Power System Planning Benefits of Dual-Fuel Gas-Electric Heating Technologies

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Overview

Space and water heating demand represents roughly 60% in the US and 80% in Europe of final energy use in residential buildings [1]. Natural gas boilers (B) are the technology of choice for heat provision due to their low investment cost and relatively low fuel cost. Electrification of residential heat, through highly-efficient heat pumps (HP), is increasingly supported by policy schemes due to security of supply concerns, decarbonization requirements and variable renewable integration. However, HP deployment rates have fallen behind expectations [2] and electric utilities are concerned about increased peak demands and reduced asset utilization.

Dual-fuel heaters, also referred to as hybrid heaters, combine the strengths of different technologies and include (i) gas boilers with resistance heaters (B-R) and (ii) HPs with gas boilers (HP-B). Dual-fuel heaters could (i) reduce upfront heater cost by optimising the capacity of the different components, (ii) reduce power system investment needs by minimising peak loads and (iii) reduce operational cost by switching from gas to electricity in order to take advantage of favorable electricity market prices.

This research aims to quantify the impacts on power system investment and operational costs of deploying dual-fuel heating technologies in the residential sector from a societal or central planning perspective. Research on dual-fuel HP-B systems to date has focused on single-house installations and direct consumer benefits [3] [4]. Power systems research largely focusses on system planning impacts of HP technology and district heating integration [5] [6].

Methods

A least-cost optimization model is developed to assess the system value of deploying dual-fuel technologies. The one-stage investment model minimises annualised investment cost, fuel cost and carbon cost for both the power sector and residential heating sector. The model depicts generation and demand hourly and in chronological order to capture wind characteristics as well as daily and seasonal demand variability. The control variables are capacity C (MW) and energy generated E (MWh) for each power and heat technology. For dual-fuel heaters, the model internally determines the optimal capacity and operation of each component.

The Irish All-Island System composed of the Republic of Ireland and Northern Ireland serves as a perfect test system for a low-carbon energy system due to its high penetration of wind energy and relatively weak interconnection to other systems. The planning horizon analyzed is 2030. It is assumed that a quarter of the Irish building stock is equipped with the different heating technologies discussed previously.

Fuel prices and non-heat electricity load data are sourced from the Irish system operator [7]. Cost and performance characteristics for power plants and fuel prices have been collected from several sources [8] [9]. A carbon price of 30 EUR per ton is assumed throughout the period. The full hourly heat demand profiles are provided from a high-resolution bottom-up simulation model for the Irish residential building stock [10].

Results

Total heat and power system cost for deploying different heating systems range within 100 million EUR with HP-only systems (HP) at the higher end and dual-fuel HP-gas boiler (HP-B) systems at the lower end (Figure 1, left). Comparing the cost impact of deploying dual-fuel technologies relative to single-technology options provides more detailed insights on the planning benefits of dual-fuel technologies (Figure 1, right). The B-R system provides natural gas savings to the consumer, by switching to cheap electricity when available, and reduces wind curtailement. Power system operational cost increase since more back-up generation is required. The majority of the energy (93%) is provided by gas. The HP-B system produces 55% of its heat demand from gas and the remainder from electricity. The advantage of this system is that it reduces power generation and heat technology investment, which more than outweighs its increased natural gas consumption.

The sensitivity analysis illustrates the impact of different planning risks on different cost categories (Figure 2) compared to the reference case (Gas price: 8.5 EUR/GJ; Carbon price 30EUR/t; HP upfront cost 1050 EUR/kW; share of heaters of energy efficient houses: 66%). Dual-fuel technologies tend to be slightly more sensitive to the planning uncertainties presented here.

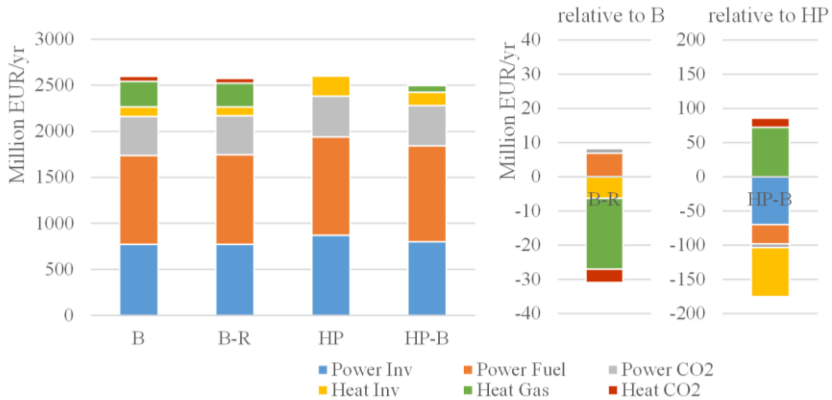

Figure 1: Total system cost in absolute terms (left) and relative terms (right) in reference case

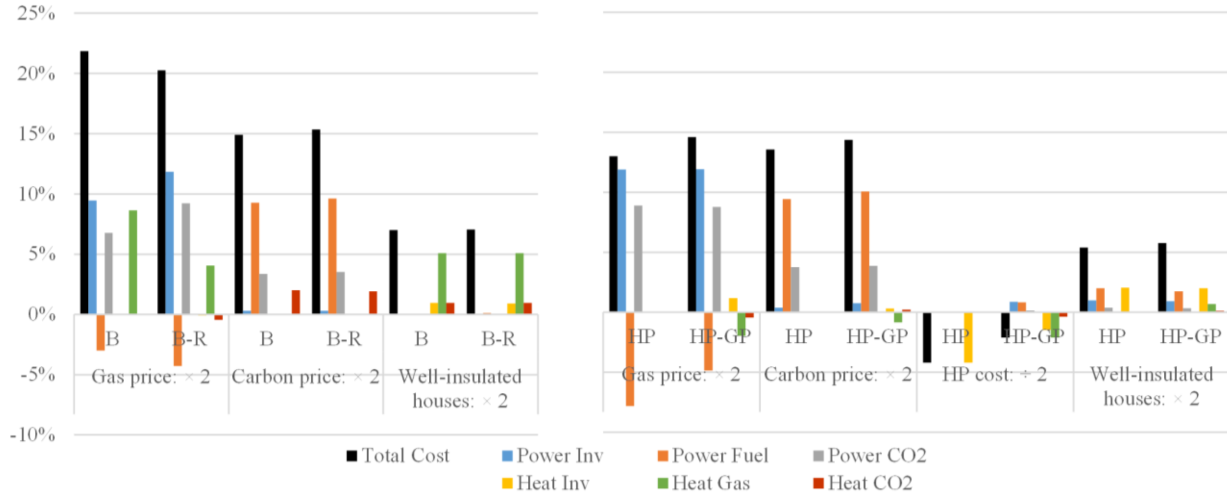

Figure 2: Sensitivity analysis on total system cost of different input parameters (gas price, carbon price, HP upfront cost and penetration of energy efficient homes) relative to reference case

Conclusions

These results confirm that dual-fuel heaters provide system-wide investment and operational cost reductions compared to single-technology heaters. The system impacts of different dual-fuel heating technologies differ based on their underlying characteristics. Dual-fuel B-R heaters provide mostly natural gas savings to consumers and reduce wind curtailement. Dual-fuel HP-B heaters provide investment cost savings to consumers and reduce investment in power generation due to peak load reductions.

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