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# LOW-CARBON HEATING: HOW CAN WE MANAGE PEAK WINTER DEMAND?

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The EU and the UK are on an ambitious path to become carbon neutral by 2050. This will require energy to be used more efficiently and fossil fuels to be replaced by renewable sources of energy. To date, most progress in reducing emissions has been made in the electricity sector, but attention is now shifting to heating, transport, and industry.

**Decarbonizing heating will be key to achieve net zero but is challenging**

Targeting greenhouse gas emissions from heating will be key: in industrialized countries in north-west Europe, for example, heat applications account for about 50 per cent of final energy demand.

Pursuing carbon neutrality in the heating sector also poses entirely new challenges:

- The building stock that is to be heated is very diverse. It has developed over more than 100 years with varying degrees of building insulation and different forms of ownership (e.g. owner occupiers and landlords).
- Any technical changes will potentially have a greater direct impact on user convenience and living standards than previous reforms in the electricity sector.
- For policies to be effective they need to address millions of households and commercial businesses. Reform in the electricity sector, by contrast, could initially focus on a few hundred commercial generation companies.

This paper explores possible technical solutions, achieving best value for money for energy users, barriers and market failures on the path to the transition, and possible policy approaches.

**Technical solutions—a diverse universe where one size does not fit all**

There is broad agreement that achieving carbon neutrality in the heating sector will broadly require a combination of the following:

- Enhanced energy efficiency in buildings—predominantly through better insulation and better targeting of the spaces to heat—to lower the end energy demand required to provide a certain level of comfort.
- The use of alternative fuels harnessed to modern and efficient conversion technologies. A key element will be heat pumps using green electricity. Others might include combustion technologies using biogas, biomethane, green hydrogen, and green fuels; combined heat and power solutions where feasible; and hybrid solutions that use heat pumps alongside boilers.
- Increased use of district heating in densely populated areas.

The focus of policymakers on significantly enhancing the energy efficiency of building shells and heating systems often abstracts from the heterogeneity of the building stock and the resulting technical and economic limits of efficiency improvements. In Germany, one of the countries we have studied in greater detail, 89 per cent of today's building stock is more than 20 years old; buildings that are new or considered fully refurbished (some of them more than 20 years old) comprise only

13 per cent of the total. About 90 per cent of heating systems are currently gas- or oil-based. There is no one-size-fits-all solution to decarbonize this existing building stock. The UK is even less efficient: only around 40 per cent of homes have reached Energy Performance Level C or higher while, like in Germany, 90 per cent of homes use fossil fuels.

As for heating technologies, electric heat pumps clearly have merits in relatively modern, well-insulated buildings (especially with underfloor heating). However, they are not necessarily the most cost-efficient option for all buildings. Other technologies have a role as well, especially given that the restructuring of the housing stock will necessarily be gradual.

For example, in order to realize the German government's target of a 2 per cent annual energy refurbishment rate, installers would have to carry out twice as many conversions each year in the next decade as in the last 20 years. During that time, the refurbishment rate has been continuously below 1 per cent despite considerable political efforts to increase it. The availability of fitters to install heat pumps is a clear limiting factor in the near term in both the UK and Germany, alongside current supply chain bottlenecks.

In view of the imperative for the heating sector to contribute to protecting the climate, alternative technology paths for reducing emissions should be considered and developed (or at least not politically foreclosed), in addition to further policies to encourage heat pump uptake. For example, hydrogen-based renewable or climate-neutral gases are potentially valuable options for helping to decarbonize the heating market. Depending on progress in energy efficiency and the market penetration of alternative technologies, the demand for hydrogen will be lower than the current share of natural gas in heat supply.

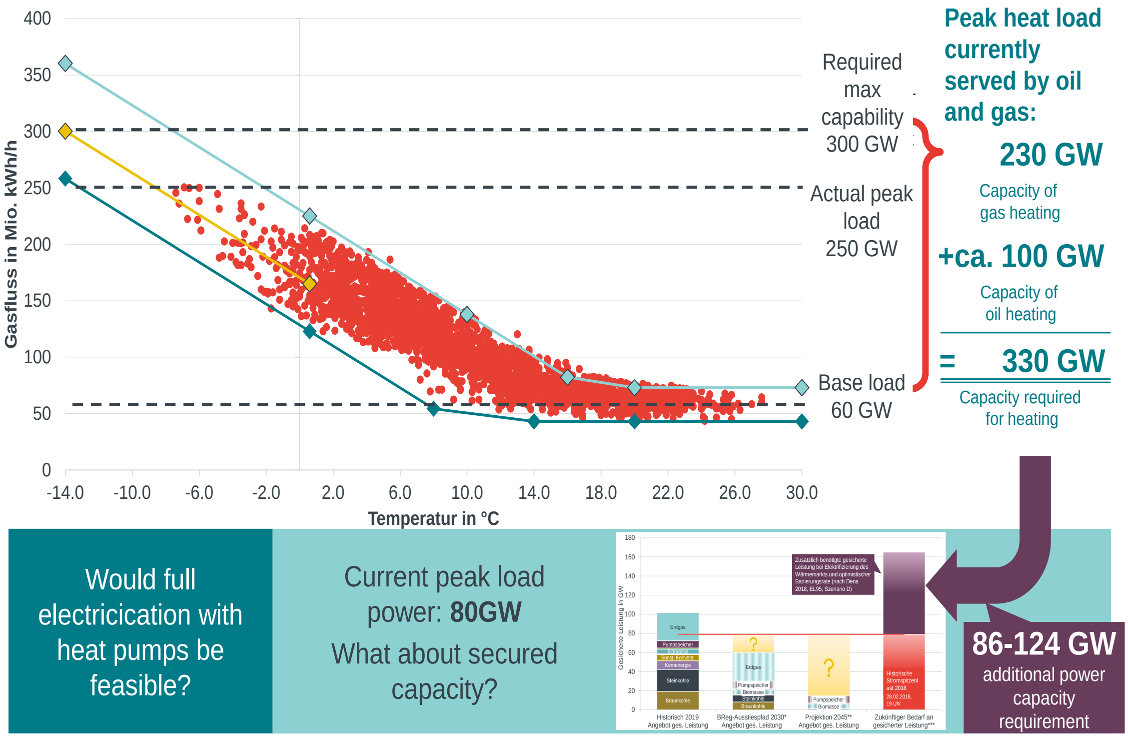
**Value added for consumers—view the system as a whole and not individual technologies in isolation**

While it is vital to bear in mind the heterogeneity of the building stock, it is at least as relevant to consider the impact on the energy system as a whole of betting either on a single technology or a portfolio of technologies to reduce emissions.

A key feature of the buildings sector is that heating demand is highly seasonal. Demand in winter months is at least four times higher than in summer, as measured by the seasonality of gas usage. Heat demand is highest during the few days of the year with the coldest, sub-zero temperatures. These are also the days when heat pumps typically operate at low efficiency and when some buildings could be heated instead with direct electrical heating.

In the case of Germany we have calculated that peak gas demand, with the existing housing stock, is 250 GW. Serving such demand reliably, including on days when temperatures fall to minus 14°C, requires supply capacity in the order of 300 GW. Of this total, 230 GW can be attributed to space and warm-water heating, while the rest meets demand for industrial heat and power production. Adding required capacity that is today supplied by oil heating, we estimate a capacity requirement for space and warm-water heating of 330 GW. If such demand were to be met solely by electric heat pumps, the current peak electricity demand of 80 GW would more than double to between 156 and 204 GW—despite the generally high efficiency of heat pumps.

**Figure 1: Temperature-driven peak heat demand and required supply capacities (Germany)**




Source: Frontier Economics (2021), *The Value of Hydrogen in the Heating Market*.

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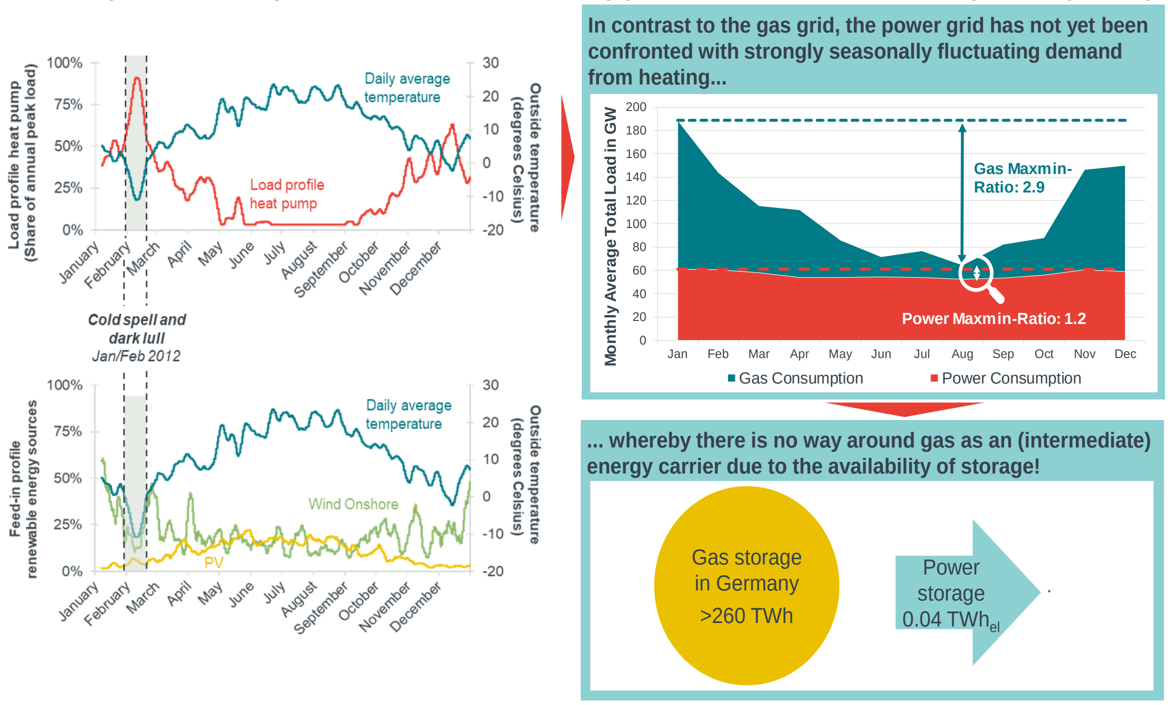
Given this seasonality of demand—which is likely to diminish only gradually with increased investment in efficiency—a heating system entirely reliant on electricity to power heat pumps would be exposed to the availability and storability of electrical energy. Renewable energies in the form of wind and solar photovoltaic will undoubtedly dominate primary energy supplies in future. But their output is variable; power is not always available, particularly on cold winter days. Without a contribution from low-carbon gas, either the electricity generation system would have to be massively overbuilt or significant seasonal electricity storage would need to be developed. But stored electricity has the disadvantage of low volumetric energy density. The required storage capacity would be prohibitively expensive and would take up large areas of space or land. Electric batteries are well suited for daily charge-discharge cycles, e.g. for electric vehicles, but not for seasonal storage cycles with intermittent wind and solar supplies.

**Figure 2: Seasonal profiles of temperature, renewable electricity production, and heat demand (Germany, 2021)**




Source: Frontier Economics (2021), *Die Rolle von Wasserstoff im Wärmemarkt*.

In other words, it is hard to conceive of practical ways of avoiding at least some use of low-carbon gas either as an energy carrier or for long-term (inter-seasonal) storage of electricity in any national energy system. There is therefore a future for energy in gaseous and liquid form in the heating sector, for use either directly in buildings or indirectly by helping to meet peak winter demand for electricity.

This low-carbon gas needs to be produced from renewable sources, as is the case for green hydrogen and fuels, biomass, biogas, and biomethane. Hence electrification will play a significant role in the heating sector, even if it is likely in part to be through so-called indirect electrification—the conversion of green electricity to hydrogen or other synthetic fuels. Conversely, as heating systems that use low-carbon gas may have drawbacks for users—for example, lower fuel efficiency or, in the case of hydrogen, the possible need to adapt the heating system, including changes to the gas pipes—some part of the fuel needed for inter-seasonal storage may be re-electrified before it is distributed to end consumers.

So, given the diversity in the building stock and consumers' differing heating needs, it is likely that a mix of solutions will be required. However, given the importance of gas/electricity networks, economies of scale are a major consideration. Hence regional zones where one or several options are taken up are likely to emerge. Hybrid solutions (e.g. hybrid heat pumps) are also possible and can be cost-effective. In addition, the dynamic development of various technologies makes it impossible to know how quickly their cost will fall. For example, the cost of modular technologies that can be rolled out in standardized form has come down much more rapidly than technologies that require large bespoke infrastructure. Accordingly, systems and policy need to be open to alternative solutions—albeit ones based on renewable primary sources of energy.

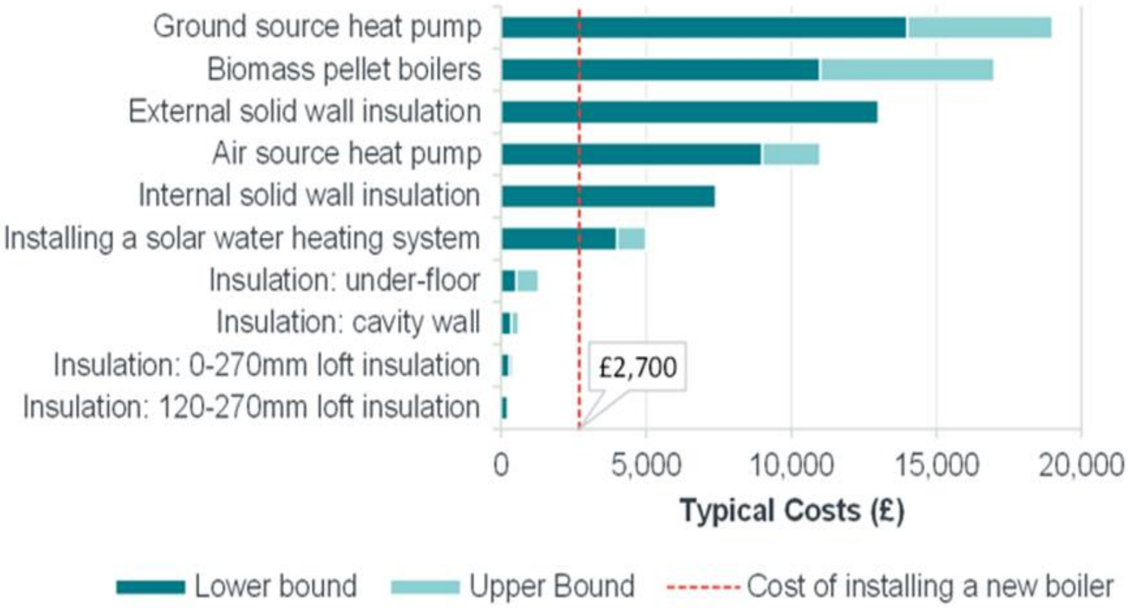
**Barriers and market failures limit a natural transition**

But will remaining technologically open-minded suffice to come up with the optimal sustainable heating system? Strong doubts are justified. Various impediments and market failures stand in the way of the desired policy outcomes. It is important to understand these obstacles first before formulating appropriate policies to overcome them. Some of the most relevant constraints can be summarized as follows.

**Need for coordination**. Many of the green options are subject to major economies of scale, as they rely on networks for the transport of low-carbon gas or electricity. This means that a coordinated approach may be needed to keep costs down. In addition, some transitions will require customers in a given part of the network to switch all at the same time (for example, when moving from natural gas to hydrogen). Again this will call for some coordination.

**High upfront costs and consumer interest in rapid pay-back.** Moving away from today's dominant heating technologies of natural gas and oil burners requires consumers to replace their heating systems. In many cases this will involve new radiators and possibly even substantial additional insulation, new ventilation, or new internal gas pipes. Low-carbon heating technologies often have higher upfront costs than fossil fuel heating systems. Upfront costs are particularly important for consumers; evidence suggests they may employ very high discount rates when choosing a new heating system, though there is significant uncertainty around the estimates. (For example, a study for the European Commission found that consumers apply discount rates of 19 ± 17 per cent when purchasing efficient energy and transport technologies.) Settling on a high discount rate means people are putting much greater weight on upfront costs in their decision-making, relative to the savings to be made over the lifetime of the investment. Even if a completely new system is cost-effective in the long run, many consumers may not be able or willing to pay the upfront costs.

**Figure 3: Upfront costs of low-carbon heating technologies (UK)**

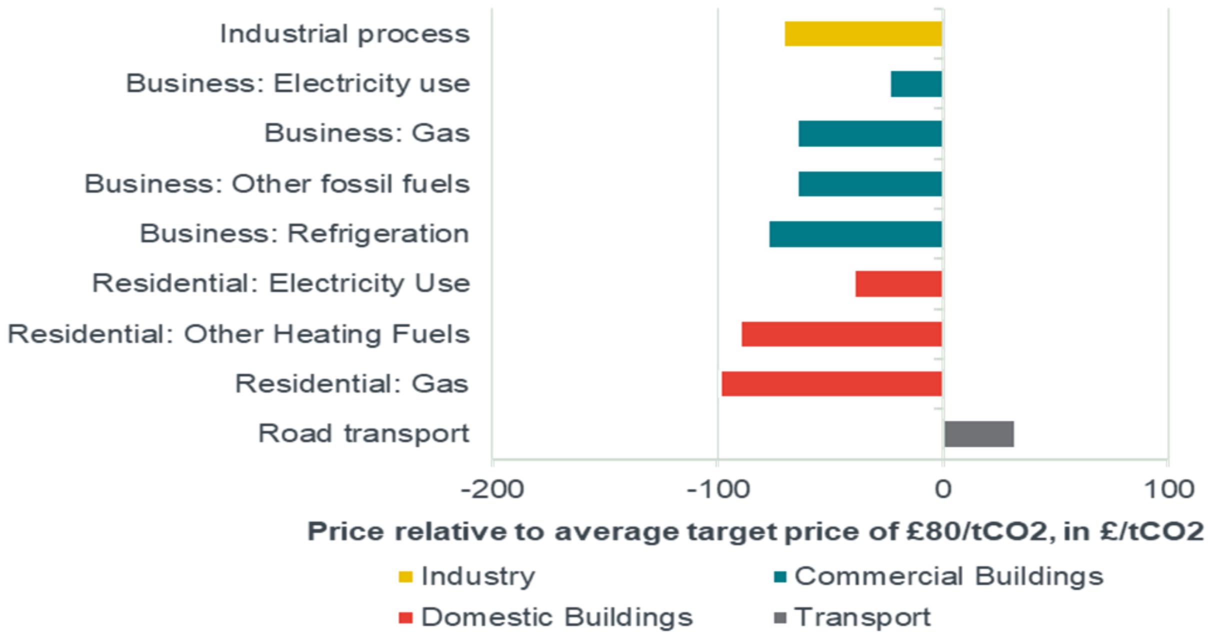



Source: Energy Savings Trust (2023), *Green Homes Grant Scheme*.

**Immature technologies.** While heat pumps are being rolled out at scale in many European countries, hydrogen boilers and appliances are at an earlier stage of development. Further investment in R&D is likely to be required.

**Distortions in the current policy framework.** Emissions externalities are not fully and consistently priced in, so consumers cannot always gain from reducing emissions. There are also distortions between fuels. In many countries, there are proportionally higher environmental levies and taxes on electricity than on natural gas, for both industrial and domestic customers. This is illustrated in the figure below for the UK, based on an Energy Systems Catapult analysis of implicit carbon prices by sector.

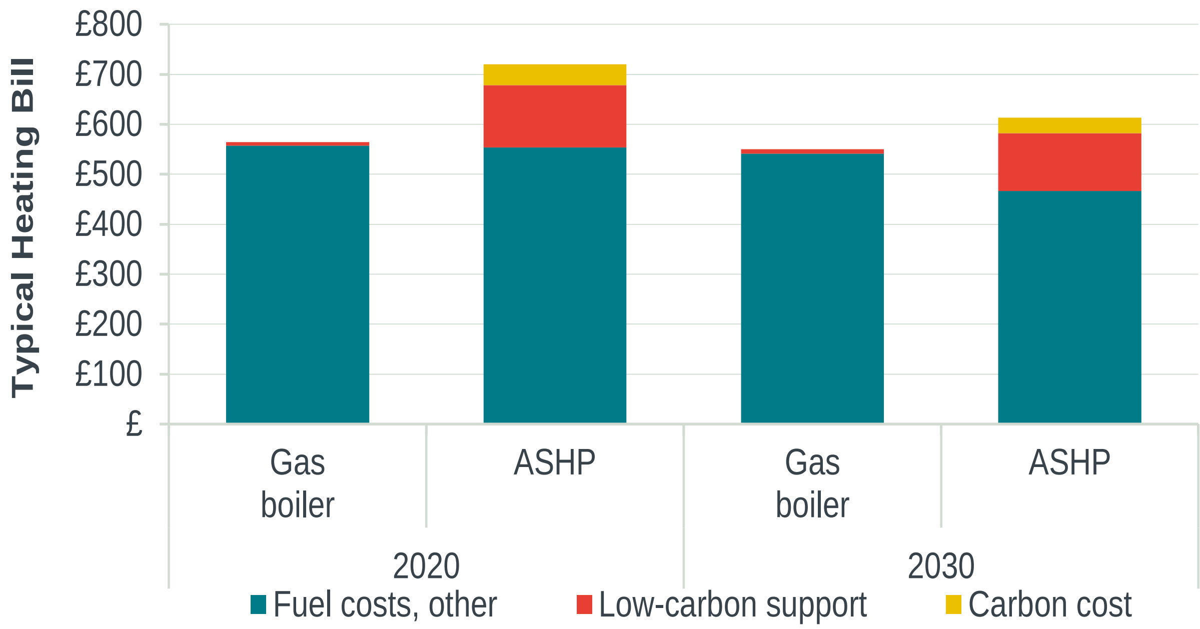
**Figure 4: Carbon price relative to average target price of £80/tonne $CO_2$ by 2030 across sectors (UK)**




Source: Energy Systems Catapult (June 2020) *Rethinking Decarbonisation Incentives: Future Carbon Policy for Clean Growth. £80/tCO2 from BEIS central scenario in BEIS (April 2019) Updated Short-term Traded Carbon Values – Used for UK public policy appraisal*.

Analysis by the Climate Change Committee shows that these differences in carbon prices can translate into variations in typical bills for consumers adopting electrified low-carbon technologies

**Figure 5: Heating bills for gas boilers and air-source heat pumps (ASHP), 2020 and 2030**




Source: Climate Change Committee (2020), *Sixth Carbon Budget*.

Carbon costs are set in line with Green Book values. As set out in the Climate Change Committee's report, electricity consumption is subject to a carbon price under the Emissions Trading System and the Carbon Price Floor in the UK, whereas there is no carbon price on gas consumption. Both electricity and gas prices include support for low-carbon and fuel-poverty schemes, at 3.5p/kWh on electricity and 2.1p/kWh on gas. Low-carbon support costs are higher for electricity as they include the costs of decarbonizing the power sector (through subsidies such as Contracts for Difference). In Germany, for comparison, this levy to finance support for renewable electricity production has recently been removed from final consumer bills. These costs are now financed by state budget and do no longer burden electricity consumption.

**Limited engagement of consumers with the market.** Apart from the high initial financial investment required, other barriers to replacing heating systems include low interest and awareness on the part of consumers (especially landlords who would be required to make necessary investments), lack of trust in energy suppliers, and risk aversion because of uncertainty about the performance of new technologies.

**Policymaking needs to address these challenges**

Bearing in mind these challenges, the transition to low-carbon heating requires the following:

- **Comprehensive cost analysis to inform choices.** Because of the presence of externalities and the maturity of some of the technologies, policymakers will need to support low-carbon heating options. The choice of which technologies to help should be based on a whole-systems analysis, taking into account economies of scale. Such an analysis should also incorporate the potential for future cost reductions, where technologies can be modularized, and where large, bespoke infrastructure can be avoided.
- **Piloting of new technologies.** Local trials should be carried out to better understand the pros and cons and system implications of immature technologies, such as hydrogen for residential heating, as is currently happening in the UK and the Netherlands.
- **Keeping technology options open.** Given the heterogeneity of the building stock as well as existing infrastructure, there is a benefit in adopting a portfolio of heating technologies. Hence policymakers should be as technology neutral as possible, and just ensure coordination where needed—for example, if it is necessary to switch over all customers in a given part of a network at the same time (e.g. when moving from natural gas to hydrogen).
- **Supply chain stability.** In the past, policymakers have often focused on giving consumers economic incentives to make changes. However, stop-start policies have not left enough time to build up the supply chain. This means that even when generous incentives have been put in place, consumers have struggled to find qualified installers. Likewise, people will not switch to a certain technology (e.g. hybrid heating with hydrogen boilers) if they cannot be confident that there will be a fully developed supply chain to supply and transport the fuel.
- **Policies that recognize consumer perspectives**. Low levels of interest in heating systems and limited awareness of the benefits of alternatives, coupled with the fact that people have to decide whether to make a switch when their existing system has broken down, may significantly slow the transition to low-carbon technologies. A policy emphasis on providing incentives at key trigger points, such as when a home is being sold or renovated, may be more successful.
- **Removal of distortions in gas and electricity pricing.** Externalities are not consistently internalized across gas and electricity use at present. A rebalancing is needed to remove such distortions.