Long-term modelling of power-to-gas capacity developments and operation in the German power system

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Overview

The German Government has formulated an ambitious program to promote electricity generation from renewable energy sources (RES). Given the target of an 80% share of RES in electricity generation in 2050, fundamental changes regarding the power system will affect the need for back-up generating and energy storage capacity, since the majority of RES will be wind and photovoltaic (PV), both fluctuating energy sources. Large capacities of expected excess electricity can be stored in the form of synthetic natural gas (SNG) or hydrogen via power-to-gas technology (PtG) in the gas network. PtG connects electricity and gas networks by converting excess electricity into gas via a one or two-step process. First, water electrolysis produces hydrogen and second, hydrogen and carbon dioxide may subsequently be converted into methane. The aim of this analysis is to assess, from a system perspective, demand, location and effective operation modes for PtG in the long-term, as well as to gain an understanding of the effects of PtG on RES integration and thermal power plant operation.

Methods

Two models are developed to assess the future integration of PtG-units into the energy system. Both models' objective is to minimize total system expenditures. The multi-period linear optimisation model PERSEUS-NET-LT is a fundamental bottom-up energy system model able to perform an integrated dispatch and investment planning to analyse the long-term development of the German power system. Electricity transmission grid constraints are taken into consideration using a DC-loadflow approach. Hence the installation of new thermal power plant capacities is based on a nodal-pricing approach enabling the model to calculate the size and the location of new capacities. Since the size of the optimisation problem restricts the temporal resolution and the possibility to model non-linear dependencies, a more detailed dispatch model is developed. This is based on a rolling time horizon approach and a higher temporal resolution, featuring a full 8760 hours resolution. It is employed to analyse the effects of fluctuating RES as well as storage capacity, especially PtG, on the power system in detail. This multi-period mixed integer optimisation model PERSEUS-NET-ST also includes a more detailed representation of power plant commitment restrictions including minimum up- and downtimes as well as part load efficiency losses.

Results

Three scenarios are considered. The first scenario concentrates on hydrogen as PtG output, the second scenario concentrates on methane as PtG output and the third scenario also concentrates on hydrogen but does not consider electrical transmission grid restrictions. Regarding the development of generation capacity, the conventional power system in 2050 comprises about 25-26 GW of gas-fired power plants, 15-16 GW of lignite-fired power plants, about 7 GW coal-fired power plants and about 7 GW of hydro-power plants. While no new hydro-power plants are constructed in the scenarios, the solution contains about 9-21 GW of newly installed PtG-units, depending on the scenario. Since methanation is more cost intensive than pure hydrogen production, the amount of PtG units in the second scenario is lower than in the first or third scenario. The demand for long-term storage shows a strong correlation with the share of RES in electricity generation. Hence the installation of units occurs mainly in future time periods when the share of RES is between 65% and 80% of electricity generation. In all three scenarios, significant amounts of RES-electricity generation cannot be integrated into the system. However the amount of curtailed energy is less in the scenarios with higher PtG capacity installed, especially regarding offshore wind energy. Consequently the amount of product gas from PtG-conversion in the scenarios differs between 20 and 80 TWh energy content. Assuming a constant withdrawal rate of product gas from the storage, the required maximum energy storage volume is about 5 TWh (See Figure 1) and thus far below the maximum available storage capacity in the natural gas infrastructure.

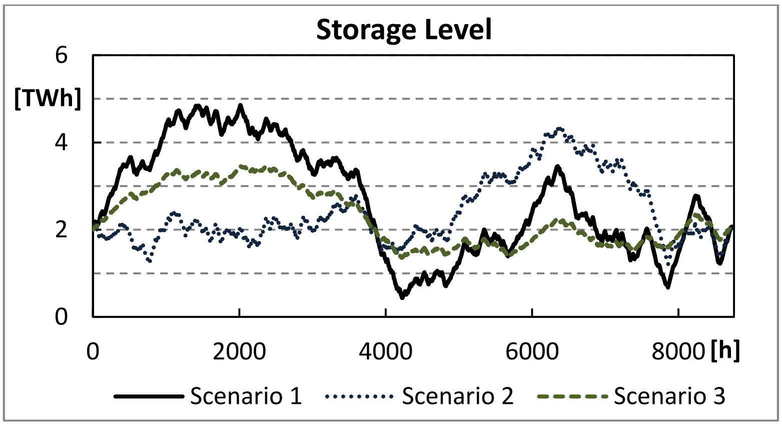

Figure 1: Storage level over the year, starting in winter.

Regarding the overall electricity mix, the short-term and long-term models show similar results, with a slightly higher share of coal-fired generation and lower shares of gas- and lignite-fired generation in the short term model. The full load hours of conventional power stations show a significant decline over the considered time-frame. The results from the long-term model were verified by the results from the short term model, taking into account a detailed feed-in characteristic of fluctuating energy.

Conclusions

The results show that there is a significant demand for long-term electricity storage, especially in northern Germany, where the majority of PtG-units are located in the model runs, to integrate offshore wind energy. Due to the rising share of RES over time, this demand occurs mainly in 2040 to 2050 when there are large amounts of fluctuating electricity generation. Even when no grid restrictions are considered (no spatial mismatch) there is a significant demand for storage capacity to balance the temporal discrepancy between electricity generation and demand. Hence network extension can replace the demand for storage capacity by a limited amount only (ca. 2 GW). The analysis does not yet include further measures to integrate intermittent RES, e.g. network expansion, smart grids and demand side management, which offer significant potential to reduce the demand for PtG. These are promising fields of research for future work.

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