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Assessing the optimal use of electric heating systems for integrating renewable energy sources

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Abstract

In order to decarbonise the energy system, alternative transition pathways were assessed in recent years that agree on the crucial role of the heating sector, due to its potential to increase the renewable-based share of energy demand and to improve energy efficiency. Simultaneously, the increasing share of fluctuating renewable energy sources (RES), such as wind and photovoltaic, raises the hourly volatility in the energy system and challenges energy utilities. To balance energy demand and RES in an optimal manner storage-based heating systems can be used as flexible loads. This study discusses to what extent smart residential heating systems can contribute to the integration of RES and quantifies the trade-off between electricity savings and flexibility provision, when replacing storage heaters by heat pumps. To answer these research questions a simulation-based scenario analysis is conducted until 2050 encompassing France, Germany and the United Kingdom. These countries are of specific interest due to their substantial share of electric heating as well as their exponentially rising wind and photovoltaic (PV) generation capacities. The study reveals that the long-term potential of heating technologies for the integration of RES is relatively limited in countries such as France or Germany, given the improved insulation of buildings and the seasonal offset between PV generation and heat demand. However, in the short- to medium-term, or in countries with low shares of PV generation but high shares of wind power (such as the UK), heating technologies may facilitate the integration of RES, especially in the absence of alternative flexibility options.

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Keywords: Bottom-up modelling; energy system analysis; heating energy demand; scenario analysis; demand side response

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1. Introduction

In its roadmap for building a low-carbon economy, the European Commission has drafted potential pathways towards an greenhouse gas emission reduction of 80 to 95% compared to 1990 levels [1]. The achievement of this target builds upon two major strategies: a comprehensive diffusion of renewable energy sources (RES) and the extensive use of energy efficiency measures to trigger energy savings. These two cornerstones aim to make the European Union's energy system more secure and sustainable and its economy more competitive.

Various scenario analyses have recently been performed to assess potential transition pathways (see e.g. the comparative study of Förster et al. [2]). The majority of studies agree that the heating sector will play a crucial role in the transformation of the energy system: Its electrification increases the use of RES-based, low-carbon electricity and helps to cut carbon emissions. In addition, the dissemination of highly-efficient heating technologies, namely heat pumps, substantially reduces primary energy demand.

However, RES deployment is expected to be realised primarily in the electricity sector, particularly through the diffusion of fluctuating generation technologies such as wind and photovoltaics (PV). Consequently, the net load which is defined as the national system load minus the generation from RES must be assumed to feature a corresponding increase in hourly volatility in the long run. At present, utilities and grid operators use storage heaters to shave load peaks and ensure a continuous utilisation of the electricity generation and transmission infrastructure, by scheduling them in night time. In the future, utilities might benefit from the shiftable capacity of storage heaters and heat pumps to balance supply and demand and integrate renewable electricity generation.

The research questions presented by the proposed framework are: To what extent can smart residential heating systems contribute to the integration of renewable energy sources? And what is the trade-off between electricity savings and flexibility, when replacing storage heaters by heat pumps?

This study aims to address these research questions by applying two simulation models in the context of a scenario analysis until 2050. It quantifies the extent to which electric heating systems in the residential sector can facilitate the integration of RES and smooth the net load under different pricing schemes. Given that the shape of the net load is also subject to transformation due to changes on the demand side (as demonstrated, for instance by [3]), the impact of electric vehicle charging is explicitly taken into account. The regional scope of this study encompasses France, Germany and the United Kingdom (UK). These countries are of specific interest because France has experienced a substantial electrification of the heating sector over the past decades and the provision of sanitary hot water here relies substantially on storage heater technology [4]. In contrast, Germany is characterised by a clear decline in the installation of night storage heaters. Simultaneously, the installation of wind and PV generation capacities is rising exponentially here and the country has an ambitious strategy for the insulation of buildings. The UK, on the other hand, is much less focused on housing insulation and it propagates the installation of heat pumps instead, aiming to cover 30% of all heat provided using this technology [5].

The remainder of this study is structured as follows: Section 2 introduces the two simulation models applied in this study. Section 3 describes the scenario analysis including the major assumptions and presents the key findings of the two models. Finally, Section 4 contains the conclusions and a critical discussion of the results.

2. Methodological approach

Within this study the energy demand models FORECAST (FORecasting Energy Consumption Analysis and Simulation Tool) and eLOAD (energy LOad curve ADjustment tool) are applied that are frequently used in German and European studies for policy makers and industrial customers [6-9]. FORECAST analysis energy demand on an annual basis, which is subsequently broken down into hourly load curves by eLOAD (see Figure 1). In the following, the structural framework and modelling procedure of both models as well as their linkage are discussed.

FORECAST

The energy demand model FORECAST aims to develop long-term scenarios of the EU28+3 (3: Norway, Switzerland, Turkey) by country up to 2050. FORECAST comprises four individual modules: industry, tertiary and residential module each representing a demand side sector and the rest is captured by the module ‘Others’ containing the agriculture and transport sector. While all sector modules follow a similar bottom-up methodology,