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A review of heat decarbonisation policies in Europe

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Executive summary

Introduction

European countries vary greatly in terms of how residential buildings are heated. These differences, built up over decades, reflect particular national resource endowments, economic resources and technical infrastructures. They also reflect different governance approaches and policy choices. Despite the many different technical, economic and political circumstances involved, a number of insights and messages emerge from a cross-national review.

In this report, we review the heating technologies and heat policies of nine European countries: the UK (with a focus on Scotland), the Netherlands, Norway, Sweden, Finland, Denmark, France, Germany and Ireland). We assess how government policy has been used to change the way heat has been delivered, and current approaches to policy-driven heat decarbonisation. We set out in detail the policy instruments – financial incentives, regulations and tax structures – that are used to drive countries toward zero-carbon heating. Where available, we also present information on how each country is developing policies and targets for the decarbonisation of heating.

Key findings

Varied contexts, opportunities and challenges

Each of the countries covered faces the challenge of heat decarbonisation with a different set of opportunities and challenges, in terms of its energy resources, established infrastructure and policy mixes. In Scotland and the UK as a whole, over 80% of residential properties are heated via a gas grid. Other countries which receive most of their home heating in this way include the Netherlands (95% of properties) and Germany (53%). Gas grids are particularly challenging to decarbonise, and achieving net-zero home heating in these countries will involve a decisive break from established forms of supply, and highly interventionist regulatory approaches, some of which are now being formulated – such as the prohibition of gas connections for new homes.

An important difference among the countries surveyed is the contrasting historic patterns of heat supply and associated carbon emissions. Heat supply infrastructures have long asset lifetimes, and change has often been slow and gradual – though with some examples of rapid transition (seen, for example, in the conversion to natural gas supply in Great Britain in the 1960s and 70s).

Countries such as Denmark and Sweden have been pursuing a move away from fossil fuel-based home heating for decades – historically as a result of energy security concerns but driven more recently by climate policy imperatives. Decarbonising district heating (DH) systems is the main challenge in Finland and Denmark, while Swedish heat is already almost fully decarbonised. Norway is distinct in having a low-carbon and almost completely electrified heating sector, in the context of a longstanding and large-scale hydroelectric power system. In France and Ireland, off-grid fossil fuel (oil) heating is still widely used, alongside a less extensive gas grid than in the UK and The Netherlands.

National planning for low-carbon heat

All countries covered have committed to some form of carbon neutrality by 2050. For those countries with more carbon-intensive heating, the precise decarbonisation pathway remains unclear. Interim emission reduction targets have also been introduced: in the Netherlands, 20% of residential properties must be supplied by renewable or low-carbon heat technologies by 2030; in France and in Germany there are targets for total heat consumption to come from renewable energy by 2030, 38% and 27% respectively.

Scotland has an interim target to decarbonise 35% of domestic properties by 2032, but this is soon to be revised to reflect a recently introduced economy-wide decarbonisation target of 75% by 2030. This is likely to result in a new interim heat decarbonisation target that is more ambitious than elsewhere in Europe.

One possible technology for helping meet these target is the conversion of the natural gas grid to some form of low-carbon hydrogen. The Netherlands, Germany and the EU as a whole have all recently released hydrogen strategies. These strategies share a view that hydrogen may become a viable option for home heating in the longer term as part of a mix of solutions, but that this role may be limited – and also, that the low-carbon hydrogen proposition goes beyond the domestic heating sector. These strategies also all emphasise the need to focus ultimately on green hydrogen (produced using renewable electricity), although with some acceptance that there is a role for blue hydrogen (produced from natural gas reformation) in the interim.

District heating is also seen as an important contributor to heat decarbonisation in many countries. Unlike low-carbon hydrogen, this is an established technology – it provides between a third and a half of domestic heating in Scandinavian countries, although a significant, if declining, share of this still comes from fossil fuels. Biomass is currently the primary means of providing low-carbon district heating in countries such as Sweden and Finland. There is, however, a greater endowment of biomass resources in these regions, and there will be much competition for the more limited biomass resource in a net-zero Scotland.

Decarbonising oil heating

Decarbonising properties which are ‘off the gas grid’ is an early policy priority in a number of countries, and is often considered a ‘low-regret’ intervention. In countries such as Finland, Denmark and Norway the main replacement technologies for off-grid properties, which often still rely on oil heating, are heat pumps and – to a lesser extent – biomass boilers.

Policy carrots and sticks

As the urgency of decarbonising buildings’ heating has grown, as part of overall targets for net-zero economies, the policy mix in many countries has seen a rise in prohibitions on fossil fuel use, alongside more established incentives for low-carbon technologies.

In many countries, these bans have been applied to new buildings first. Norway and Denmark have prohibited oil heating in new buildings since the early 2010s, and bans have since been extended to apply to any new fossil fuel heating in new Norwegian buildings, and any replacement of oil heating technology in existing buildings in Danish 'collective heat zones'. Norway has also recently completely banned the use of oil heating. Bans on fossil fuel heating in new buildings will be introduced in the early 2020s in the Netherlands, Ireland, the UK and Scotland.

In all countries surveyed, purchase subsidies (grants, loans or tax credits) are used to incentivise the purchase of heat pumps and, in some cases, other technologies, such as solar thermal and biomass boilers. Low-interest loans for low-carbon heat are available in Germany, France and Scotland. Until recently – before the introduction of the new Green Homes Grant scheme – the UK stood alone as the only country to subsidise the energy generated rather than the upfront costs of the technology (using the Renewable Heat Incentive).

Tax rates

Although beyond the control of the Scottish Government, the relative levels of tax on fuel are an important component of overall heat decarbonisation policy. Of the countries considered, the UK has by far the lowest tax rate on the domestic use of natural gas (see Table 1, below). Although this low level has been seen as a means to address fuel poverty concerns, the disparity between gas and electricity tax levies is increasingly anomalous in a context where the electrification of heating is seen as a key means for decarbonisation of the Scottish and UK heat sectors. The relatively high-level tax on domestic electricity use is associated with high fuel poverty rates in Scottish properties using electric heating. In this context, realising ambitious policy targets for heat decarbonisation and fuel poverty are likely to require changes to energy and fuel direct tax rates and/or contributions from general taxes such as income tax.

Table 1: Residential heating carbon intensities and taxes, selected countries

Country	Carbon intensity of residential heating (2015) (gCO_2/kWh)	Carbon intensity of electricity (2017) (gCO_2/kWh)	Overall tax on residential energy use (%)*			
			Gas	Oil	Electricity	Biomass
UK	185	268	5	24	22	5
Netherlands	200	452	54	63	26	/
Norway	/ **	19	/	45	36	0
Sweden	29	9	45	/	39	/
Finland	95	83	43	45	33	0***
Denmark	118	147	56	50	35****	0
France	100	67	24	34	36	0
Germany	200	419	24	25	54	/
Ireland	254	393	17	29	12	/

Source of carbon intensity data: (Bertelsen and Vad Mathiesen, 2020); / = data was not able to be located

** Tax components include value-added taxes and excise taxes, levies and public charges (IEA, 2020)*

*** Data not available, but likely to be lower than all other countries reviewed here*

**** 0% on second generation biomass only; **** Tax rate is doubled if not used for residential heating*

Contents

1. Background

Decarbonising the heating of homes and the wider building stock is one of the key challenges within the climate change mitigation policies of many countries. Due to the adoption of net-zero emission reduction targets, the 2020s is a hugely important decade for the phase out of fossil fuel heating. These heating systems include boilers fuelled by a mains gas grid, standalone boilers running on oil, liquid petroleum gas or solid fuels like coal, and the fossil-fuelled plant in district heating systems. Electric heating may also currently be carbon intensive but with electricity decarbonisation a fundamental part of overall climate policy, electric heating systems will likely play a significant role in the future.

In Europe, the scale of the heat challenge varies considerably, with some countries almost entirely reliant on fossil fuels for heat e.g. the UK, the Netherlands and Germany, and others where fossil fuels currently play only a minor role e.g. Norway and Sweden. In countries still reliant on fossil fuel heating, the future mix of low-carbon technologies is often still deeply uncertain. The scale of the challenge faced, however, means that significant moves toward decarbonisation must be made in the next few years. Decisions on how government policy can effectively facilitate the transition must be taken, with the policy mechanisms e.g. subsidies, energy taxation and regulations that bring about the change likely to be subject to much greater public and political scrutiny.

Although this review addresses all heat decarbonisation policy, it has a focus on policy relating to the decarbonisation of standalone fossil boiler systems using oil, LPG and solid fuels. The uncertainty associated with how to best decarbonise properties on the gas grid means that off-gas grid fossil heating systems are often viewed as being ‘low regret’ with a greater consensus around the most appropriate low-carbon replacement options (CCC, 2019; EHAS, 2019). These systems are a priority for decarbonisation in Scotland, cited for ‘decisive, near-term action’ by the UK Government (BEIS, 2018a) and scheduled for decarbonisation in the 2020s (HM Government, 2017).

This review sets out in detail how selected European governments have been and are currently facilitating the decarbonisation of home heating. The review seeks to inform the policy making and research communities in Scotland and other jurisdictions which are addressing the problem of how to effectively phase out fossil fuel heating. This report accompanies a larger study of technology phase out in the energy sector (see Kerr and Winskel, forthcoming) which draws on a wider international evidence base than is presented here.

2. Case studies

This section reviews how heat is currently provided and how heat decarbonisation policy is designed in selected European countries. The wider European cases were chosen on the basis of their comparability to Scotland and the UK, in terms of having similar policy objectives (often led by EU policy), broadly similar governance structures, and similar climates – with buildings’ heating constituting a significant source of national energy demand. An additional consideration in case selection was the availability of evidence. As the phase out of oil-based heating is a priority area for decarbonisation in Scotland and the rest of the UK, the review goes into greater detail on oil-related policies where applicable. Each case includes the most recently available data on the heating sources for residential buildings (where residential building data was not available, data for all buildings – residential and commercial/public were used) and the overall carbon intensity of national residential heating.

2.1 UK and Scotland

About 85% of residential properties in the UK are heated by mains gas (BEIS, 2018b), 9% are heated by electricity and about 5% by off-grid fuels, including oil, LPG and solid fuels (CCC, 2016; Policy Connect, 2019). The carbon intensity of overall UK residential heating was about 185 grams CO_2/kilowatt hour in 2015 (Bertelsen and Vad Mathiesen, 2020). In Scotland, around 81% of residential properties are heated by mains gas, 10% by electricity and 7% by oil, LPG or solid fuels (Scottish Government, 2020b).

Figures 1 and 2: UK and Scotland residential buildings heating type

Figure 1: UK

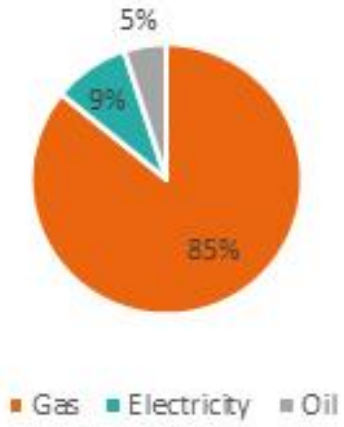
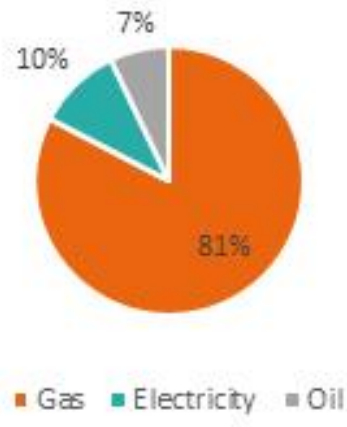


Figure 2: Scotland



Heat decarbonisation policy in the UK has focused mainly on the demand side, in terms of energy efficiently retrofitting existing buildings, and on improving the efficiency of existing fossil heating technologies. The main retrofit policy instrument has been energy supplier obligations (ESOs)[1] – there has been some form of ESO in the UK since the early 1990s, shortly after the privatisation of the electricity and gas industries (Mallaburn and Eyre, 2013; Kerr et al., 2017). Under the current 'Energy Company Obligation' energy efficiency and heating measures apply solely to low income, fuel poor or vulnerable households. This restricted approach reflects the potentially regressive nature of ESOs, as their costs are passed on to all consumer bills.

Scottish consumers have historically been awarded a disproportionately large share of UK-wide ESO funding. The Scottish Government provides additional funding for retrofit in Scotland under the Energy Efficient Scotland (EES) programme. The dedicated Scottish funds and the high share of UK funds means that Scotland received four times more public investment in retrofit than England in 2017, on a pro-rata basis (Guertler, 2018)

Minimum energy efficiency regulations for housing have been introduced in the UK in recent years. All regulations in the UK and Scotland are structured using Energy Performance Certificate (EPC) bands. In the private rented sector, there are different requirements and timeframes in Scotland compared to England and Wales (DECC, 2014; Scottish Government, 2018b; Scottish Government, 2019b)[2]. Under the Energy Efficient Scotland programme, the Scottish Government also regulates the social

[1] ESOs: government policy that obliges energy suppliers that conform to certain criteria e.g. number of customers, to instigate energy efficiency measures, normally outside their organisation.

[2] The Scottish PRS regulations were due to come into force on 1 April 2020 but have been delayed due to the Covid-19 crisis. See https://www.gov.scot/policies/home-energy-and-fuel-poverty/energy-efficiency-in-private-rented-housing/

housing sector and has recently run a consultation process on regulating the owner-occupied sector (Scottish Government, 2018b; Scottish Government, 2019a). Although the UK Government aims for "as many homes as possible" to be EPC band C by 2035 (HM Government, 2017), there are currently no minimum energy efficiency standards for owner occupiers in England and Wales (or for social housing, although standards are generally higher in this sector) (House of Commons, 2019).

The efficiency of fossil heat supply was improved by the introduction of minimum efficiency standards for gas and oil boilers in 2005 (Mallaburn and Eyre, 2013). The main policy instrument currently supporting the uptake of low-carbon heat supply in buildings is the Renewable Heat Incentive (RHI)[3]. RHI offers a payment for every unit of heat generated for specified technologies over a designated time period (7 years for domestic and 20 years for non-domestic). Uptake of the RHI has been lower than expected (PAC, 2018). As with ESO funding, there has been a greater pro-rata uptake in Scotland, with c.19% of all GB domestic and non-domestic accredited measures (Scotland has c.8.5% of the GB population) (BEIS, 2020b). This greater share of uptake is aided by the existence of a 0% loan for low-carbon heat and energy efficiency in Scotland (and not England) that can be used alongside the RHI.

In April 2020, the UK Government proposed moving to a Clean Heat Grant from 2022 which would offer grants of up to £4000 for heat pumps and biomass with a capacity of less than or equal to 45kW. Biomass will only be supported where there is evidence that a heat pump would not be appropriate (BEIS, 2020a). The UK Government plan to get to 600,000 heat pump installation a year by 2028 (HM Government, 2020). Tax rates on different heating fuels vary widely: overall tax rates are estimated to be 24% on heating oil (IEA, 2020), 22% for electricity (OFGEM, 2019) and 5% for mains gas and biomass (IEA, 2019b) (HMRC, 2016).

Both Scotland and the UK have legislated net-zero targets for 2045 and 2050 respectively. The 2019 Climate Change (Emissions Reduction Targets) (Scotland) Act's legislated target of 75% reduction in economy-wide emissions by 2030 (against 1990 levels) (Scottish Government, 2019c) led to the publication of a Climate Change Plan update in December 2020 and a Draft Heat in Buildings Strategy in February 2021 (Scottish Government, 2020c; Scottish Government, 2021).

Prior to these developments, Scotland had interim targets for the heating sector of 11% of non-electrical heat demand to be met by renewables in 2020 - in 2019 the figure was 6.5% (EST, 2020) - and an overall 35% of heat in domestic buildings supplied using low-carbon technologies by 2032 (Scottish Government, 2018a). The Draft Heat in Buildings Strategy sets out the ambition to move 1 million homes currently using mains gas, and the vast majority of off-gas homes (altogether accounting for about 50% of the housing stock) to zero-emission heating by 2030 (Scottish Government, 2020a; Scottish Government, 2021)[4]. The Government see the majority of these properties moving to some form of electric heating with these likely to be an individual heat pump or a heat network running on a heat pump. All new homes consented from 2024 must also use zero-carbon heat (Scottish Government, 2019).

[3] There have been separate RHI schemes for Great Britain (England, Scotland and Wales) and for Northern Ireland. In this report we refer solely to the GB scheme. The NI scheme was closed in 2016 due to faults in the design of the scheme causing excessive expenditure, which led to political resignations and a public inquiry. See https://www.rhiinquiry.org/key-documents

[4] See https://www.parliament.scot/S5_EconomyJobsFairWork/Inquiries/20200207-MinECI-EnergyStatement.pdf

In England, the Future Homes Standard is expected to require new properties in England built from 2025 to have a low-carbon heating system[5] (MHCLG, 2019). The UK Government has stated that it plans to phase out the installation of high-carbon fossil fuel heating in new and existing off gas grid residential buildings "during the 2020s" (HM Government, 2017). Decarbonisation of most existing homes on the gas grid will take place at a later stage, although the development of district heating networks is also considered a low regrets priority and may result in some areas on the gas grid moving to low-carbon heat earlier. A UK Heat and Buildings Strategy is due to be published in early 2021. Scottish and UK Governments are weighing up the prospects of heat electrification, district heating, the use of hydrogen in a re-purposed gas grid or some form of hybrid system (Scottish Government, 2017; CCC, 2018; BEIS, 2018a).

There is considerable uncertainty over the extent to which hydrogen should be used for home heating. Unlike Germany and the Netherlands, the UK has yet to publish a national hydrogen strategy[6]. Scotland released a hydrogen policy statement and action plan in late 2020 (Scottish Government, 2020d). The UK's statutory independent advisor on climate policy, the Climate Change Committee (CCC) recently suggested that hydrogen would be best used to meet peak heat demand in hybrid domestic heating systems or district heating (CCC, 2018; CCC, 2019). The CCC anticipates that the majority of hydrogen production to 2050 will be from gas reformation with carbon capture and storage (CCS) (so-called 'blue hydrogen') with a small amount from electrolysis and renewable energy ('green hydrogen') (CCC, 2019). Blue hydrogen is also the primary production method in the hypothetical 'hydrogen pathway' (where hydrogen makes up 62% of home heating demand) in the UK Clean Growth Strategy (HM Government, 2017). Although green hydrogen is lower carbon, current cost estimates make it much more expensive (Speirs et al., 2017). The UK government aims to have a 'Hydrogen Town' – equivalent to tens of thousands of homes – by 2030 (HM Government, 2020).

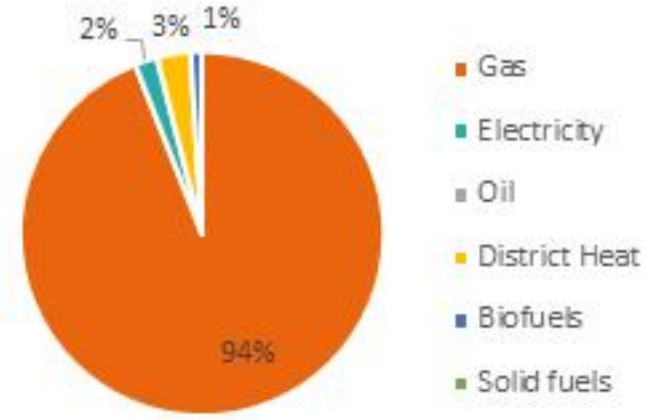
2.2 The Netherlands

The Netherlands is the only country in Europe with a more comprehensive gas grid than the UK, with almost 19 out of 20 homes connected; small amounts of heating are provided by electricity, district heating and biomass (Figure 3). Individual high-carbon systems such as oil, LPG and coal provide less than 1% of home heating requirements (Fleiter et al., 2017). The carbon intensity of Dutch domestic heating was about 200 g CO_2/kWh in 2015 with next to no change since 1990 (Bertelsen and Vad Mathiesen, 2020).

[5] It is not yet clear whether all properties built in 2025 should conform to the new standard. The BEIS Select Committee highlighted that as late as 2018 many house builders built properties "to standards that pre-date the 2013 regulations". See https://publications.parliament.uk/pa/cm201719/cmselect/cmbeis/1730/1730.pdf

[6] See https://hydrogenstrategynow.co.uk/

Figure 3: Netherlands residential buildings heating types (Vivid Economics & Imperial College, 2017b)



The Netherlands has moved from being the largest producer of natural gas in Europe to having gas fields that are approaching exhaustion (van der Burg and Runkel, 2017). The Dutch government is to end oil and gas extraction from the Groningen field by 2030 (partly due to the occurrence of earthquakes) although there is no wider offshore oil and gas extraction cessation target (Beckman and van den Beukel, 2019).

Alongside a long-term target to eliminate fossil fuel heating by 2050, the Dutch government has recently begun to set shorter-term deadlines for change. In 2017 it was agreed that no new buildings will be heated by natural gas after 2021 (Beckman and van den Beukel, 2019). In 2018 the government removed a legal obligation for new homes to be connected to the gas grid (if requested by the project developer) (van der Burg and Runkel, 2017). The 2019 Climate Accord sets out that the ban only applies to buildings where the building permit was applied for after 1st July 2018, and so between 2018 and 2021 there will still be some new buildings connected to the gas grid (Dutch Government, 2019a).

From 2020, all new Dutch buildings are required to be 'almost energy neutral'; this translates to a maximum heat demand of 25 kWh/m^2/year with at least 50% of energy from renewables (van Eck, 2016). Existing buildings using fossil fuels are expected to be made 'sustainable'[7] by 2050. There is a shorter-term target of 1.5 million existing houses to have 'sustainable heating' by 2030, starting at a rate of 30-50,000 homes per year and ramping up to 200,000 a year (the current building stock is about 7.7 million homes and 1 million non-domestic buildings) (Beckman and van den Beukel, 2019).

This transition is to be encouraged by a gradual increase in the tax on natural gas and decrease in tax on electricity (in a manner that is fiscally neutral overall) (Beckman and van den Beukel, 2019). The current overall tax rate on heating oil in the Netherlands is around 63% (IEA, 2020); tax breaks for heating oil ended in 2013 (van der Burg and Runkel, 2017). The tax rate on mains gas is 54% (IEA, 2019b) and the tax on electricity is 26% (IEA, 2020). There is also a renewable heat subsidy scheme (ISDE), with a budget of €100 million for 2019 specifically for heat pumps, solar water heaters and biomass systems (Dutch Government, 2019a); capital subsidies include between €1,000–2,500 for a domestic heat pump (RON, 2020).

[7] What constitutes 'sustainable heating' is not currently defined in the Dutch Climate Agreement but a range of technologies are mentioned including heat pumps, hybrid heat pumps, district heating, biomass boilers and boilers with low-carbon gas (Dutch Government, 2019b). It is inferred that sustainable heating means achieving agreed emission reduction targets (Beckman and van den Beukel, 2019).

The Dutch Government has provided an indicative estimate that low-carbon heating systems will be 50% district heat (with various renewable energy sources suggested, including industrial waste heat, biomass, power to heat or biogas) and 50% heat pumps (including all-electric and hybrids) (Beckman and van den Beukel, 2019). The 2019 National Climate Agreement notes a consensus that hydrogen will play an important role in the Dutch low-carbon transition, and is an option for heating buildings when there is no feasible alternative (Dutch Government, 2019. p. 172). The Government emphasises the need ultimately to use only green hydrogen, but that blue hydrogen will be necessary in the interim – significant volumes of green hydrogen are expected to only become available after 2030. The use of blue hydrogen is, however, only seen as a 'stepping stone' and one that must not 'impede' the eventual transition to green hydrogen (Dutch Government, 2019a; Beckman and van den Beukel, 2019).

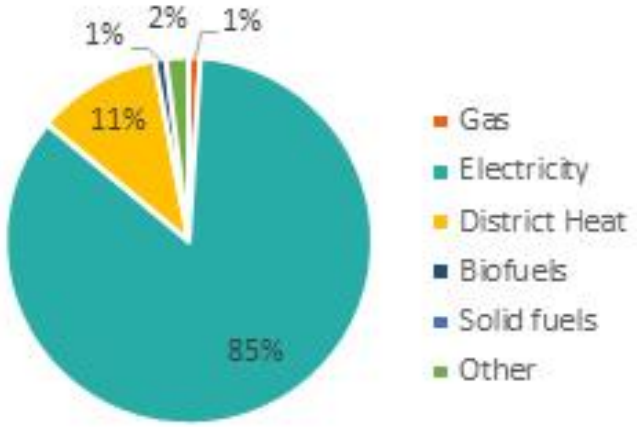
The Dutch Hydrogen Strategy states that green hydrogen may have potential to make a significant contribution to heating in the longer term, but that uncertainty over its cost maked it difficult to predict whether it will be an 'affordable option' for home heating; 3-4GW of electrolysers producing green hydrogen are planned for 2030. The strategy also states that the government is considering imposing a blending obligation for green hydrogen in the natural gas grid as a means of boosting demand and scaling up production (MEZK, 2020).

The approach to governing heat decarbonisation in the Netherlands has been developed using the 'Polder Model', in which selected representatives from across society agree the measures to be taken (Peet, 2002; Dekker, 2017). Under this approach, Renewable Energy Strategies (RES) are to be developed for each of the 30 Dutch regions by municipal and provincial authorities, housing corporations, energy companies, business associations, citizen groups, and water boards (Beckman and van den Beukel, 2019).

2.3 Norway

Buildings in Norway are predominantly heated using electricity (85%), largely powered by hydroelectricity. Around 11% of heat comes from district heating, with municipal waste the primary source of fuel (60%) for DH followed by biofuels (24%) and electricity (10%) (IEA, 2017b). While DH has more than doubled in the past decade, fossil fuels have only ever provided a small portion of overall supply (ibid, Figure 3.10). As the carbon intensity of electricity was estimated to be 19 g CO_2/kWh in recent years (EEA, 2020), the overall carbon intensity of heat is likely to be the lowest in this review (although no exact figure was found).

Figure 4: Norway residential and non-residential buildings heating types (Patronen et al., 2017)



Historically, Norwegian homes have been heated using direct resistive electric heating[8], and while this is still the dominant source of domestic heat, it is estimated that a third of domestic properties now have some form of heat pump (Vivid Economics & Imperial College, 2017a). The use of both heat pumps and district heating has increased in recent years; This is attributed to rising electricity prices (stemming from increased demand and limited hydro capacity), while subsidies from 2003 helped drive the move to district heating and heat pumps.

In 2017, the Norwegian Government set out to ban the use of oil (kerosene) for the heating of buildings with effect from 1st January 2020. The intention to regulate was announced in Parliament in 2012[9]. This is a hard end point after which no use of the fuel is allowed, rather than the point after which replacement systems must not use fossil fuels. Existing heating systems can continue to be used with certain biofuels[10]. Exemptions are applied to buildings not on the electricity grid and to oil-fired district heating systems over 1 MW (European Commission, 2017); agricultural buildings are exempt until 2025 (Klima-og miljødepartementet, 2019). The ban is enforced at the point of sale, with the sale of heating oil monitored (Enova, 2018). For new buildings, oil heating as baseload has been banned since 2011 with all fossil fuel heating systems banned since 2016 (IEA, 2017b; Brekke et al., 2018).

There were around 180,000 residential properties and 20,000 commercial properties using some form of oil heating in 2009 (Miljødirektoratet, 2015). By early 2018, around 80,000 domestic residences were still using oil heating as the primary or a secondary source (Enova, 2018). Heating-oil sales collapsed from 1,238,000 m^3 in 2005 to 319,000 m^3 in 2015 (IEA, 2017b). As the vast majority of Norwegian buildings use electric heating, the regulation is forecast to save less than 1% of Norwegian emissions (Reuters, 2017) . Those converting away from oil are expected to adopt heat pumps, other form of electric heating, district heating or bio-oil (hydro treated vegetable oil - biodiesel).

In 2019, the overall tax rate on heating oil in Norway was 45% (including VAT standing at a full rate of 25% – a reduced rate is used for other fuels) (IEA, 2020), compared to

[8] The passage of an electric current through a conductor produces heat, examples include electric panel heaters and radiators (sometimes oil filled).

[9] The intention to regulate was first announced in Parliament in 2012. (Personal communication with the Norwegian Environment Agency).

[10] The regulation specifies that "biofuels should provide a reduction of at least … 50% from 2017 and then to 60% … from 2018" (Miljødirektoratet, 2015).

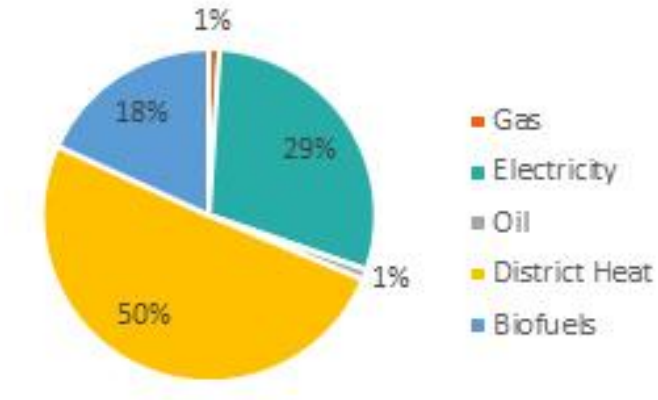
36% for electricity (IEA, 2020) and 0% on biomass (OECD, 2018a; IEA, 2020). The transition from heating oil has been supported by a gradual increase in the relevant taxes (Det Kongelige Finansdepartement, 2019, see figure 13.19).

Alongside these 'negative' regulations are positive incentives. Norwegian renewable heat subsidy payments totalled 275 million NOK in 2018 (£25 million), up from 165 million NOK (£15 million) in 2017; 14,500 grants were issued in 2018 to remove existing heating systems and, in most cases, subsidise a new one. Over 90% of those receiving a grant to convert to a new energy system chose some form of heat pump (Enova, 2018).

2.4 Sweden

As of 2016, heating (by energy) in Swedish domestic buildings came mainly from district heating (50%), followed by electric heating (29%), biomass systems (18%) and with small fractions for natural gas (1%) and oil boilers (1%). Oil heating has gradually fallen from 43% of residential heating energy in 1983. District heating has risen from 23% in 1983 to 50% in 2016 (Swedish Energy Agency, 2018). About three quarters of district heat in Sweden is powered by biofuels and waste; a small proportion uses fossil fuels (thought to be 8% in 2016, split roughly evenly between coal, gas and oil) – which is to be phased out by 2020 (Karolyte, 2017; IEA, 2019c). In 1990 fossils fuels provided about 40% of district heat (Sweden Energy Agency, 2018, Table 7.2). Sweden has the lowest carbon intensity of residential heating of the EU-28 at 29 CO_2/kWh in 2015 (Bertelsen and Vad Mathiesen, 2020).

Figure 5: Sweden residential buildings heating types (Sweden Energy Agency, 2018, Table 3.4).



The target for the phasing out of fossil fuels for heating by 2020 has been in place since 2009 (Regeringskansliet, 2009). However, given the relatively low-carbon intensity of heat in Sweden at present, there are no proposals for the mandatory cessation of fossil fuel heating. Remaining fossil fuel heating systems are likely to be replaced with low-carbon district heating, biomass or electric heating[11].

The Swedish system of taxes on fossil fuels and incentives for heat pumps, district heating and biomass systems has transformed heat provision since the 1970s (Karolyte, 2017). Factors that instigated this shift include the oil crises of the 1970s, public opposition to the expansion of nuclear power and the efficiency of heating new homes with district heating (Werner, 2017; Johansson, 2017).

Climate change mitigation policy began to have an influence from the early 1990s, with a carbon tax introduced in 1991, now the highest in Europe (Vivid Economics & Imperial

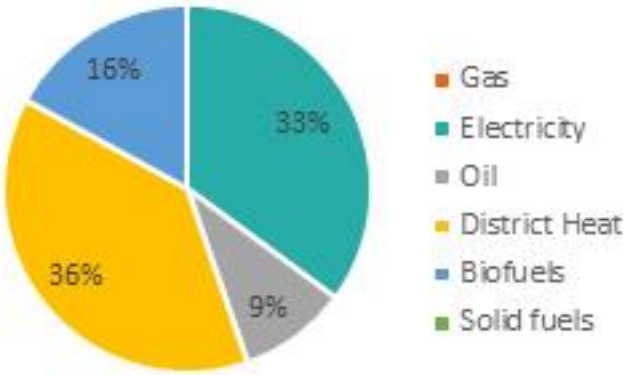
[11] Swedish electricity has the lowest carbon intensity of any EU member state (Moro and Lonza, 2018) with a 100% renewable target by 2040 (Swedish Energy Agency, 2019).

College, 2017b). The switch from fossil fuel district heat to the majority of heat coming from biomass has been driven by carbon taxation (IEA, 2019c). Overall tax rates are 45% for natural gas and 39% for electricity (IEA, 2019a, 2020)[12]. Another distinctive aspect of Swedish policy has been the funding of research and development of new heat technologies since the 1970s, including for heat pumps and district heating (Kiss et al., 2012; Karolyte, 2017; Johansson, 2017).

2.5 Finland

As of 2016, residential heating (by energy) in Finland was made up of 36% district heating, 33% electric heating, 16% biomass and 9% oil (Figure 6). Twenty years earlier, oil heating was much more prevalent, supplying 28% of home heating energy in 1995, with electricity at 28% and district heat at 25% (Oxford ECI, 1999). In 2016, over half – 54% – of DH was still provided by fossil fuels (coal, peat, gas and oil), although this was down from over 80% in 2006; biofuels provided 32% and waste generation 7% (IEA, 2018). This mix resulted in a carbon intensity of about 95g CO_2/kWh in 2015 (Bertelsen and Vad Mathiesen, 2020).

Figure 6: Finland residential buildings heating types (Fleiter et al., 2017)



Under the National Energy and Climate Strategy for 2030, a 10% blend of bio-liquid fuels will be obligatory in heating oil by 2030, with a gradual increasing rate from 2021 (Finnish Ministry of Employment and the Economy, 2017; Voegele, 2019). This measure is expected to raise the cost of heating oil by 8%; the use of oil is expected to fall to 5% of heating energy in all buildings by 2030 (ibid). From 2025, oil heating will not be permitted in state-owned properties, with other 'public sector operators' encouraged to follow (Ympäristöministeriö, 2019). The most recent Climate Plan models heating oil use falling to very low levels by 2040 with heat pumps the main replacement technology (MEAE, 2019; Sovacool and Martiskainen, 2020).

Finland has one of the highest rates of heat pump sales in Europe, supported by a tax deduction subsidy whereby 60% of the installation (labour) costs (up to €3,000) can be deducted from personal taxation (Hanna et al., 2016; IEA, 2018). Finland offers an example of relatively rapid heat pump uptake, going from less than 50,000 installations in the early 2000s to nearly a million in 2018; currently about 70% of small, new build homes install a heat pump (Kivimaa et al., 2019) – the vast majority of which are air-air heat pumps (Sovacool and Martiskainen, 2020).

In district heating, the switch from fossil fuels to biomass and waste heat generation has been driven by carbon taxation (IEA, 2018). In 1990, Finland was the first country in the

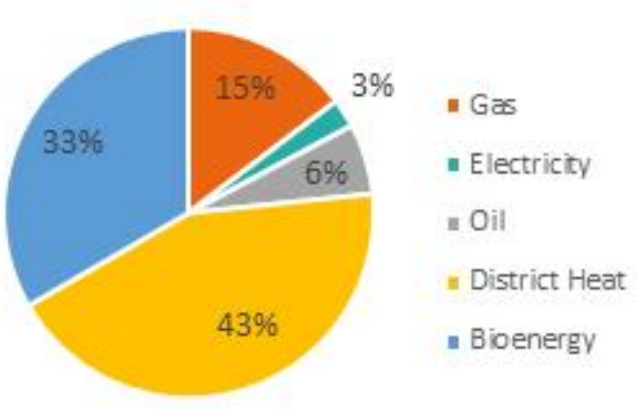
[12] This review was not able to locate data on heating oil tax rates in Sweden.

world to introduce a carbon tax (Hanna et al., 2016). The current overall tax rate on heating oil in Finland is 45%, 43% on natural gas (Statistics Finland, 2019)[13] and 33% on electricity (IEA, 2020). Biofuels are subject to a variable carbon tax – from full (fossil) levels, if they don't achieve sustainability standards, 50% on first generation biofuels (from crops grown specifically for biofuel) and 0% on second generation biofuels from waste or wood (IEA, 2018; OECD, 2019). In the absence of carbon tax (second generation biofuel), the overall tax of biofuel heating oil is around a third of that on fossil oil and 40% of that on gas (IEA, 2018).

2.6 Denmark

In 2015, almost half of heating for residential buildings in Denmark used district heating, with about 15% from natural gas, 33% from biofuels, and small amounts from oil and electricity (Figure 7). In 2016, around 60% of DH was fuelled by biofuels and waste, with coal and gas fuelling about 20% each respectively (IEA, 2017a). Oil for heating in residential buildings has been gradually falling for several decades in Denmark, from around a third of properties in 1990, to 22% in 2000, and around 6% in 2017 (IEA, 2017a; DEA, 2018). Residential heating had a carbon intensity of 118 gCO_2/kWh in 2015, although this had reduced from 244 gCO_2/kWh in 1990, the highest reduction in the EU (Bertelsen and Vad Mathiesen, 2020).

Figure 7: Residential buildings heating types (DEA, 2020)



The 2012 Energy Agreement prohibited the installation of oil heating for new buildings from 2013, and the installation of new (or replacement) oil-fired boilers in existing buildings in 'collective heat zones' from 2016 (IEA, 2017a). Exemptions are available for existing properties where it is considered unreasonably expensive to comply (although this is not thought to apply to many properties due to the structure of energy taxes in Denmark – see below).

The Danish Government plans for all heating supply to buildings to be from renewable sources by 2035 (Harrestrup and Svendsen, 2014). While at one point there was a commitment to phase out all oil burners by 2030 (Ropenus and Klinge Jacobsen, 2015), the current plan is that oil for heating will account for less than 2% of household energy consumption by 2030 (DEA, 2018). Households outside a collective heat zone are expected to gradually migrate from oil heating on economic grounds, with heat pumps and biomass modelled as more cost-effective.

The oil crises in the 1970s led to a move toward energy independence with government support for district heating and combined heat and power (CHP). There is a strong link

[13] Using data from Appendix Table 1 and 2

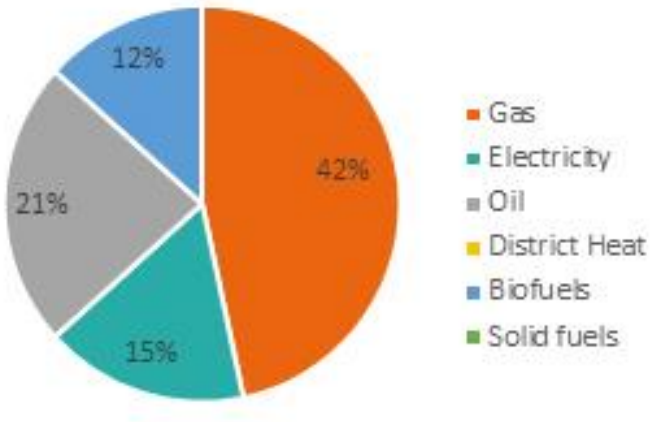
between CHP and DH in Denmark with 80% of DH coming from CHP plants and 50% of electricity (Sovacool and Martiskainen, 2020). A tax on oil introduced in 1977 substantially increased the cost of oil heating and created a significant incentive to switch (Hanna et al., 2016). District heating has gradually moved from fossil fuels to biomass (and some amount of solar thermal) as a result of environmental taxation. While DH with solar heating and large thermal energy stores has grown in recent years due to taxes of fossil fuels and efficiency requirements on DH (IEA, 2017a). The current overall tax rates are 50% on heating oil, 56% on natural gas and 0% on biomass (OECD, 2018a; IEA, 2019b; IEA, 2020). The tax rate on residential electricity is currently 70%, but this is more than halved if it is used for heating (IEA, 2017a; Vaasa ETT, 2019; IEA, 2020).

Although subsidies for heat pumps were first introduced in the early 1980s, support for electric heating was patchy in the 1990s and early 2000s (Hanna et al., 2016). Political support did not consolidate until 2008, with the introduction of subsidies for the replacement of oil heaters with heat pumps, solar hot water or district heating. Denmark currently prohibits heat pumps in 'collective heat zones'[14], but there is increasing support for them outside these areas (Ibid).

2.7 France

The supply of buildings heating in France comprises 42% gas, 21% oil, 15% electricity and 12% biofuels and waste (Figure 8). As with several other European countries, oil for home heating was far more prevalent in the past, supplying around 40% of residential energy in the early 1980s (IEA, 2016; Service de l'observation et des statistiques, 2019). Residential heating had an overall average carbon intensity of about 100 g CO_2/kWh (Bertelsen and Vad Mathiesen, 2020).

Figure 8: France residential and non-residential buildings heating types (Vivid Economics & Imperial College, 2017b; Service de l'observation et des statistiques, 2019)



Low-carbon heat policy in France has involved significant changes to taxes on energy services and products. The French Government has been trying to reform the system, reducing tax on less carbon intensive fuels and removing tax rebates on high fossil fuels.

[14] In Danish heat law there is a distinction between central and decentralised district heating areas. It is illegal to install large heat pumps (> 250 kW, typically used for district heat) in the central areas. In the decentralised areas, large heat pumps are allowed but must go through the standard project procedure to be approved. Individual building heat pumps are allowed in some local municipalities' heat zones but not others, often dependent on whether municipality has a heat zone plan that obliges connection to district heat.

Since 2014, domestic excise taxes on energy products have been linked to carbon content, with tax rates scheduled to increase on an annual basis. Alongside this, many tax exemptions for high carbon products have been ended (ODI, 2017). A support scheme for fuel oil heating ('prime à la cove') has ended, as has an exemption from internal consumption tax (ICT) on natural gas, coal, lignite and coking coal consumption. The exemption rate for ICT is applied to biomass with biomass subject to 0% taxation (IEA, 2016; OECD, 2018c). Overall tax rates are around 34% for heating oil, 24% for natural gas and 36% for electricity (IEA, 2019a, 2020).

The CITE (Tax Credit for Energy Transition) covers up to 30% of capital costs of energy efficient and renewable energy equipment, with a limit of €16,000. There is also a 0% interest loan of up to €30,000 available for energy efficient residential renovations, including the installation of renewable heat. The 2012 'Regulation Thermique' requires all new single-family dwellings to achieve primary energy consumption below 50 kW/m2 per year – representing a *de facto* ban on direct electric heating. Renovation projects eligible for the CITE credit can also benefit from a reduced VAT rate of 5.5% compared to 10% for other residential renovation projects (Vivid Economics & Imperial College, 2017b; Vivid Economics & Imperial College, 2017a; Guertler, 2018).

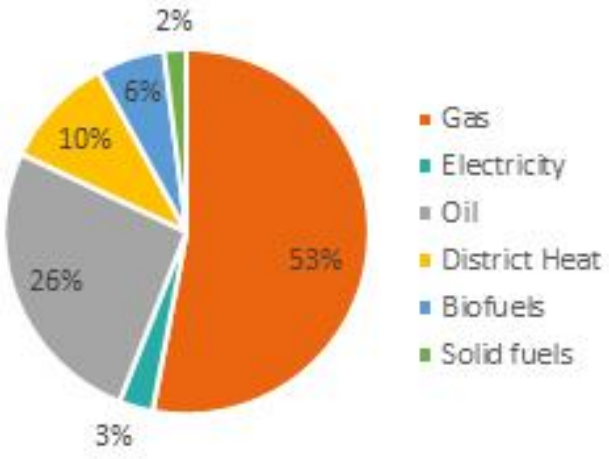
France plan to move away from fossil fuel and direct electric heating with a target in law for 38% of heating[15] to come from renewable sources by 2030 (Vivid Economics & Imperial College, 2017b). The French Government launched a Hydrogen Deployment Plan in 2018, with support for experimental projects to assess the potential for producing hydrogen from curtailed renewable energy for use in the existing gas grid (so-called 'power to gas'). The Plan focuses on the potential of green hydrogen from electrolysis, anticipating that a rising carbon price will eventually make it cost competitive with blue hydrogen (there is very limited reference to the use of CCS). Public support will be needed to support green hydrogen until it can compete economically, with indicative targets set out for its use e.g. 40% of all hydrogen by 2028 (currently it comprises 5% of the total). (MTES, 2018).

2.8 Germany

Over half of German homes are heated by natural gas, around a quarter by oil and smaller proportions use district heating and biofuels (Figure 9). The share of oil heating has declined from 40% to 26% between 1995 and 2019, while sales of oil-fired boilers fell from 25% of all central heating systems in 2005 to less than 9% in 2017 (Dickel, 2018). For new homes, oil heating has reduced from 14% of properties in 2005, to negligible levels by 2017 (Vivid Economics & Imperial College, 2017b). The average carbon intensity of residential heating was about 200 g CO_2/kWh in 2015 down from 250g CO_2 in 1990 (Bertelsen and Vad Mathiesen, 2020)

[15] This target applies to 'final heat consumption' and is economy-wide, encompassing buildings and industry; the equivalent figure in 2015 was 20% (Collier, 2018).

Figure 9: Germany residential buildings heating types (IEA, 2020)



The move away from oil to heat pumps for new buildings reflects a mix of energy performance building regulations and financial incentives. Energy performance regulations for new buildings (known as Energy Efficiency Ordinance, or 'EnEV') do not require the use of renewable energy but tend to result in some form of renewable installation as, under the Market Incentive Programme, renewable energy is often most cost-effective. In 2016, heat pumps were installed in 23% of new homes, up from less than 1% in 2000 (Vivid Economics & Imperial College, 2017b) (district heating stood at about 22%, with the remainder primarily gas). Current overall tax rates are around 25% on heating oil, 24% for natural gas and 54% for electricity (IEA, 2019a, 2020).

Under the 2019 Climate Policy Package the installation of oil heating systems will be banned in new and existing buildings from 2026, with some exemptions (Rosenow and Lowes, 2020). In existing buildings, it is already mandatory to replace all fossil fuel heating systems that are over 30 years old. This latter regulation is particularly challenging: around 40% of boiler systems are 25 years old or more, and as yet there is no competitively priced low-carbon alternative, without further policy intervention the vast majority are expected to see replacement gas or oil boilers (Dickel, 2018). Either massive subsidies or the banning of fossil fuel boilers will be needed (Dickel, 2018).

The KfW development bank offers grants and low interest loans (of up to € 30,000) for energy efficiency and low-carbon heat investments. The subsidy and interest rate are linked to energy performance improvement. The combined loan and subsidy system leverages a high level of private investment in energy renovation; in 2016, around €1.5 billion in public funds faciltated over €10 billion in overall investment (Kerr and Winskel, 2018; Guertler, 2018).

The National Energy and Climate Plan launched in June 2020, contained a target of 27% renewable energy share in heating[16] (BMWi, 2020b). The National Hydrogen Strategy, launched at the same time, states that hydrogen is primarily intended for industry and transport decarbonisation, but that there may also be a longer term role in heating buildings.[17] As in the Netherlands, the German approach sees green hydrogen as the only sustainable option in the long term, although blue hydrogen is seen as having a possible transitional role. The strategy aims for 5GW of electrolyser capacity by

[16] This applies to final-energy consumption for heating and cooling across buildings (currently about two thirds of the total) and industry (about one third) (BMWi, 2020b).

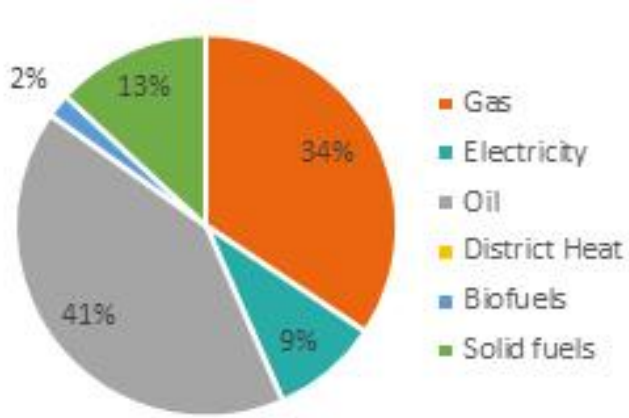
[17] There is some debate over whether the strategy should have included a larger role for green hydrogen in buildings heating. See, for example (Heilmann, 2020; Amelang and Waldholz, 2020)

2030, corresponding to hydrogen production of 14TWh, requiring 20TWh of renewable electricity, primarily from offshore wind. Total German demand for hydrogen is anticipated to be 90-110TWh by 2030 (BMWi, 2020a).

2.9 Ireland

Around 40% of homes in Ireland use an oil-fired boiler for home heating with small amounts using peat and coal). About a third are on the gas grid and 9% use electric heating (see Figure 10). Ireland had the second highest carbon intensity for residential heating in the EU at 254g CO_2/kWh in 2015 (Bertelsen and Vad Mathiesen, 2020), while the IEA estimate that Ireland has the highest share of fossil fuels for home heating of all of its member countries (IEA, 2019a).

Figure 10: Ireland residential buildings' heating type (SEAI, 2018)



The Climate Action Plan of 2019 sets out proposals to 'effectively ban' the installation of oil boilers from 2022 and gas boilers from 2025 in all new dwellings, through the introduction of new regulatory standards (Irish Government, 2019). In December 2019, the Irish Government published a General Scheme for the Climate Action (Amendment) Bill 2019 (DCCAE, 2019); this sets out a review, to take place in 2020, to consider 'how and when the replacement of oil and gas boilers in existing dwellings could commence'.

The Better Energy Homes scheme provides grants to homeowners of up to 30% of the cost of heat pumps, solar thermal heaters, upgrading building heating control systems and a range of energy efficiency measures. About 15,000 homes received grants, totalling €16 million by the end of 2017. Grant support for replacing an oil or gas boiler was ended in 2017; instead, a grant programme for heat pumps of up to €3500 was introduced, available only for individual homes reaching a minimum standard of energy performance, with households required to conduct a home energy assessment to qualify (IEA, 2019a). Current overall tax rates are 29% on heating oil, 17% on natural gas and 12% on electricity (IEA, 2020).

3. Summary and conclusions

3.1 Varied contexts, opportunities and challenges

This report has set out policy and regulatory responses to the heat decarbonisation challenge in nine European countries. The scale and urgency of the challenge varies considerably among the countries reviewed: while some face a transformative challenge,

in that they need to move from almost entirely fossil fuel systems to near-zero carbon heating in the next 20-30 years, others face a much more modest challenge as they already have very low-carbon heating systems.

These differences, built up over decades, reflect different national resource endowments, economic resources and technical infrastructures. However, they also reflect different governance approaches and policy choices. In some cases, rather similar challenges – such as the historic disruption of European energy economies in the 1970s – were met with contrasting responses. This variety reflects social and political choices, alongside national techno-economic characteristics, and means that the national heating systems discussed here span a wide range of carbon emission intensities (Table 2)

Table 2: Residential heating carbon intensities and taxes - selected countries

Country	Carbon intensity of residential heating (2015) (gCO_2/kWh)	Carbon intensity of electricity (2017) (gCO_2/kWh)	Overall tax on residential energy use (%)*			
			Gas	Oil	Electricity	Biomass
UK	185	268	5	24	22	5
Netherlands	200	452	54	63	26	/
Norway	/ **	19	/	45	36	0
Sweden	29	9	45	/	39	/
Finland	95	83	43	45	33	0***
Denmark	118	147	56	50	35****	0
France	100	67	24	34	36	0
Germany	200	419	24	25	54	/
Ireland	254	393	17	29	12	/

Source of carbon intensity data (Bertelsen and Vad Mathiesen, 2020)

/ = data was not able to be located

** Tax components include value-added taxes and excise taxes, levies and public charges (IEA, 2020)*

*** Data not available, but likely to be lower than all other countries reviewed here*

**** 0% on second generation biomass only*

***** Tax rate is doubled if not used for residential heating*

3.2 The speed and scale of change

Countries such as Denmark and Sweden have been pursuing a move away from imported fossil fuels for decades, historically because of energy security concerns, but more recently reflecting climate policy imperatives. Norway and Sweden are already close to fully decarbonising buildings heat supply, with fossil fuel use in district heating

the primary remaining source of emissions. Norway and Sweden have also taken differing approaches to phasing out the remaining small portion of high-carbon heat: regulations have been introduced in Norway prohibiting oil use from 2020 – an approach not taken in Sweden where the relative cost-competitiveness of low-carbon heat is seen as a sufficient means of facilitating the transition.

In other countries, fossil fuel phase out has been instigated more recently, primarily as a result of climate policy. Countries where fossil fuels currently provide a larger share of heat supply face a more challenging, accelerated transition than those which have had longer traditions of fossil fuel phase out. This is particularly apparent in countries where a gas grid infrastructure provides the majority of heat in buildings. Gas grids are considered particularly challenging to switch to renewable heat (IRENA, IEA and REN21, 2018).

For countries such as the UK, the Netherlands and Germany, decarbonising home heating will involve a decisive break from established approaches to the sector, and highly interventionist regulatory approaches are currently being formulated, such as the prohibition of gas connections for new homes. Interim 2030 targets already exist in the Netherlands, Germany and France for using renewable energy for heating in approximately 20%[18], 27% and 38% of homes or across the economy, respectively. In Scotland, an economy-wide emission reduction targets of 75% by 2030 presents a radical heat decarbonisation challenge, and the policy response is now being formulated (CCC, 2020).

3.3 Policy and technology mixes: financial incentives, taxes and regulations

Capital costs for renewable and low-carbon heating equipment are often relatively high, and purchase subsidies or tax credits are common for specified technologies. Low-interest loans are available in Germany, France and Scotland, and such loans can enable greater overall investment by using public funds to leverage private investment (Kerr and Winskel, 2018). The UK has, until now, followed a less common approach with its Renewable Heat Incentive: subsidising the operational cost of renewable heat, rather than the upfront cost.

Running costs are more commonly addressed by taxation levels and setting different rates for different fuels (summarised in Table 1). Most countries reviewed encourage biomass with lower rates of tax, and most also disincentivise oil relative to natural gas. Standalone biomass for heat systems i.e. not DH, currently contribute between 10-20% to the heat supply of Sweden, Denmark, Finland and France. A wider contribution than this is restricted in many countries due to the lack of sustainable resources.

Electricity is already a significant contributor to heating in Norway, Sweden and Finland and is a key potential future source of low-carbon heating. Its widespread use for this purpose will require decarbonised supply and potentially disruptive reinforcement of the electricity grid. Electricity is also distinct as it is used for other domestic energy services i.e. appliances and lighting. These factors help to explain why taxation policy is at present not widely used to incentivise electricity for heat. Denmark offers a model for a more targeted approach, with tax on electricity halved if it is used for heat. Having high tax rates on electricity relative to fossil fuels (see Table 1) has been identified as an impediment to decarbonisation in the UK and Germany (IEA, 2020).

[18] The 20% figure for the Netherlands is based on the commitment for 1.5 million homes to be made 'sustainable' by 2030. It assumes that the housing stock remains at the same level as it is today i.e. 7.7 million.

Low-carbon heat policy is often tailored to different building types and population segments e.g. on/off gas grid, public buildings, new buildings, commercial buildings, social housing, private rented housing, owner-occupied housing. New buildings are frequently an early target for regulatory change – seen, for example, with the prohibition of natural gas heating in Scotland, the UK and the Netherlands. Public buildings are subject to distinct rules in Finland.

Regulations can apply immediately, or more commonly at a specified future date, perhaps to coincide with a 'trigger point' – for example, the sale of a property or the replacement of a domestic technology. In Norway, heating oil has been prohibited since the beginning of 2020, while in Denmark a more gradual approach has been adopted, with oil heating no longer allowed in new buildings after 2013.

Additional measures, which focus on the fuel rather than the heating system, include regulations to allow the blending of biofuel in heating oil, as seen in Norway and Finland. This may entail a gradual increase in the permitted blend level, as set out in Finnish policy, or a deadline after which only biofuel of a certain blend is permitted. Continued, incremental increases in biofuel levels is complicated due to the backwards compatibility problems – existing heat technologies are often only able to operate on relatively low biofuel blends. It is impractical and costly for manufacturers to design and produce multiple systems, each compatible with a different biofuel blend, and so either low blends or a step-change to 100% biofuel is the likely eventual outcome (Kerr and Winskel, n.d.)

Oil heating was much more prevalent in the past in countries such as France, Sweden and Germany. While there has been a decline in the contribution of oil-based heating in many countries, as natural gas grids and district heating networks have expanded, it still provides a significant share in countries such as Ireland, France and Germany. District heating has proliferated in Sweden, Denmark and Finland. In Finland and Denmark, fossil fuels still provide a significant share of DH supply. Decarbonising these systems can involve conversion to biomass (IRENA, 2017) or the integration of renewable energy systems, heat pumps and thermal energy stores in lower temperatures so-called fourth generation district heat (Lund et al., 2014; Werner, 2017). The move to biomass-powered district heating in Finland and particularly Sweden has been driven by carbon taxation.

A global race is emerging with respect to the production and use of hydrogen. This year has seen national hydrogen strategies published in Germany and the Netherlands – both envisage a role for hydrogen in heating buildings, but only where other options are not available. Both also assert that green hydrogen is the only long-term sustainable source, while also recognising the large uncertainties around its cost, and therefore suitability, for heating.

The EU Hydrogen Strategy (European Commission, 2020) also takes the view that only green hydrogen is feasible long term, envisioning up to €180–479bn investment in green hydrogen, compared to only €3-18bn in fossil derived hydrogen. While the UK has yet to produce an equivalent national hydrogen strategy, recent projections from the UK Government and the Committee on Climate Change suggest that although its precise role in the future energy system remains uncertain, hydrogen from gas reformation with CCS is likely to provide the bulk of any future supplies, at least in the medium term.

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