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The potential of decentralized power-to-heat as a flexibility option for the german electricity system: A microeconomic perspective☆

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HIGHLIGHTS

- We investigate the future potential of decentralized Power-to-Heat.
- Focus lies on hybrid Power-to-Heat systems with condensing gas or oil boiler.
- We analyze the economic incentives at household level.
- Simulation of heat load profiles and spot prices in 2020.
- Savings prove modest as long as household electricity prices are not heavily reduced.

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ABSTRACT

One fundamental challenge of the German energy transition for the electricity market is the growing imbalance between inflexible generation and generally inelastic load. Against this background, we investigate the future potential of decentralized Power-to-Heat (P2H) as an additional demand-side flexibility option for the German electricity system. Precisely, we analyze the case of hybrid systems, where conventional gas and oil condensing boiler systems are equipped with an electric heating rod. In contrast to previous approaches, we set our focus on the economic incentives at household level: only if the switch to a P2H-hybrid system can reduce individual heating expenses significantly, a considerable number of these systems will be installed. For this purpose, we implemented an integrated approach combining three distinct simulation modules. First, a stochastic simulation of the electricity spot market prices in 2020 was conducted. Second, average heat load profiles were generated based on a standard bottom-up analysis. Both results were then fed into an optimization model calculating the cost-minimizing paths of heat generation at household level during the year 2020. The simulated annual savings prove modest as long as household electricity prices are not heavily reduced through political influence.

1. Introduction

1.1. Motivation

The transition of Germany's energy system (Energiewende) is proceeding rapidly and has recently generated considerable research interest. According to the 2013 German Federal Governments coalition agreement, nuclear power is about to phase out in 2022, while energy from renewable resources has to account for at least 40% of the German gross electricity consumption in 2025 (CDU/CSU SPD, 2013).[1] In 2000, the share of electricity from renewable energy sources accounted for 6.2% of gross electricity consumption, whereas it was already above 25.3% in the year 2013 (BMWi, 2015b). This rising share of electricity from volatile renewable energy sources such as wind power and photovoltaics has created complex challenges for the power system (e.g. Schleicher-

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[1] In the aftermath of the Fukushima Daiichi nuclear disaster in summer 2011, the German Bundestag agreed to phase-out nuclear energy by 2022.

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Tappeser, 2012; BMWi, 2015a). One fundamental challenge in the system integration of renewable energy sources for electricity generation (RES-E) is the increasing imbalance between volatile generation and generally inelastic load. Accordingly, demand for flexibility to maintain grid stability and security of supply is rising along with increasing amounts of volatile RES-E.

Alongside the challenges of the electricity sector, the sluggish decarbonization of the heating sector is gaining attention. This is also addressed in the coalition agreement and it is emphasized that the heating sector is of significant importance for a successful energy transition (CDU/CSU SPD, 2013). Residential heating accounted for almost 23% of Germany's final energy consumption in 2012 (Destatis, 2013; AGEB, 2014). In order to develop the German heating market towards the use of more renewable energy sources, a number of laws have been implemented by the German government to legally support these efforts. For instance, the Renewable Energy Heating Act (EEWärmeG) has set the goal to increase the share of renewable energy sources in residential heating and cooling provision to 14% by 2020. In this context, the exploitation of potential surplus electricity from renewables for other applications such as heating purposes is recommended specifically. The Federal Ministry for Economic Affairs and Energy (BMWi) gives a concrete example: "In times of low residual load, electricity can also generate heat directly, thus saving fuel oil or gas" (BMWi, 2015a).

In this context, Power-to-Heat (P2H) systems have been propagated as a potential tool to enhance demand-side flexibility and to interlink power and heat markets. Regarding P2H most attempts have focused on identifying its potential for district heating purposes and/or as a part of virtual power plants providing system services. Since only 5.4% of the German building stock (Destatis, 2011) is connected to a district heating network, decentralized P2H systems seems worth a consideration.

Our paper adds a new perspective to the debate by investigating the future potential of decentralized P2H systems to serve as an additional flexibility option for the German electricity system. Specifically, we focus on two forms of P2H-hybrid systems. In the first one, a conventional gas condensing boiler, a hot water storage tank and an electric heating rod are combined. In the second one, the same is done with an oil-fired condensing boiler.[2] The appeal of these hybrid solutions is obvious both from a technical and an economic perspective. With a market share slightly above 92% of central heating systems, gas and oil-fired heating boilers currently constitute the most frequent technologies in the German heating market (BDH, 2014). Therefore, the transformation of these systems can create a channel for delegating significant amounts of excess electricity to a useful purpose. In 2012, the gas and oil consumption for purposes of heating and hot water in single and two family houses amounted to roughly 250 TWh (Destatis, 2013). Even if only a small share of this energy demand is provided by RES-E, this could be a significant step towards the use of less fossil fuels and an increasing share of renewable energy in the residential heating sector. Moreover, in contrast to pure electric heating systems, these hybrid systems do not cause a permanent increase in electricity demand. Provided they are operated based on economic principles, a demand effect will only occur in those times were the costs of electricity-based heating are comparatively low. In presence of appropriate price signals on the electricity retail markets, this would contribute to the matching of electricity demand with volatile electricity supply, thereby exerting a positive impact on system stability.

Economic incentives are likewise central for the investment decision: the potential societal gains will only be realized if heating owners can expect to recoup the costs of modifying their heating system (purchase of electric heater, communication equipment etc.) in reasonable time through lower heating expenses. The focus of our analysis will therefore be on the (micro-) economics of P2H-hybrid systems. Based on the premise of time-flexible electricity retail prices in the future, the potential annual cost savings from switching to a hybrid system are simulated for the exemplary year 2020.

1.2. Research context and related literature

There is a growing strand of literature concerning flexibility requirements and suitable measures in the presence of energy system transformation. Against this backdrop Lise et al. (2013) quantify the integration costs of steadily increasing intermittent supply with an adaption cost model and find growing demand for flexibility in the power system besides flexible supply. They identify six measures suitable to enhance system flexibility: (in order of increasing cost) demand response, interconnection capacity, storage capacity, backup capacity, intermittent RES-E curtailment and load shedding.[3]

Concerning the involvement of the demand side, researchers have discussed different approaches to interlink the electricity market with the heating market. A part of this literature is focused on the economic potential of electrical load management by the heating sector. Fehrenbach et al. (2014) investigate the capabilities of heat pumps and (micro-) combined heat and power systems to provide flexible consumption capacity in times of imbalance in the electricity market using an optimization model. Although the authors see economic potential for heat pumps and (micro-) combined heat and power systems under the premise of an optimal and central organized system, options to use these systems in large-scale load management are rather limited in the near future in Germany. Hao et al. (2015) and Mathieu et al. (2015) examine the potential of residential thermostatically controlled loads (air conditioning, water heaters, heat pumps) in California to serve as providers of system services and estimate cost and revenues for these devices. Both papers come to the conclusion that the technical potential is high and expected revenues are only for some technologies sufficiently large.

Regarding P2H as a demand side flexibility option, Böttger et al. (2014) analyze the potential of P2H in German district heating grids by combining district heating demand profiles and forecasted negative residual loads. The authors find that the technical potential of P2H in district heating grids accounts for 6 GW in 2015 and 20 GW in 2030. In this context Böttger et al. (2015) incorporate electric boilers in district heating grids in a fundamental European power market model to investigate the potential of P2H to serve as a provider of secondary control power in Germany. They find that the provision of secondary control power via electric boilers in district heating grids may reduce the need for must-run power plants and therefore allows both for cost savings and a reduction of carbon dioxide emissions. Bernhard and Fieger (2011) analyze the technical supply side potential of oil-fired heating systems combined with a heating rod to provide negative control power. They find an average potential of about 1–3 GW per hour.

Different flexibility options have been discussed in the related literature and each one has its pros and cons. However, to our knowledge the individual savings potential of a gas or oil fired central heating systems with a heating rod in the residential

[2] Hereinafter both heating systems are referred to as P2H-hybrid systems. For the technical setup please refer to Fig. 6.

[3] Regarding the analysis of other flexibility options, the interested reader is referred to e.g. Schill (2014) – optimal storage – or Klinge Jacobsen and Schröder (2012) – optimal level of RES curtailment.