# An analysis of the investment trade-offs in smart electrification for decarbonising heating: A whole system perspective

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## Overview

Electrification using heat pumps is anticipated to play a major role in decarbonising heating in buildings. The extensive electrification of heating, however, poses challenges on both the supply and demand sides, especially in countries where fossil fuel-based boilers are prevalent and the use of electricity for heating in buildings is very limited. If not well planned, transferring a large-scale variable heating demand to the electricity grid could significantly increase the peak electricity demand and the variations in electricity demand with the outside temperature. That would lead to a substantial increase in capacity and flexibility requirements of the electricity system. The purpose of this study is to examine planning strategies and integrated approaches for enhancing the system value and emission reduction benefits of electrifying heating using heat pumps and identify the trade-offs between associated consumers' investment and infrastructure requirements.

## Methods

We take a whole system approach using the HEGIT (Heat, Electricity and Gas Infrastructure and Technology) model to examine the interactions between the electricity grid, gas grid and heating systems in order to quantify the value of smart electrification schemes for delivering zero and low-carbon hot water and space heating in buildings. HEGIT is a framework for studying the coordinated planning of electricity, gas and heat systems and is designed to assess the impacts of different policies and decisions for decarbonising heating on the operation and long-term planning of the gas and electricity grids. The model is an integrated multi-scale capacity-planning and unit-commitment model based on Mixed Integer Linear Programming (MILP). It co-optimises the investments and operations of electricity and gas grids as well as end-use heating technologies while maintaining the security of supply. We used the UK as an example of a country that has a high dependency on fossil fuels for heating, limited current use of electricity for heating and an ambitious net-zero emission target.

Our study examined the system-wide implications of smart electrification from two perspectives: system planning and demand side. We looked at two sets of scenarios based on the level of direct emissions from heating at the end of the planning horizon in 2050. For the the case of zero-emission target from heating in 2050, we examined complete electrification of heating (ZDE.EL), accelerated electrification of heating (ZDE.AEL), and using hydrogen as a complementary option to electrification for decarbonising heating (ZDE.EL-H2). Also, we examined three scenarios based on different levels of residual emissions from heating in 2050: 5 $\mathrm{Mton}_{CO2}$ (EO.5 Mton), 10 $\mathrm{Mton}_{CO2}$ (EO.10 Mton), and No constraint on residual emissions from heating (EO.UNL). On the demand-side, in order to identify cost-effective practices for managing electric heating demand, we examined the combinations of four investment and operation trade-offs: (i) grid integration of heat pumps using smart meters; (ii) comparison of ground-source heat pumps (GSHPs) and air-source heat pumps (ASHPs); (iii) reducing the output temperature of heat pumps and sharing the load with electric resistance heaters (45°C vs 55°C); and (iv) installing a hot-water storage tank with different capacities.

## Results

Our results indicate that, in the case of the UK, if all heating demand were to be transferred to the electricity grid, peak electricity demand would increase from 49 GW to 133 GW while the load factor for electricity demand would decrease from 0.68 to 0.45 and result in a 160% increase in the installed capacity required in the electricity grid (Figure 1). Even though the growth in electricity demand in this scenario offers the opportunity to deploy indigenous low-carbon renewable generation in the electricity grid and increase the diversity of resources, the mismatch between variable renewable output and demand leads to inefficient and costly integration of these resources. The inflexibility of the electric heating demand and the mismatches between renewable output and demand substantially increase the flexibility requirements of the system. Our results show that relying only on the upstream electricity system flexibility mechanisms (such as fossil fuel-based reserves, peak generation and grid-scale storage) reduces the utilisation rates of assets, therefore increasing the abatement cost in the complete electrification of heating scenario. The problem could be exacerbated if plans for accelerating electrification of heating are not coordinated with decarbonisation and expansion planning of the electricity grid, and heat pumps are adopted when the electricity grid lacks sufficient low-carbon flexibility mechanisms. Our results show that this could lead to an oversizing of the system in the ZDE.ELA scenario (Figure 1) and an increase in the cost of abatement of about 23 £/$\mathrm{ton}_{CO2}$.

Both hydrogen and partial carbon offsetting, despite having different infrastructure requirements, were shown to be valuable options to complement electrification, reduce the electricity grid expansion and flexibility requirements, and facilitate more efficient use of assets. Our results suggest that, for the core scenarios, when hydrogen is an available option in the model, the cost-optimal degree of electrification is about 50%, and the rest of the heating demand is supplied by hydrogen. Partial carbon offsetting also allows avoiding fuel switching in some regions or for some consumer groups. Additionally, it facilitates the efficient use of biomass resources for heating in the form of bio-methane, bio-hydrogen, and bio-electricity. On the other hand, the lower growth in electricity demand in both cases reduces the potential for deployment of renewable generation. Furthermore, the whole system efficiency decreases in both pathways compared to the complete-electrification scenario (more resources will be used to supply the same demand), as the system would partially rely on combustion to provide part of the heating demand. The availability of both options, the extent to which they can be used and implications in terms of long-term security risks depend on various factors such as the availability of carbon capture and storage, the existing infrastructure in a country, countries' endowment and access to global commodity markets.

Although the scale and nature of the heating demand could be a challenge for the widespread electrification of heating, if implemented smartly, electrified heating demand can offer considerable scope for load shifting and grid-balancing services. Our results indicate that grid integration of heat pumps with smart meters combined with additional thermal storage at the consumer end can unlock significant potential for diurnal load shifting. This would reduce peak electricity demand and ramping rate requirements of the electricity grid significantly, resulting in a more cost-effective integration of renewable generation. Although this requires additional consumer investment, the savings in electricity grid capacity investment and operating costs across the value chain exceed the former, and the total transition costs would decrease. For example, our results show that 5 b£ additional investment in such demand-side flexibility schemes (thermal storage equal to 100 L/person and grid-integrated heat pumps) can reduce the total system transition cost by ~ 22 b£ compared to the case of relying solely on supply-side flexibility (thermal storage of 50 L/person and not integrated heat pumps). It is also possible to reduce the consumer investment in the example above by 7.5 b£ by lowering the output temperature of heat pumps from 55 °C to 45 °C and sharing the heating duty with electric resistance heaters since in this way a smaller heat pump unit can be installed. Although this could increase the peak electricity demand, the impacts could be offset by grid integration of heat pumps and installing sufficient thermal storage capacity. Furthermore, our results show that GSHPs offer limited system value in domestic applications. This is because the benefits of GSHPs (lower peak demand for electricity and smaller variations in heating demand with outside temperature) can instead be provided by grid integration of ASHPs and increased thermal storage capacity at a lower cost to consumers and with additional flexibility and balancing benefits for the electricity grid.

Overall, the results of our integrated assessment show that a coordinated system expansion and decarbonisation planning is key for accelerating electrification (time) and enhancing a cost-effective and reliable level of electrification (scale). The use of smart strategies at the demand side can reduce the supply-side flexibility requirements for early deployment of electric heating and a higher proportion of renewable generation around 2030. Therefore, rather than investing in sub-optimal short-term flexibility solutions (such as open-cycel gas turbine (OCGT) or combined cycle gas turbine (CCGT)), the system will have time to expand its flexibility portfolio and invest in other low-carbon flexibility options with greater long-term value. This prevents oversizing the system and increasing the transition cost.

## Conclusions

Overall, our results suggest that if policy and investment decisions at both the electricity grid and demand-side levels are made based on the whole system value, the system capacity requirements and consumer costs can be reduced. Decarbonising heating through electrification can be done more rapidly, at a lower cost to consumers, and with greater system benefits if a smart and coordinated approach is implemented which considers different aspects of the system and maximises system flexibility.

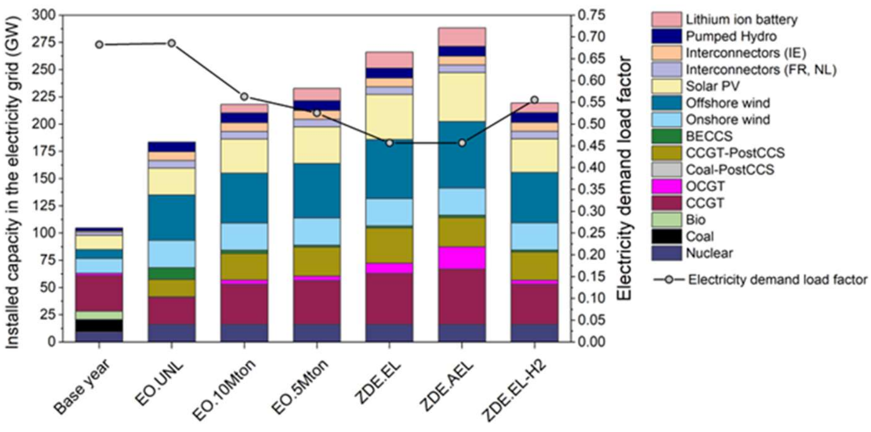


Figure 1. The required installed capacity and technology mix in the electricity grid in 2050 for each scenario compared to the base year (2020). The plotted line represents the electricity demand load factor in each scenario.