetic natural gas (SNG) by means of electrolysis and methanation provides an appropriate long-term storage solution, since SNG can easily be fed into an existing gas grid infrastructure, whether it is in general only possible to a limited extend.

Due to the limited potentials of pumped hydroelectric storage (PHS) [1,6,16,32,42] and biogas plants [45], PtG has the capability to become the principal energy storage concept for large-scale implementations. The capacity of natural gas reservoirs in Germany amounts to 219 TW h_{th} [15], giving it the highest energy storage capacity compared to other technologies [43,39,33].

Since 2012 several implemented PtG plants with sizes between 25 and 6000 kW_{el} have proven their technical feasibility [7,9,14]. However, the economic potential of PtG to trade on the energy exchange market has not yet been demonstrated, as PtG competes for energy surpluses against energy export and Power-to-Heat (PtH) [2]. Other studies show that PtG becomes increasingly important in scenarios with a high share of RE [26]. The optimisation of the entire energy system of the Berlin-Brandenburg region by [24] shows that PtG is a main part of a cost optimal energy system with RE shares above 75%.

However, the optimal usage of PtG within a dynamic and highly detailed power supply system based on an existing model region has not yet been studied. This study investigates the role of PtG within a future energy system via a complex dynamic optimisation model, including PHS, PtH, and waste heat utilisation, using elaborated potential analysis. The question of how the integration of PtG in an energy system with high shares of RE is influenced by financial conditions or the interaction with additional technology components has not yet been answered. The following sensitivity analyses will investigate this question in detail.

Theorem 1. *PtG will prevail in dynamic energy systems against other innovative and favourable balancing components, such as PtH or lithium batteries, despite its comparatively low system efficiency.*

* Corresponding author.
E-mail address: Editha.Koetter@rl-institut.de (E. Kötter).
[1] Current address: Fraunhofer Institut für Windenergie und Energiesystemtechnik, Königstör 59, 34119 Kassel, Germany.

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2. Methods

2.1. Model region

To investigate PtG in an energy supply system with 100% RE an appropriate model region in Rhineland-Palatinate is defined. The selected region already has a high share of RE of 59% (calculated with [8]) and corresponds approximately to the power grid region *Trier-Amprion 5*. The geographical size corresponds to 1% of Germany. It is a rural area with a high percentage of forests and agricultural areas. The map in Fig. 1 illustrates the position and dimensions of the model region including administrative borders, major cities, and rivers. The model region is divided into 17 subregions based on administrative borders and the existing 110 kV electricity grid.

2.2. Energy system model

The model is built with P^{2}IONEER [36], a component based energy flow simulation with a resolution of 15-minute time-steps (see Fig. 2). The analysed scenarios refer to a 100% RE share in the year 2030. The amount of conventional energy is, however,

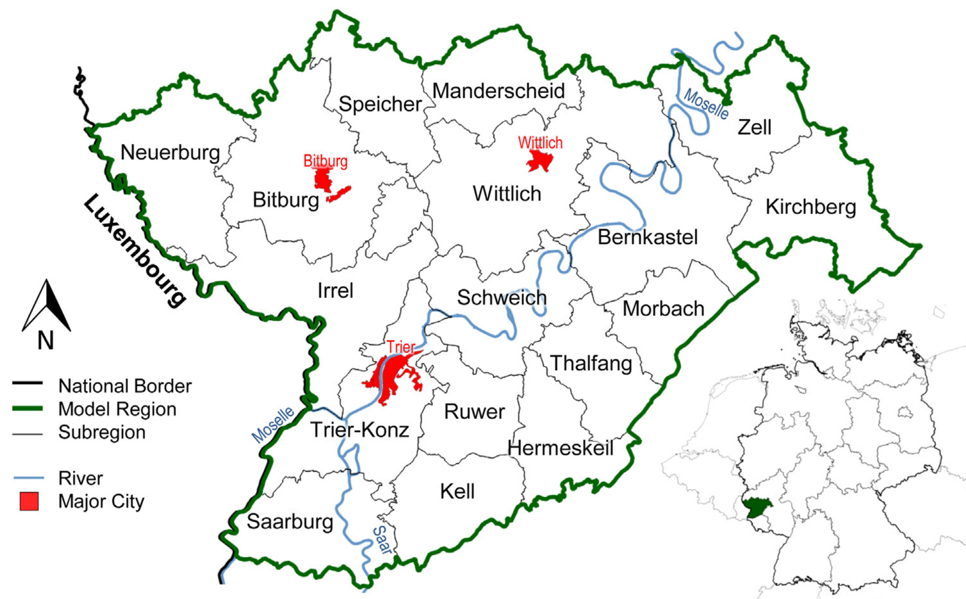

Fig. 1. General map of the model region [4].

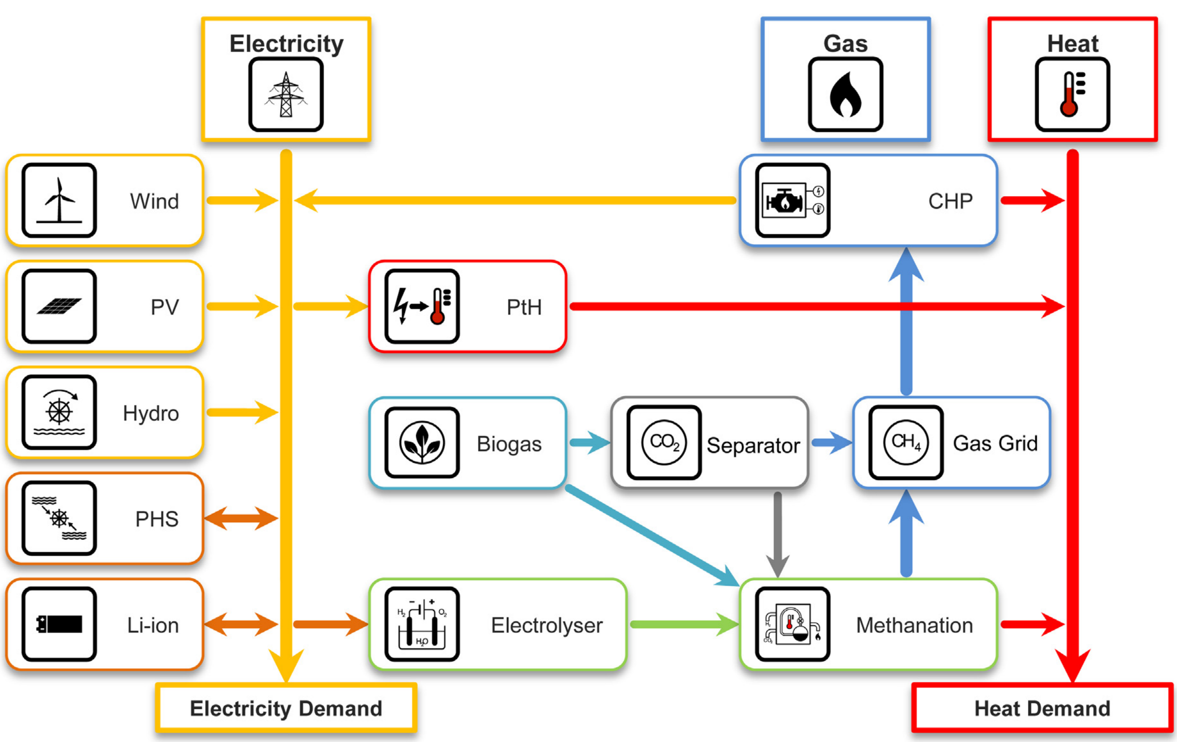

Fig. 2. Flow chart of the energy system model.