

Carbon Footprint of Heat Generation



Heat policy takes into account the carbon footprint of different heating technologies. This POSTnote summarises evidence about the carbon footprints of current and emerging heating technologies in the domestic, commercial and industrial sectors. It then outlines wider considerations for heat policy and broad assessments of the 'best' way to reduce emissions from heating.

Background

Heat is used for domestic, commercial and industrial purposes and accounts for around a third of UK greenhouse gas (GHG) emissions.¹⁻³ Other large emissions sources include power generation, transport, industrial processes and agriculture. Around 50% of heat emissions come from the domestic sector, 20% from the commercial sector and 30% from the industrial sector.^{2,3} In the UK domestic and commercial setting, 98% of GHG emissions from heat come from space and water heating, with 2% from cooking.¹ In the industrial sector, only 13% come from space and water heating; the rest are from specialised industrial processes.

Box 1. UK and EU Emissions and Renewables Targets

The Climate Change Act 2008 established a target for the UK to reduce its GHG emissions by at least 80% (from 1990 levels) by 2050. It also enabled interim targets (known as 'carbon budgets') for five-yearly periods from 2008 onwards. The fourth carbon budget targets a 52% reduction in GHG emissions by 2023-2027 and the fifth carbon budget is due to be set in June 2016. In preparation, the Committee on Climate Change, has formally recommended that the Government legislates for a 57% reduction by 2028-2032.⁴ Separate EU targets require that by 2020, renewable sources should provide 15% of the UK's energy and new buildings should produce little or no net carbon emissions.⁵⁻⁷

Overview

- Most UK heating used natural gas in 2015.
- To meet binding EU renewables targets for 2020 the UK will likely need to deploy more low carbon heating. Significant deployment will be needed by 2030 to meet UK greenhouse gas emissions targets.
- The carbon footprint of electrical or hydrogen heating and heat networks can be lower than fossil-fuelled heating, but only if the footprint of the energy source is low. Biomass boilers and bio-sourced gas usually have a low footprint.
- For industrial heating, carbon capture and storage offers a key low footprint option.
- The success of heat policy will also depend on consumer preferences, technological constraints and energy efficiency. These make the widespread decarbonisation of heating a major challenge.

The Government is aiming to reduce GHG emissions from heat and increase the proportion of heat from renewable sources from 2% in 2014 to 12% by 2020 to help the UK meet binding targets (see Box 1).^{7,8} However, progress on the decarbonisation of heating has been criticised as too slow.⁸⁻¹² Following this criticism, the Energy and Climate Change Committee has started an inquiry on progress towards the 2020 renewable heat targets.

Carbon Footprints

The carbon footprint method can be used to assess the amount of GHG emissions produced by different heating technologies.¹³ It takes account of the total quantity of GHGs associated with a heating product, including the emissions from manufacture, producing the energy supply, as well as the direct emissions produced during heating. The carbon footprint of a heating technology is measured in grams of carbon dioxide equivalent per kilowatt-hour of heat (gCO₂eq/kWh). Carbon dioxide is the most important GHG, so others are measured in CO₂ equivalent. To meet the UK's carbon targets the Government's statutory adviser, the Committee on Climate Change (CCC) suggests that average emissions from domestic and commercial heat might be reduced from around 220 gCO₂eq/kWh in 2015 to 180 gCO₂eq/kWh in 2030 and closer to zero by 2050.¹⁴

The next two sections summarise the carbon footprint of heating technologies used in the domestic and commercial sectors, and the industrial sector.

Domestic and Commercial Heating Space and Water Heating

In 2015, fossil-fuelled boilers generated 88% of domestic space and water heating, electric heaters provided 7%, bioenergy provided 5% and a small amount came from emerging technologies.^{1,15-18} Tables 1-3 show the range of published carbon footprint estimates for all non-electric, electric and hydrogen-based technologies.¹⁹

Non-electric Technologies

Table 1 shows that bio-sourced, solar and geothermal technologies typically have much lower carbon footprints than fossil fuel technologies.

- **New boilers** are required to have an efficiency rating of at least A or B,²⁰ which equates to a carbon footprint of 210-230 gCO₂eq/kWh for gas boilers. 53% of UK boilers met this standard in 2014.¹⁷ Older gas boilers can have footprints of 300-380 gCO₂eq/kWh.
- **Gas micro combined heat and power (micro-CHP)** is an emerging small scale technology that uses gas in a boiler or fuel cell to generate both heat and electricity. The footprint associated with heat generation is similar to gas boilers, but they will produce lower carbon electricity than consumers can access from the grid for a number of years (Box 2). The estimates in Table 1 do not account for these electricity emissions savings.^{21,22}
- **Gas absorption heat pumps (GAHPs)** capture heat from the ground or air and transfer it inside a building, using a gas burner to operate the heat pumping cycle. There are only footprint estimates available for GAHPs under optimum operation; there have been no field trials.
- **Bio-sourced gases** contain methane and once refined can be used in the same ways as natural gas, as listed above. They are produced from organic materials, such as waste matter or dedicated bio-energy crops.¹⁵
- **Biomass boilers** burn solid organic material (biomass) to generate heat. Biomass is often classed as 'carbon neutral' because the CO₂ released by burning is equivalent to the CO₂ absorbed by the plants during growth.⁷ However, a footprint arises from fertilizer production, harvesting, drying and transportation.
- **Geothermal heating** uses heat extracted from water or rock deep underground. The heat can then be distributed through a heat network (see District Heat Networks).

Table 1. Carbon footprint estimates for non-electric space and water heating.^{21,23-39}

Technology	Footprint range (gCO ₂ eq/kWh)	Number of estimates
Oil boilers	310-550	3
Gas boilers	210-380	6
Gas micro-CHP	220-300 ²²	4
GAHP	150-200 ⁴⁰	4
Bio-sourced gases	20-100 ⁴¹	2
Biomass boilers	5-200 (most below 100) ⁴²	9
Geothermal	10	1
Solar thermal	10-35	6

- **Solar thermal collectors** produce hot water by absorbing the Sun's energy. The footprint primarily comes from manufacturing, maintenance and disposal.^{29,30,43} Solar thermal cannot meet most UK homes' needs in the winter, so a back-up source of heat is usually required; this is not accounted for in the footprint estimates.⁴³

The footprint of a particular natural gas, biomass and bio-sourced gas technology could be higher than indicated if the fuel comes from a particularly high carbon source. For example, the footprint of biomass may be higher if the material used is not replanted or if it must be dried or imported.⁴⁴ Liquefied natural gas or natural gas from unconventional sources can have higher emissions than conventional natural gas (see [POSTnote 513](#)).

Electric Technologies

The carbon footprints of electric heating technologies depend almost entirely upon the carbon footprint of the electricity used, which averaged 370 gCO₂eq/kWh in the UK in 2015.⁴⁵ Following a reduction in electricity emissions in 2015, electric technologies now have a similar or lower carbon footprint than fossil-fuelled heating. Table 2 summarises the footprints of electric heaters and electric heat pumps under three electricity supply scenarios (outlined in Box 2).

- **Electric heaters** convert electricity directly to heat but are less efficient than heat pumps.
- **Electric heat pumps** (see [POSTnote 426](#)) are more established than GAHPs (see above).⁴⁶ Ground source electric heat pumps running at high efficiency have a footprint of 70-100 gCO₂eq/kWh but in some field trials it has been as high as 120-190 gCO₂eq/kWh because of inefficient running or poor installation.⁴⁷

Hydrogen Technologies

Hydrogen can be used to generate heat by burning it in a boiler or using it in a fuel cell, which generates both electricity and heat. In either case there are no direct GHG emissions. However, the carbon footprint of hydrogen heating technologies can vary greatly depending upon the source of hydrogen. Hydrogen can be produced:

- from natural gas, coal or biomass resulting in direct carbon emissions, which could be captured and stored underground using carbon capture and storage (CCS).⁴⁸

Table 2. Carbon footprint estimates for electric heating technologies under the three electricity supply scenarios outlined in Box 2.^{35,49-58}

Technology	Electricity footprint estimate	Footprint range (gCO ₂ eq/kWh)	Number of estimates
Electric heaters	Current (370)	~370	Personal Communication ⁵⁹
	Reduced (250)	~250	
	Low (100)	~100	
Ground source heat pumps	Current (370)	70-190	15
	Reduced (250)	50-125	
	Low (100)	20-50	
Air source heat pumps	Current (370)	90-250	11
	Reduced (250)	60-170	
	Low (100)	30-70	

Box 2. Future Electricity Emissions

GHG emissions from UK electricity are expected to fall over the next two decades. To outline possible future carbon footprints of electric heating technologies, three electricity emissions scenarios are used in this note.

- 370 gCO₂eq/kWh: the average electricity emissions in 2015, following a fall from 440 gCO₂eq/kWh in 2014.
- 250 gCO₂eq/kWh: the CCC has suggested that electricity emissions ought to be below this level by 2020.
- 100 gCO₂eq/kWh: The CCC has suggested that electricity emissions ought to be below this level by 2030.⁶⁰ To achieve this, there will need to be a large increase in renewable or nuclear generation or the use of carbon capture and storage. Some stakeholders have suggested this will not be achieved.

[POSTnote 383](#) outlines the carbon footprint of individual electricity generation technologies.

- by using electricity, giving a carbon footprint associated with the source of electricity.

Table 3 shows the footprint of hydrogen-fuelled heating using different hydrogen sources. Hydrogen-fuelled heating only has a lower carbon footprint than fossil-fuelled heating if electricity-based hydrogen production uses electricity that is much lower-carbon than the UK’s current average, or fuel-based hydrogen production uses CCS. Within these footprints the manufacturing of the boiler or fuel cell system contributes only 5-20 gCO₂eq/kWh.^{31,34}

Hybrid Systems

A hybrid system refers to either an all-in-one product that contains two or more heat generating technologies or a combination of two or more separate heating technologies that are used to heat the same building. They draw on the different benefits of the two technologies. One combination could consist of an electric heat pump and a gas boiler, the footprint of which would likely be in the range of 150-200 gCO₂eq/kWh (if running at optimal efficiency in 2016).⁶¹ Footprint estimates are not available for most combinations.

District Heat Networks (DHNs) and Surplus Heat

DHNs distribute heat (hot water) from a centralised heat source directly to homes and other buildings. The source of heat could be any of those listed above, scaled up to provide heat for a larger number of dwellings or businesses. Alternatively, DHNs could use surplus heat from a nearby power station or factory (see Industrial Heat); around one sixth of industrial heat production is surplus.⁷³ 10% of this

Table 3. Carbon footprint of hydrogen-fuelled heating in cases with different sources of hydrogen.⁶²⁻⁷²

Production method	Footprint range (gCO ₂ eq/kWh)	Number of estimates
Electricity 370	470-925	4
Electricity 250	315-625	
Electricity 100	125-250	
Coal without CCS	500-700	5
Gas without CCS	220-545	8
Coal with CCS	40-100	3
Gas with CCS	30-90	3

The ‘Electricity’ scenarios follow those outlined in Box 2.

surplus heat could be commercially viable to use for space and water heating or low temperature industrial processes.⁷³ The carbon footprint of a DHN is typically similar to the DHN’s heat source, but can be up to twice as high in DHNs where there is significant heat leakage.⁷⁴

Cooking

Gas and electrical cookers each provide around half of the UK’s cooking heat. Emissions from cooking will decrease as electricity is decarbonised or lower carbon gases are used.

Industrial Heat

Heat is intensively used in several industries: paper, rubber, plastic, metal, mineral, chemical, coke and petroleum. Industrial heat use can be classified into high temperature (>200 °C) and low temperature (<200 °C).

High Temperature Processes

High temperature heating made up 25% of industrial heat use in 2013.¹ It is typically used for chemical and refining processes, which usually use fossil fuels to achieve the high temperatures, although specialised electric heating can be used for some processes. Table 4 shows estimates of the carbon footprint of high temperature industrial sources. The carbon footprint of coal, oil and gas heating varies depending upon the efficiency (and age) of different boilers. The lower ends of these ranges are achieved when heat is recovered from the exhaust gases. Options for reducing emissions include using CCS, bioenergy, hydrogen and, in the medium term, combined heat and power (CHP).⁷⁵ Bioenergy can be combined with CCS to achieve a negative carbon footprint. Most modern industries use CHP, but there is no CCS in place at present.⁷⁶

Low Temperature Processes

Low temperature heating made up 75% of industrial heat use in 2013.¹ The processes typically use steam or heat for the drying, treating, separation or preparation of products such as food and drink, paper, electronics and clothes. Most industries still use fossil fuel boilers for low temperature heat. However, low temperature processes can make use of the heating technologies used in the domestic and commercial sector, including surplus high temperature heat.

Table 4. Carbon footprint estimates for high temperature industrial heating.^{23,24,26,27,68,75,77-84}

Technology	Footprint range (gCO ₂ eq/kWh)	Number of estimates
Electricity 370	~370	Personal Communication ⁵⁹
Coal	400-550	2
Oil	350-500	2
Gas	225-330	2
Coal with CCS	60-120	5
Oil with CCS	50-100	2
Gas with CCS	35-50	4
Gas CHP ²²	220-300	2
Hydrogen	See Table 3	-
Biomass	6-100 ⁴¹	5
Bioenergy with CCS	-140 to -200 ⁸⁵	2 ⁸⁵
Bio-sourced gas	20-100 ⁴²	2

Wider considerations for heat policy

The carbon footprint is far from the only factor to be considered in finding the 'best' way to decarbonise heating. The way heat is decarbonised, the choice of heating option and the speed that consumers move to new technologies will also depend on a wider range of important factors.⁸⁶

Consumer Preference

A range of consumer preferences may inhibit the adoption of alternative technologies.⁸⁸

- Most consumers seek the cheapest heating option, which for most is a boiler.^{89,90} Government policies (Box 3) have made some lower carbon options cost competitive, if lower running costs are taken into account. However, the upfront costs of some of these technologies are several thousand pounds more than a gas boiler. The costs of many newer technologies are expected to fall as supply chains improve.^{86,91-93}
- Heat pumps, solar thermal and hydrogen fuel cell heating do not perform in the way that consumers with boilers are used to. These technologies usually generate steady low temperature heat rather than heating with controllable timing and temperature. They also work better in well insulated buildings.
- DHNs also face some consumer scepticism, with concerns that they limit consumer choice.^{94,95}

Technological Constraints and Advantages

There are a variety of technological constraints that may affect or limit the use of different technologies.

- The widespread use of biomass may be limited by the availability of sustainable biomass.⁹⁶ Biomass burning can also affect air quality, by producing nitrous oxide and particulates, such as soot (see [POSTnote 458](#)).
- If hydrogen was injected into UK gas pipes and made up more than a small amount of the subsequent gas, then all gas-using appliances would need to be adapted.^{34,48} Some new technologies require more space than existing technologies. This can create difficulties for smaller urban properties and in properties with strict planning rules.
- Geothermal is limited to areas with suitable geology.^{100,101}

Conversely, DHNs have benefits beyond being low carbon. They can take advantage of the benefits of more than one heat source at one location. They also allow heat sources to be changed (to a low-carbon heat source) with little disruption to consumers once the DHN is initially fitted.¹⁰²

Box 3. UK Government Heat Policies

The Government is supporting the development of some heating technologies through the following policies:

- The Renewable Heat Incentive supports biomass boilers, injection of bio-sourced gas into the gas grid, CHP, heat pumps and solar thermal by paying users of these technologies.⁹⁷ Uptake has mainly been for biomass boilers, heat pumps and solar thermal.
- Heat networks were allocated £300m in the spending review.⁹⁸ The Government's Heat Network Delivery Unit also provides support and guidance on heat networks to local authorities.⁹⁹
- The Government has funded research into geothermal, hydrogen and CCS technologies, but has not funded their deployment.

Reductions in Heat Demand

A complementary approach to reducing emissions from heating is to make the use of heat more efficient. The efficiency of heat use in UK buildings can be improved through standards on new buildings, insulating older buildings and by encouraging occupants to engage in energy saving behaviour. These measures are also a key policy approach to reducing fuel poverty.⁸⁷

Security of Heating Supply and Economic Considerations

The reliability of consumers' heating depends upon reliable supplies of electricity (see [POSTnotes 399](#) and [464](#)), gas (see [POSTnote 513](#)) and biomass and the reliable functioning of the individual heat generating units. The widespread electrification of domestic heating using heat pumps would likely require significantly increased electricity generation capacity and transmission network infrastructure, which is considered a major challenge.^{15,103}

Heating policy options can also have economic effects beyond the direct cost of heating, including on UK jobs and the balance of trade. However, no analysis is available on the economic effects of supporting different technologies.

Approaches to Reducing Heat Emissions

Models of how 'best' to decarbonise heat have differing priorities: minimising cost, maximising emissions cuts or satisfying consumer preferences.¹⁰⁴ The models vary greatly but suggest that:

- from 2030, a significant proportion of domestic heating should come from electrification using heat pumps (including hybrid heat pumps) and electric heaters; using bio-sourced gases or hydrogen in the gas grid and an increase in district heat networks^{8,15,94,95,105-108}
- in the industrial sector, CCS is a key technology to decarbonise high temperature heat; electrification plays a role in some industries.⁷⁵
- low-carbon heating should be introduced in parallel with the decarbonisation of electricity and a reduction in heat demand from increased energy efficiency.^{8,109}

It is widely agreed that this will be difficult to achieve and is likely to require an increase in policy intervention.^{10,110}

Policies to encourage the take-up of low carbon heating could include the following options.^{10,60}

- Incentives – grants or tax breaks for companies or individuals using a low-carbon heat system.
- Taxation – such as increasing the 5% VAT rate on fossil-fuelled heating or expanding the Carbon Floor Price and EU Emissions Trading System to include heating.^{60,111}
- Regulation – establishing organisations with the power to assist with large scale or localised heating projects.

Endnotes

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