# The future role of the gas grid in supplying heating in buildings: A whole-system perspective

**Pooya Hoseinpoori***, Sustainable gas Institute (SGI), Centre for Environmental Policy (CEP), Department of Chemical Engineering, Imperial College London, Phone: 020-75948299, p.hoseinpoori17@imperial.ac.uk
**Richard Hanna**, Centre for Environmental Policy (CEP), Imperial College London, r.hanna@imperial.ac.uk
**Nilay Shah**, Department of Chemical Engineering, Imperial College London, n.shah@imperial.ac.uk
**Jeremy Woods**, Centre for Environmental Policy (CEP), Imperial College London, jeremy.woods@imperial.ac.uk
**Christos N. Markides**, Department of Chemical Engineering, Imperial College London, c.markides@imperial.ac.uk

## Overview

In this paper, we take a whole system approach to quantify the implications of decarbonising heating in buildings for the operation and investment planning of the electricity and gas grids in the context of different scenarios for the future of the gas grid. We analyse and compare the technology portfolio mix and the level of investment required in both electricity and gas grids, as well as the resources and complementary infrastructure required in different scenarios for the future of the medium and low-pressure gas grid. In addition, we discuss how different decisions about the future of the gas grid, aimed at meeting climate change mitigation targets, would interact with other policy goals such as energy security. Such a whole system approach is crucial for identifying the optimal use of available resources and technologies, efficient and coordinated planning of long-term system developments and providing policy recommendations.

## Methods

We developed a framework for studying the coordinated operation and investment planning of Heating, electricity and gas systems, HEGIT (Heat, Electricity and Gas Infrastructure and Technology). The centrepiece of HEGIT is a Mixed Integer Linear Programming (MILP) multi-scale capacity planning and unit commitment model of integrated gas and electricity systems. It evaluates the cost-optimal heating portfolio and technology mix in buildings as well as the optimal technology mix, the dispatch profiles and transition over the planning horizon of both electricity and gas grids. This study uses HEGIT to quantify the infrastructure requirements and the system-wide implications of different pathways for decarbonising heating in the context of different scenarios for the future of the gas grid. Four key sets of scenarios for the future of the gas grid was examined: a) complete electrification of heating in buildings and moving away from the gas grid; b) conversion of the gas grid to deliver hydrogen; c) hybrid heatpump with gas boiler scenario, and d) greener gas grid. We are using the UK as a case study in this paper to exemplify a country with a dominance of natural gas in providing heating to buildings and an ambitious net-zero emissions target.

## Results

Electrification of heat using heat pumps and moving away from the gas grid can pose challenges and also provide opportunities to a system depending on how it is implemented. Our results show that electrification of heat at scale could increase the peak electricity demand in the UK from 49 GW in the base year to about 133 GW. Therefore a significant expansion and reinforcement of the electricity grid (about 160\% increase of installed capacity) will be required to securely supply the electricity demand (Figure 1). The considerable growth in the annual electricity demand (from 295 TWh to 507 TWh in the 100\% electrification scenario), however, will provide the opportunity for deployment and higher penetration of renewables in the electricity system. This not only enables the heating sector to benefit from the rapid decarbonisation of the electricity grid but also increases fuel mix diversification and reduces traditional fuel security risks and vulnerabilities to price volatility in the system through decoupleing the heating provision from the fuel source. On the other hand, the elevated peak and higher variability and temperature dependency in the electricity demand, along with the higher variability and uncertainty of supply in this scenario, will increase the rate, frequency and extent of variations in the net load. This could pose reliability risks to the system increases the flexibility requirements of the electricity system.

If the electrification of heating is implemented smartly through grid integration of heat pumps, the controlled transfer of the heating load to the electricity grid could reduce the reliability risks of electrification and also provide flexibility services to the electricity grid. Smart electrification can have different forms while grid integrated heat pumps can provide load shifting services to the grid; hybrid heat pumps with natural gas in regions connected to the gas grid could reduce the peak electric heating load by putting a cap on the electricity demand for heating. Both measures were shown to effectively reduce the cost of transition and reliability risks associated with electrification.

A lower degree of electrification and partial conversion of the gas grid to deliver hydrogen was also shown to further reduce the strain on the electricity grid and therefore reduce the flexibility and reserve requirements in the electricity grid. The cost-optimal degree of electrification in this case was found to be around 50% in the UK. However, lower growth in electricity demand, lower dispatchable capacity available in the electricity grid, lower efficiency and cost competitiveness of renewable hydrogen options in hydrogen scenarios would limit the potential for integrating renewables into the system. Our results indicate that, hydrogen-based heating would limit the resource mix diversification potential of decarbonising heating as it would potentially increase dependency on natural gas and therefore increase the system vulnerability to variations in the natural gas prices. On the other hand, short-term and long-term flexibility mechanisms in a hydrogen network are limited with respect to a natural gas network. This is due to the relative inflexibility of commercial hydrogen production units, the lower calorific value of hydrogen compared to natural gas, uncertainties about the availability of hydrogen turbines for short-term balancing, as well as uncertainties about the international hydrogen market such the availability of hydrogen inter-connectors and liquid hydrogen market. To securely supply hydrogen at scale for heating; therefore, it would be necessary to have an oversized production and storage capacity. This, along with increased dependency on complementary carbon capture and storage (CCS) infrastructure, would thwart the economic gains from repurposing the gas grid. Carbon offsetting via negative emission technologies using biomass in both the gas and electricity grids (in the form of bio-electricity, bio-hydrogen and bio-methane) was shown to be an effective strategy to partially avoid fuel switching in some regions or for consumer groups. This strategy not only provides the opportunity to effectively increase the share of biomass in the resource mix but also reduces the required rate of transformation in both the electricity and gas grids. However, an increased reliance on negative emissions using biomass resources could pose new fuel risk challenges and increase the system vulnerability to variation in the price of biomass.

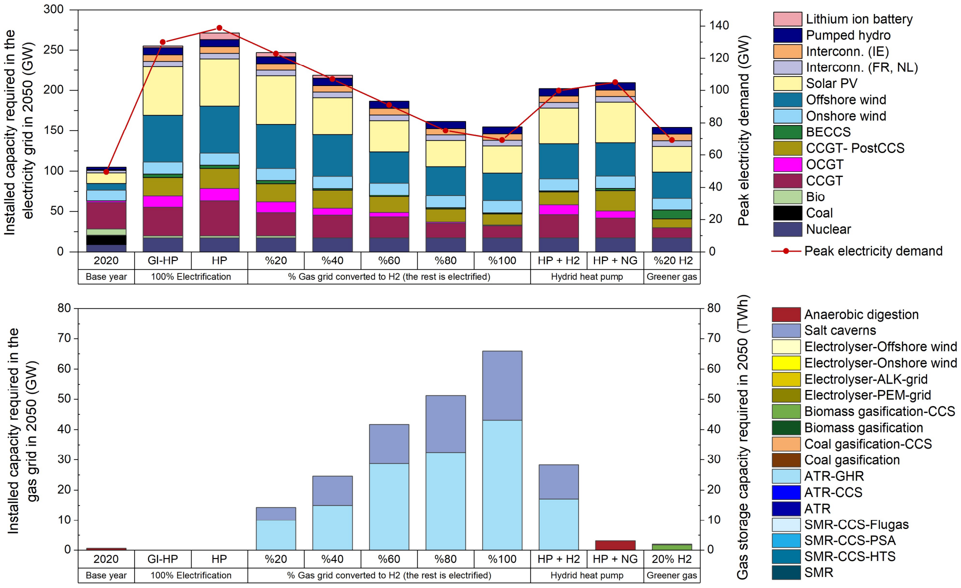


*Figure 1) The installed capacity required in 2050 in the electricity grid (**top**) and the gas grid (**bottom**) in different scenarios for the future of the gas grid as compared to the base year (2020) for the case study of the UK. The red dotted line in the top graph represents the peak load in the electricity grid.*

## Conclusions

Our results show that the total system cost in all the scenarios ranging from complete electrification to complete conversion of the gas grid to hydrogen is relatively close, which will reduce the significance of cost as a guiding factor (from a whole system perspective) for deciding on the decarbonisation pathway for heating. Therefore, determining the role of low-carbon gases and electrification for decarbonising heating is better guided by the trade-offs between short- and long-term reliability risks (fuel security), as well as trade-offs between consumer investment in fuel switching and infrastructure requirements (energy equity). In our analysis of these trade-offs we found that although electrification of heating with heat pumps is not the cheapest option to decarbonise heating, it is the right option, as it reduces energy security risks and avoids locking in a system with a high demand for fossil fuels and their complementary CCS infrastructure. To address the short-term reliability risks of electrification and enhance energy equity, a combination of different strategies, such as grid integration of heat pumps and hybrid heat pumps with natural gas boilers, is needed. Using hydrogen for heating and carbon offsetting could also be complementary options to electrification to reduce the reliability risks of electrification at scale.