Model-based evaluation of the economic potential of innovative residential heating technologies in TIMES

Daniel FEHRENBACH[1#], Erik MERKEL[2], Ute KARL[1], Russell MCKENNA[2], Wolf FICHTNER[2]

1) European Institute for Energy Research (EIFER), Karlsruhe, Germany, #) fehrenbach@eifer.org
2) Chair of Energy Economics, Institute for Industrial Production (IIP),
Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

(1) Background and Introduction

In the context of the „Energiewende" (energy transition), the German government has set a number of ambitious objectives with regard to energy efficiency and renewable energy sources. While in terms of primary energy consumption, the cross-sectoral objective amounts to a reduction of 50 % until 2050, in the residential sector the objective amounts to -80 % in that year.

In 2010, residential space heating (SH) and hot water supply (DHW) represented 86.2 % of the final energy consumption of the residential sector, corresponding to 28.5 % of the total final energy consumption across all sectors in Germany, making residential SH and DHW supply a key challenge for the Energiewende. Supposed measures for reaching the abovementioned mitigation objectives include energetic renovation of existing buildings and progressively strict efficiency standards for new buildings. Additionally, on the supply side, energy efficient as well as renewable conversion technologies may contribute to achieving the objectives, such as the micro-cogeneration of heat and power (mCHP) and heat pumps (HP).

Furthermore, recent publications discuss possibilities of the residential sector to beneficially contribute to the challenges that the Energiewende imposes on the electricity sector, particularly the growing capacities of fluctuating renewable electricity (RES-E) generation technologies. The German government has committed to an expansion of wind and photovoltaic capacities of 107 GW_{el} as soon as 2020, while this figure is projected to increase to up to 150 GW_{el} in 2050 (Nitsch et al. 2012). Nabe, Hasche, Seefeldt et al. (2011) analyse the potential of electrical load management with residential heat pumps (HP) for the system integration of RES-E technologies. Likewise, flexible fast-ramp-up backup capacity can be provided by mCHP units. In both cases thermal storage is used for temporal decoupling of electrical production or usage and thermal demand.

(2) Methods

For the analysis of such concepts aiming at the creation of techno-economic synergies between the residential heating and the electricity sector as described above, the work presented in this contribution uses an integrated bottom-up technology-explicit partial-equilibrium linear programming (LP) model approach of these two sectors in Germany, with the objective function representing the minimisation of total discounted system expenditures. Optimisation constraints notably comprise the satisfaction of largely model-exogenous heat and electricity demand. Decision variables primarily represent the investment in and the dispatch of energy conversion technologies in the two modelled sectors. Analysing the period from the base year 2010 to 2050, the model is realised in the TIMES energy modelling environment (Loulou et al. 2005).

The characterisation of the electricity sector focuses on a disaggregated representation of the conversion technology capacities, classified by technology type, electrical power and plant vintage. Electricity transport and demand are represented in an aggregated way. In the residential heat sector, this simplification cannot be carried out. Residential heat supply lacks a universally available transport and distribution grid, the vast majority of heat being produced within the object it supplies. Consequently, as opposed to grid-based electricity supply, object-based heat supply units have to match the building they supply.

For this reason, as opposed to the electricity section of the model, in the residential heat section, space heating and hot water demand is classified into 48 classes of building-specific heat consumption and building-external infrastructure availability. The demand is projected until 2050 based on the calculations of a separate building stock model developed in McKenna et al. (2013). Conversion technologies, represented in 45 classes of technology type and thermal power, are allocated to specific heat demand classes. The conversion technology options compete with thermal insulation measure options for the satisfaction of the exogenous demand.

(3) Results

Preliminary model results show that both HP and mCHP technologies are part of the LP solution and therefore part of the technology mix with minimal system expenditures. In function of scenarios of the evolution of energy carrier and CO_2 emission certificate prices, techno-economic assumptions and RES-E capacity expansion, HP are in the optimum solution with capacities between 22.2 GW_{th} and 59.8 GW_{th} installed in the German residential sector in 2030. In 2050, in scenarios with increasing fossil energy prices, increasing CO_2 emission certificate prices, high RES-E expansion and decreasing specific investment assumptions for mCHP and HP, the latter technology expands up to 156 GW_{th}. In scenarios of moderate fossil energy prices, moderate CO_2 emission certificate prices, moderate RES-E expansion and static specific investment assumptions for HP, after 2030 no further expansion can be observed. For mCHP on the other hand, capacities range between 1.6 and 2.8 GW_{el} installed in the German residential sector in 2030. In 2050 however, in scenarios of moderate evolutions of energy carrier prices, CO_2 emission certificates and RES-E expansion, no further expansion or a negative growth of of mCHP can be observed, and in scenarios of strongly increasing energy and emission prices as well as RES-E expansion, mCHP is phased out altogether.

(4) Conclusions

In the context of rising shares of fluctuating RES-E, even under constant techno-economic assumptions for mCHP and HP (compared to the year 2010), the model suggests an economic potential for both technologies in combination with thermal storage under the premise of minimisation of system expenditures, corresponding to the optimal operation by a centralised control entity using forecasts. The results for HP indicate a considerable potential for electrical load management playing a significant role in the balancing of fluctuating RES-E technologies. Also, when compared to the situation at the time of writing, there is a considerable potential for the use of mCHP, providing a non-negligible contribution to providing flexible peak load capacity for balancing fluctuating RES-E. In scenarios with high RES-E expansion however, the phase-out of mCHP towards the end of the model horizon is an implication of the ample availability of renewable electricity, shifting the weight from need for flexible electrical generation to need for electrical load management, and hence making HP displace mCHP. Due to these complex interactions, the potential of these technologies to contribute to the energy transition in the German residential and electricity sector should be studied in more detail.

References

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