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ReHeat: Review of the Irish Heat Sector - Policies, Technologies, and Best Practice

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Project Information

This research project has been funded as part of the **EPA Support for Climate Change Advisory Council Research Fellowships**. This research provides an overview of best practice in policies and technologies for the Irish residential heating sector. It has a particular focus on research, technology and evidence that are most relevant for Ireland in pursuit of national decarbonisation goals.

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Executive Summary

The decarbonisation of the heating sector in Ireland has progressed at a slow pace. Ireland has the second lowest share of renewable heating in the European Union and the average Irish home has 58% higher carbon emissions than the EU average (IERC 2020; SEAI 2018a). The recent implementation of the Climate Action and Low Carbon Development Bill (Government of Ireland 2021a) sets a legally binding net zero emissions target by 2050. Decarbonisation of heat via renewable heating technologies and improved energy efficiency will play a key role in achieving this goal. This study aims to provide an overview of the policies, technologies, barriers and trade-offs which are relevant for transitioning to low-carbon heating across the residential sector in Ireland

Chapter 1 in this report provides an overview of policies aimed at reducing emissions and improving heating systems in the residential sector. It details relevant international policies and evaluates their applicability to the Republic of Ireland. The introduction of national carbon budgets to reach 2030 targets is an important step (CCAC 2021). Focusing on the residential sector, key measures outlined in the Climate Action Plan (Government of Ireland 2021) seek to achieve change across new construction, retrofit of existing dwellings, transitioning towards electrification of heating demand and the commencement of low-carbon district heating networks in urban settings. Although ambitious plans and targets are important, implementation is key in realising actual emissions savings. Uncertainty on the details of delivery measures will delay action and hence information on future technologies and related policies is required urgently to accelerate implementation.

In the second chapter, we present the context for which the current mix of heating technologies is applied in Ireland. This context is paramount to understanding the potential for future low carbon technology adoption. The chapter features an exploration of the history of heating technologies in Ireland, and the transition to modern centralized heating systems. We discuss key relevant statistics on the current building stock and demographics which are critical determinants of current and future heating technology adoption. Factors such as dwelling age, type, size, type of tenure, occupancy and efficiency are important in explaining

both the currently employed mix of heating technologies and the potential for future low-carbon technologies. Some of the currently installed low-carbon heating options are discussed, and the Irish heating fuel mix is compared to similar European countries. The data on the past and present mix of heating fuels in Ireland show that while the current transformation to low carbon residential heating systems is ambitious, in the past the Irish heating sector has transitioned from only 39% of the population with central heating systems in 1981 to 98% with central heating systems in 2011. Thus, the scale of the challenge to decarbonise the residential sector by 2050 is within the same time frame.

Chapter 3 discusses the factors influencing heating technology adoption as identified by the relevant literature. Factors identified include high implicit discount rates, high upfront costs, liquidity constraints, sociodemographic factors (such as occupant age, income, tenure status) spatial and built environment factors (such as path dependency), and behavioural patterns such as present bias, loss aversion, administrative burden (or "Sludge"). Chapter 3 also mentions some select modelling predictions for future heating technology adoption in Ireland, for some of the technologies identified in Chapter 2. Finally, it discusses the uncertainty surrounding future residential heating demand, stemming from the impacts of climate change itself as well as the transition to home working resulting from the global COVID-19 pandemic. The main findings of this chapter are that there are a variety of barriers and enablers to heating technology adoption and therefore a variety of technologies and policy approaches will be required in encouraging low-carbon heating uptake. It is important to understand the different characteristics of households and technologies and match suitable low carbon solutions to individual situations.

A review of progress to date in the use of district heating as a low-carbon heating technology is the focus of Chapter 4. This is especially pertinent for Ireland, where district heating has not been deployed extensively to date. It considers policies and operational systems in other countries and highlights some of the most effective policies, with a view towards their ability for Ireland to deliver on 2050 climate goals. District heating is a promising, flexible low carbon heating fuel for use in urban areas that can operate with power generation, waste-to-energy and industrial waste heat (Renewable Energy Ireland 2021). Despite its vast potential, Ireland lags European peers on the use of district heating. Since there are no shortcuts to achieving change, a number of upcoming pilot schemes in Dublin will serve as national exemplars and develop skills and expertise to foster nationwide adoption. The expected introduction of a district heating policy framework will be an important support to facilitate adoption (Government of Ireland 2021b).

In Chapter 5 we explore some of the multiple benefits and costs associated with low-carbon heating technology adoption and energy efficiency improvement. Areas such as health, comfort, poverty alleviation, energy security and the rebound effect are priorities for households and policymakers and warrant attention. Each of these benefits/costs need to be quantified carefully where possible in heating policy assessments in order to optimise policy decisions for society. In addition, we consider how the framing of multiple benefits and targeting of policy supports will be important in reaching consumers who stand to benefit the most from low-carbon heating and retrofit policy.

Finally, in the last chapter we synthesise the analysis from the preceding chapters and identify key areas for consideration. These are summarised in Table ES1. Some of the key insights include a need for a mix of low-carbon heating technologies which are matched with user needs, the advantages of leveraging behavioural change and multiple benefits, and a discussion on solving some of the resource constraints to enacting change.

Table ES1 Five key considerations for low carbon heating in Ireland

A multi fuel future	No one fuel source is a silver bullet to residential decarbonisation. Electrification of residential heating can support a transition from fossil fuel use - particularly for standalone dwellings. New developments in urban settings should seek to leverage economies of scale through district heating.
Matching technologies with users	The current suite of policy supports for residential energy efficiency should be reviewed to ensure efficient and equitable allocation of funds and effectiveness of policy instruments. Nationwide guidance on the optimal heating technology choice based on type of dwelling, location, and circumstances would facilitate better matching.

Behaviours and barriers	Behavioural change will be critical in lowering overall energy demand and increasing the uptake of low-carbon heating technologies. Multiple barriers such as high upfront costs and liquidity constraints, sociodemographic characteristics (such as age and income), landlord-tenant principal-agent problems and other behavioural patterns hinder adoption and require policy intervention.
Leveraging multiple benefits	Decarbonisation policies have additional multiple benefits and costs which accrue both to individuals and to society as whole. Such benefits (e.g. health, comfort, fuel poverty alleviation, energy security) and costs (i.e. rebound effects) should be quantified, promoted and considered in analyses of policy impacts, as some are priorities for households and society.
Resource constraints	Achieving targets is conditional on having adequate factors of production - especially skilled labour – that are required for both new build and retrofit targets. Policies such as the B2 retrofit target will likely exacerbate competition for limited resources. Decisions may be needed on allocation and prioritisation of resources for new housing versus retrofit targets. There are trade-offs between new residential developments that are highly efficient with low carbon technologies and retrofit of the existing poor quality building stock. The timing of rollout of new heating technologies and related policies should factor in carbon budget constraints, as well as costs and uptake readiness.

1 Residential Heat Sector Policies

This section features a review of policies aimed at improving heating systems in the residential sector. It details relevant policies and targets at a global level. It will also assess their applicability to the Republic of Ireland (referred to as 'Ireland' throughout, for brevity) and the United Kingdom, as a comparable country. This Work Package will highlight the most effective policies, with a critical evaluation of their ability to achieve 2050 goals.

1.1 International Policy Context

The effects of climate change have the potential to fundamentally change our society. At a global level, forecasts have noted the need to keep global temperature rise, relative to pre-industrial levels, below two degrees Celsius (UN-IPCC 2018). The urgent need to address climate change has been noted at a near-universal scale, with the Paris Agreement signalling a commitment to achieve this goal (United Nations 2015a). The United Nations has listed *Affordable and Clean Energy* as a Sustainable Development Goal as part of the 2030 Agenda for Sustainable Development (United Nations 2015b) with three main targets:

Table 1.1 Targets of UN Affordable and Clean Energy SDG (United Nations 2015b)

- Ensure universal access to affordable, reliable and modern energy services
- Substantially increase the share of renewable energy in the global energy mix
- Double the global rate of improvement in energy efficiency

The Paris Agreement serves as a guiding light for countries on this issue. The annual Emissions Gap Report published by the United Nations serves as a helpful benchmark of progress towards 2030 targets. It notes that although the COVID-19 pandemic resulted in a fall in carbon dioxide emissions in 2020, atmospheric concentrations of greenhouse gas emissions continue to rise. It emphasises the need for a post-COVID recovery that incorporates decarbonisation to achieve targets. It also highlights the need for long-term strategies that are consistent with the Paris Agreement and the need for national policies that are consistent with stated net-zero emissions goals (United Nations Environment Programme 2020).

Table 1.2 Headline European Union 2030 climate targets (European Commission 2019a; European Parliament 2018)

• Source 32% of the energy mix from renewable sources • Reduce greenhouse gas emissions by at least 55% from 1990 levels • Improve energy efficiency by 32.5%, relative to a 2007 forecast of 2030 energy use

The European Union Green Deal is the latest policy designed to deliver on the region's climate targets, in line with the UN 2030 agenda. It aims to ensure net zero greenhouse gas emissions by 2050, with economic growth decoupled from resource use and a just transition for affected citizens and regions (European Commission 2019a). Pursuant to this, the European Commission has ratified the first European 'Climate Law' that legally enshrines the 2050 climate neutrality objective. Table 1.2 notes the latest targets for progress required by 2030, with the European Green Deal raising the emissions target for 2030 to 55% (European Commission 2019a). Proposed revisions to policy instruments, such as the Renewable Energy Directive and the Energy Efficiency Directive will be considered in the EU Fit for 55 package.[1]

Importantly, the Commission notes the potential for a carbon border adjustment mechanism in the event that this monumental effort becomes nullified by carbon-leakage if other countries do not share similar ambition. Although future trends are difficult to predict, it is important for policymakers to strive for timely change. Considering that it takes 25 years to transform all of the value chains within a sector requires bold decisions in the coming years to reach 2050 targets (European Commission 2019a).

1.1.1 The European Residential Sector

In the EU, buildings are responsible for roughly 40% of energy use and 36% of carbon dioxide emissions (European Commission, 2019). The residential sector represents 25.4% of final energy use in the EU in 2016 (Eurostat 2019), with annual renovation rates ranging from 0.4 to 1.2% in Member States (European Commission 2018). It is anticipated the rate of renovation will have to double to reach EU energy efficiency and climate goals.

[1] See https://www.consilium.europa.eu/en/policies/eu-plan-for-a-green-transition/

Vogel et al. (2015) outline a staggering 38 barriers to building energy efficiency, across three levels of decision-making: project level (information, interest level), sector level (industrial barriers to change) and contextual level (regulations and policies). Bertoldi and Economidou (2018) consider eight categories of policy measure designed to improve energy efficiency in buildings: Regulatory, Financial, Information, Qualification, Market-based, Voluntary, Infrastructure Investment and Other (e.g. research and innovation). It is widely accepted that no single policy can overcome all barriers to transforming the existing building stock while reducing energy use (Economidou et al. 2020).

Research has noted **active** solutions that can limit energy waste including insulation, efficient glazing, efficient heating/cooling generation systems (Martinopoulos et al. 2018). It also notes more **passive** solutions such as better spatial planning, building orientation, natural ventilation and the use of solar systems for heating and cooling can also improve thermal comfort while reducing energy use (Martínez-Molina et al. 2016). Such policies can also achieve **multiple benefits**, improving security of energy supply, reducing local pollution, eliminating fuel poverty and creating local jobs (Fawcett and Killip 2019). The additional benefits of energy policies are discussed later in Chapter 5.

Past EU energy efficiency policies have played an important role in fostering building energy efficiency (Economidou et al. 2020). Notable early EU policies include the 1989 "Construction Products Directive", the 1992 "Boiler Directive" and the 1993 "SAVE Directive", the latter of which focused on member states aiming to improve energy efficiency to reduce emissions. The broader 2000 Energy Efficiency Action Plan was motivated, by ambitions of the 1997 Kyoto agreement, the limited success of the "SAVE Directive" and the need to allow Member States to determine their own efficiency requirements. In the intervening years, revised policies have sought to build on progress, culminating in several versions of the Energy Performance of Buildings Directive (EPBD) (European Commission 2019b).

1.1.2 European Residential Sector Policies

The European Green Deal seeks to promote policies that achieve multiple policy targets by lowering energy bills, reducing energy poverty and presenting an opportunity to support the construction and SME sector (European Commission 2019a). For households, addressing energy poverty through financing that allows renovation would help the environment and the occupant maintain living standards. The European Green Deal considers the following areas as critical for renovating buildings in a resource efficient manner:

Table 1.3 Key Areas of European Green Deal (European Commission 2019a)

- Double rate of building renovation
- Create a ‘renovation wave’ of public and private buildings
- Enforce building energy performance legislation and assess current progress
- Develop new model of building renovation, including financing constraints

A large pillar of EU regulation in the residential sector is the Energy Performance of Buildings Directive (EPBD) (European Commission 2019b), which has evolved from the broader “SAVE” Directive on energy efficiency, introduced in 1993 (Elagöz 1994). The EPBD emphasises the use of Energy Performance Certificates (EPCs) for building sales and rentals (European Commission 2018) to improve information for buyers and sellers on the indicative energy performance of a building. EPCs also contribute towards other aspects of the EPBD, such as providing guidance on possible energy efficiency improvements.[2]

The EPBD policy framework aims to i) set minimum performance standards in new and existing buildings, ii) improve information for buyers and renters on energy efficiency and iii) encourage investors to engage in energy efficiency projects. The latest revision of the EPBD in 2018 (Directive 2014/844/EU) aligns the policy with 2030 EU-level targets. This revised policy aims to achieve a decarbonized building stock by 2050. Denmark has been cited as a leader in this space, with a 67% decrease in the minimum energy performance of NZEB buildings in 2021, compared to new buildings in 2006 (Economidou et al. 2020).

[2] See https://ec.europa.eu/energy/en/content/introduction-11

EU-level policies addressing energy efficiency across the built environment are closely related to policies for buildings. The Energy Efficiency Directive (2012/27/EU) was a prominent part of the European Energy and Climate Package (European Parliament 2012), adopted in 2012 (Rosenow et al. 2017). This details the EU target of 20% energy efficiency by 2020 (in terms of absolute primary and final energy consumption), with specific member state targets. It also features provisions related to building energy efficiency.

The Energy Efficiency Directive (2012/27/EU) outlined requirements for the renovation of public sector buildings (Article 5), to provide for energy use metering (Articles 9-11) and a pioneering strategy for long-term building renovation at the national level (Article 4). It also required member states to seek to remove split incentives (Article 19a), and to foster demand response (Article 15).

Table 1.4 Summary of EPBD 2018 (Adapted from Economidou et al. (2020))

- Establish country-level Long Term Renovation Strategies
- Stimulate cost-effective 'deep' retrofit in existing buildings
- A common and optional EU scheme that rates the 'smart-readiness' of buildings
- Promote the use of ICT and smart technologies in buildings
- Improve cross-country comparison of national energy performance requirements
- Promote building user health, wellbeing and combat energy poverty

Since its inception, the EED has been revised in 2018 to include 2030 energy efficiency targets. Article 4 features pioneering long-term renovation strategies which are designed to provide a common reference point to allow all member states to plan for the decarbonisation of the residential and commercial building stock. Rather than focus on particular technologies or policy interventions, it is intended to provide an overview of a country's building stock, identify key policies to stimulate renovations and estimate the expected energy savings and wider benefit. It is also designed to identify cost-effective approaches on the basis of climate and building type and serve as a template for future investments (Economidou et al. 2020). This Article has been introduced into the EPBD (Article 2.a) with a plan towards a decarbonized building stock by 2050, with milestones in 2030 and 2050 and measurable progress indicators towards the 2030 EU-level target of 32.5% increase in energy efficiency.

In summary, EU-level policies such as the EED and EPBD are important structures to improve building standards, such as the minimum energy performance standards, across member states. Such policies have coincided with a fall in average energy use in the residential sector. In addition to policies around building standards, there has been recognition of the importance of financial matters in fostering the transition towards a climate-neutral building sector. These factors converge as part of the European Green Deal, which aims to foster a "renovation wave" through a tailored policy framework to deliver on 2050 goals.

1.2 Irish Policy Context

Ireland has a strong track record of participating in global efforts to reduce emissions and improve energy efficiency. As a signatory of the Paris Agreement (United Nations 2015a), Ireland has committed to taking the necessary steps to limit the effects of global warming. In fact, Ireland was the second country in the world (after the UK) to declare a Climate and Biodiversity Emergency. As an EU member, Ireland is a signatory to the suite of policies and targets discussed earlier. This section will detail the key national policies for Ireland, highlight progress towards current targets and outline key residential sector policies.

1.2.1 National Policies

Building on the landmark Paris Agreement, the Irish government published a Climate Action Plan 2019 (Government of Ireland 2019) and subsequently a Climate Action Plan 2021 (Government of Ireland 2021), which reflect a commitment to building a net zero carbon economy, consistent with the EU target. The Plans serve as a roadmap of policy actions to achieve that goal across the built environment. The policy aligns with the UN Sustainable Development Goals and succinctly previews the potential benefits:

> “many of the changes that are required will have positive economic and societal co-benefits, including cleaner air, warmer homes, and a more sustainable economy for the long term.”
> Climate Action Plan (2019)

Table 1.5 lists the key sectors targeted under the Climate Action Plans, with the objective to reduce Irish carbon emissions by 51% by 2030, relative to 2018.

Table 1.5 Climate Action Plan targeted sectors and emissions reductions by 2030 (Government of Ireland 2021)

- Electricity: 62-81%
- Buildings: 44-56%
- Transport: 42-50%
- Agriculture: 22-30%
- Land use and forestry: 37-58%

There has been further recognition of the importance of the climate crisis. In March 2021 the Irish government introduced the Climate Action and Low Carbon Development (Amendment) Bill (Government of Ireland 2021a), which commits Ireland to a legally binding target of net zero emissions before 2050. This legislation is a clear signal to improve on earlier policies by establishing a legally binding framework with clear targets and commitments in order to reach national and EU-level climate obligations in both the short and long term. A major aspect of the legislation is to legally establish a process of carbon budgeting, featuring economy-wide five-year carbon budgets with sectoral targets.

The first carbon budget for Ireland was launched in October 2021 (CCAC 2021). Pursuant to the 2050 net zero target, the budgets are designed to reduce emissions (of industry, agriculture, energy, land use and other anthropogenic activities) by 51% in 2030, compared to 2018 levels. This target can be achieved with an annual 4.8% reduction over the first budget period (2021-2025) and an annual average reduction of 8.3% for the second budget period (2026-2030) (CCAC 2021). This budget is similar in approach to the UK Climate Change Act (UK Government 2008).

Although the first budget appears to be more approachable in terms of annual reductions, the majority of required savings are during the second budget period. Although this signalling serves an important role, any underperformance in the first period will place additional pressure on achieving targets closer to 2030 (CCAC 2021).

The latest carbon budget framework, paired with existing legislation is designed to improve monitoring, with a legal basis for annual sectoral activities to be monitored and detailed through an annual Climate Action Plan. It also moves beyond a national Climate Action plan and provides for local authorities to prepare their own Climate Action Plan, which features mitigation and adaptation measures and alignment with the broader Development Plan for each local authority. Finally, the legislation places an emphasis on responsibility, as government ministers must account for their progress towards legally binding targets for their own sectoral targets. This includes an obligation to discuss this progress at an annual Oireachtas Committee (meeting of government) (Government of Ireland 2021a).

Aside from policies to address climate change mitigation (i.e. reducing emissions), a separate line of inquiry into climate change adaptation seeks to highlight the risk posed by a changing climate while identifying solutions to facilitate adaptation. The National Adaptation Framework (NAF) highlights government ambition to foster climate adaptation through engagement with public stakeholders, the private sector and the wider research community (DCCAE 2018). Similar to the UK, researchers have conducted a Climate Change Risk Assessment (CCRA) of impacts of climate change for Ireland (Flood et al. 2020). This mixed methods study is aligned with the Irish NAF and highlights that sea level rise, coastal storms and flooding are the most immediate risks. Conversely, heat-related risks are a longer-term concern (Flood et al. 2020). The report highlights the need for iterative adaptation planning and improved data availability to perform spatial and time-specific impact evaluation.

In summary, it is a welcome development that Irish legislation has been revised to embed climate change and sustainability into the heart of policy making, with commensurate structures designed to define targets, monitor progress and achieve goals. Beyond alignment with EU targets, these developments help to set a foundation for success in achieving targets.

1.2.2 The Irish Residential Sector

The 2019 Climate Action Plan provides clear targets to decarbonise the residential sector. Table 1.6 details some of the relevant policy levers identified. In addition to the stated desire to improve building fabric, much focus is dedicated to transitioning away from high-carbon fuels (oil, coal, peat) to low-carbon alternatives (electricity, gas, district heating).

Table 1.6 Policies for decarbonisation of buildings (from Government of Ireland (2019))

- Impose stricter building codes for new construction and refurbishments
- Design policy to upgrade 500,000 existing homes to B2 EPC standard
- Design policy to install 400,000 heat pumps in existing homes
- Deliver two district heating systems (serving approx. 60,000 homes)
- Develop supply chain for home retrofits at group level that realise economies of scale

The aggressive policy ambitions in the residential sector reflect the scale of the challenge, as Irish homes consume 7% more energy than the EU average while emitting 58% more CO_2 equivalent, on average. This is largely since 70% of Irish buildings are powered by fossil fuels and are relatively energy inefficient (Government of Ireland 2019).

The challenge of reducing emissions is compounded by the composition of the dwelling stock, where EU-SILC data from 2017 shows that 8.3 per cent of the Irish population live in apartments (Eurostat 2017), lower than the EU average of 41.9 per cent and almost half the second-lowest ranked country, the UK (14.7 per cent). As noted by the Sustainable Energy Authority of Ireland, Ireland is second last out of 28 EU countries in decarbonising heating, primarily due to the spatially dispersed nature of dwellings (SEAI 2019a). The suitability of the dwelling stock for particular heating technologies is discussed in Chapter 2.

Improved building standards with a minimum A-rated energy performance certificate (EPC) will help to ensure that new buildings are not contributing to the existing problem. Marginal additions to the building stock will help to improve the average efficiency of the dwelling stock.

However, the Irish property market has been constrained by a lack of supply of new housing, with a three per cent increase in the housing stock from Q1 2011 to Q1 2019 being dwarfed by a seven per cent increase in population over the same period (Doval Tedin and Faubert 2020). The result is that national strides in residential decarbonisation attributable to new additions to the housing stock might be slower than expected.

Due to the limited pace of new construction, there is significant policy emphasis on the energy efficient retrofit of the current dwelling stock. This is an area where Ireland has long held a presence, with grant funding through the SEAI *Better Energy Homes* (BEH) scheme. The scheme supports measures to improve home insulation, fuel type, heating controls and to encourage the uptake of solar heating. Since its launch in 2009 to June 2018, the scheme has retrofitted 219,988 homes through funding of €225 million.[3] Despite this achievement, the 2019 Climate Action Plan seeks to retrofit half a million homes to B2 EPC standard. In 2017, just 990 homes were retrofitted to at least B2 standard and 14,000 heat pumps were in existing buildings (Government of Ireland 2019).

Achieving future targets will require substantial 'deep' retrofits, which feature multiple measures and additional complexity. It is expected that economies of scale can be achieved by providing area-based retrofit to several households at a time - this would streamline planning and installation processes. Such policies outline an intention to develop 'green' financing pathways and flexible payment methods that seek to address the upfront nature of costs. These plans will leverage existing community structures to improve information that engages target households and stimulates adoption (Government of Ireland 2019).

The *National Home Retrofit Scheme*[4] seeks to move towards an ecosystem of retrofit for groups of households, Housing Associations, Local Authorities and One-Stop Shops. It seeks to achieve national retrofit targets while realizing economies in supply chains and embracing innovative payment structures and improving information for consumers. By April 2021, 92%

[3] For more, see seai.ie/data-and-insights/seai-statistics/better-energy-home-statistics/
[4] For more, see https://www.seai.ie/grants/national-home-retrofit/

of the budget for the scheme has been allocated. Although these schemes are in their infancy they demonstrate a new level of ambition.

Table 1.7 Stated benefits of National Home Retrofit Scheme (Source: SEAI)

- Cost effective delivery (through group retrofit)
- Reduce emissions attributed to home heating
- More comfort for occupants
- Cheaper heating bills
- Home improved to minimum B2 BER

1.3 Comparison Country Context

The United Kingdom serves as an appropriate comparison to Ireland throughout this study, especially when compared on the basis of socioeconomic and climatic conditions.[5] Both the UK and Ireland can be viewed as developed economies that have been historical contributors to climate change (UK Committee on Climate Change 2019). This section will highlight commonality between the UK and Ireland, with a focus on the residential sector.

1.3.1 Overview - The UK Climate Change Act

The United Kingdom serves as a global leader in decarbonising energy supply (IEA 2019a). It has adopted the Paris Agreement, aiming to limit global temperature increase to two degrees Celsius (United Nations 2015a). Central to this effort has been the **UK Climate Change Act**, first adopted in 2008, with legally binding emission reduction targets (UK Government 2008). Originally, this legislation aimed to reduce greenhouse gas emissions by 80 per cent by 2050 (relative to 1990 levels).[6]

[5] Chapter 2 provides additional context of residential heating sources in the UK and Ireland.

[6] For more, see: https://www.lse.ac.uk/granthaminstitute/explainers/what-is-the-2008-climate-change-act/#:~:text=The%20Climate%20Change%20Act%20was,target%20set%20by%20a%20country.

It outlines carbon budgets in advance, serves as the basis for concrete policy and converts long-term targets into digestible, near-term targets (Fankhauser et al. 2018). The UK also recognises the key role and responsibility of the administrations in Scotland, Wales and Northern Ireland to contribute to the UK's overall target. This is consistent with the Paris Agreement in recognising the role of sub-national actors.

A ten-year review notes that the UK Climate Change Act has been instrumental in fostering i) better political debate on climate change, ii) maintain a cross-party consensus on the issue of climate change, iii) serve as an international leader. It has also helped to boost the share of low-carbon power from 20% to 45% by 2016 over the period (Fankhauser et al. 2018).

The UK Climate Change Act served as an effective policy, with the first and second carbon budgets successfully came in under budget by 1 and 14 per cent, respectively (Mc Guire et al. 2020). A review has highlighted important learnings for other countries, namely the need for clear, statutory targets signalled for the entire economy and set well in advance (Fankhauser et al. 2018). The review also noted the need for an independent body to ensure consistent delivery of policy, paired with decision making that is evidence-based (Fankhauser et al. 2018). The UK experience highlights the value of ex-post analysis, which shows how achievement can be influenced by economic activity and policy (Mc Guire et al. 2020).

The Climate Change Act provided a strong regulatory framework with carbon budgets set in five-year increments. In 2016, the UK government adopted their fifth carbon budget (for the period 2028-2032) which aims to reduce emissions by 57%, relative to 1990 levels. The first two budget targets were achieved, and the third target (2018-2022) will likely be met. However, a UK Committee on Climate Change (2018) review has noted the need for stronger, more detailed policies to achieve the fourth (2023-2027) and fifth carbon budgets (2028-2032). The need for more detailed and ambitious policies is central to achieving targets (UK Committee on Climate Change 2019). This problem is not unique to the UK.

In 2019, the Climate Change Act was augmented with a commitment to a net zero carbon emissions target by 2050, following a recommendation that such a target was "necessary, feasible and cost-effective" (UK Committee on Climate Change 2019). Within this net zero target, it is recommended that Wales can achieve a 95% reduction in greenhouse gas emissions by 2050, while Scotland can achieve net zero by the year 2045, reflecting their decarbonisation capacities (UK Committee on Climate Change 2019).

In addition to mitigation, the UK Climate Change Act also concerns adaptation by legislating for a series of five-year Climate Change Risk Assessments (CCRAs) that intend to prepare for the unavoidable risks of climate change across the economy. Within each cycle, the CCRA serves as a platform for a subsequent National Adaptation Programme (NAP), which responds to the outlined risks. Two CCRAs have been implemented (2012 and 2017) with NAPs following one year after. Notably, the CCRA is handled on a UK-wide basis, with the NAP only pertaining to England. The other member states (Scotland, Wales, Northern Ireland) have their own arrangements (Fankhauser et al. 2018).

1.3.2 Limitations of UK Policy

While the Climate Change Act links energy policy and emissions reduction ('mitigation'), environmental policy has been pursued through a parallel process. A review of the Act featured qualitative evidence from relevant stakeholders, noting that the Act does not work perfectly for particular sectors, including land-use and agriculture (Fankhauser et al. 2018). Although UK policies align with international ambition to reduce emissions, it does not formally detail how the UK will contribute towards international climate finance for developing countries - a key area where the UK has already demonstrated leadership, but where specific objectives would be welcome (Fankhauser et al. 2018). There remains substantial overlap in EU policies in the UK - especially in terms of renewable energy, energy efficiency and membership of the EU emissions trading scheme (ETS), which covers roughly 40 per cent of UK emissions for certain sectors.

1.3.3 The UK Residential Sector

Homes account for 22 per cent of UK emissions (13 per cent, excluding electricity)[7] and have experienced a substantial 17 per cent reduction in energy use per household since 1990.[8] This is notable since the dwelling stock also increased by almost a quarter from 1990 to 2015. Reasons cited for this improvement include higher building standards, better materials (e.g. boilers), the uptake of energy efficiency measures and greater awareness of potential energy savings (BEIS 2017).

The 2017 UK Clean Growth Strategy outlines the policy actions and initiatives to achieve progress across the built environment (BEIS 2017). Notable targets include eliminating the sale of ICE cars and vans by 2040 and to achieve 85% of UK electricity generated from renewable sources by 2032. A major part of the UK Clean Growth Strategy is to achieve progress in the residential sector. For the residential sector, the Clean Growth Strategy aims to lower residential emissions by a further twenty per cent in 2032, to 58 million tonnes of CO_2 equivalent, while ensuring that "our policies will encourage people to improve their homes where it is cost effective and affordable for them to do so" (BEIS 2017). There are several policies within the 2017 Clean Growth Strategy designed to spur the uptake of residential energy efficiency.

In addition to supports targeting energy efficiency and improving information, there is a focus on expanding the use of low carbon heating fuels to meet 2032 targets. This is viewed as the "most difficult policy and technology challenge" (BEIS 2017), which is a common challenge faced by many countries. The Clean Growth Strategy outlines a menu of low-carbon heating technologies including heat pumps, district heating and low-carbon gases.

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[7] BEIS (2017) Annex 1990 – 2015 Final emissions by end user and fuel type: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/604354/ Annex_1990-2015_Final_emissions_by_end_user_and_fuel_type.pdf

[8] BEIS (2017) Energy Consumption in the UK: https://www.gov.uk/government/statistics/energy-consumption-in-the-uk Change in average consumption per household 1990-2016.

A review of the Clean Growth Strategy noted the lack of a plan for decarbonising UK heating systems, with no large-scale trials for heat pumps or hydrogen - two technologies viewed as catalysts for change (UK Committee on Climate Change 2019). Furthermore, there is a lack of sectoral emissions targets in strategy for the fifth carbon budget (IEA 2019a).

There are several important reasons as to why residential energy efficiency warrants public support. As in many other countries, the health-related benefits of home energy efficiency are a key justification: Estimates suggest that cold and damp homes cost the UK National Health Service £760 million per year.[9] In addition to mitigating energy use, UK policymakers have committed to researching the potential for rising temperatures to lead to overheating (BEIS 2017). Finally, investments in the residential sector tend to feature substantial lock-in, with any inefficiency likely to persist over time. This results in recent changes having a long-lasting consequence for achieving future decarbonisation targets (UN-IPCC 2018).

The Clean Growth Strategy demonstrates an awareness of the aforementioned issues, with a stated need to avoid i) new homes that will eventually need to be retrofitted, ii) that such dwellings can accommodate low carbon heating and iii) homes that are not on the gas grid can transition to low-carbon heating (e.g. using heat pump). This latter problem is not as pronounced, since 85% of English households feature gas central heating, per the English Housing Survey (Ministry of Housing Communities & Local Government 2019).

By comparison, over half of occupied Irish homes (per 2016 census of circa. 1.7 million households) feature oil or solid fuel as the main heating source (SEAI 2018a). A separate report notes that almost two thirds of the Irish dwelling stock are not connected to the gas grid, with scope for only an additional 300,000 households to connect (Ervia 2018). This highlights the similar problems of different magnitude that face residential decarbonisation in Ireland.

[9] Building Research Establishment (2011): The cost of poor housing to the NHS BEIS analysis based on English Housing Survey data

1.4 Chapter 1 - Key Findings

This chapter has outlined some of the ways in which climate change presents a challenge for how society functions. It has highlighted the importance of the residential sector within the broader global context. At a global level, there is a clear awareness of the issue of climate change. This is evident by the aggressive ambition of the European Green Deal, which has quickly followed the previously stated ambition of a net zero carbon economy by 2050, in line with the Paris Agreement.

This report has a particular focus on taking stock of the targets and progress made in Ireland. This helps to contextualise the substantial progress that has been made towards delivering change in the residential sector. In Ireland, the 2019 Climate Action Plan has outlined an awareness of the need for fundamental change across the built environment. This ambition has begun to be met by action, through the legal enshrinement of climate targets (Government of Ireland 2021a) and the introduction of Ireland's first carbon budget. In the residential sector, this increased ambition has begun to take shape through the National Retrofit Scheme. It is hoped that actions today will bear fruit in the months and years to follow, as Ireland works to meet its climate obligations. In this chapter, a comparison with the United Kingdom highlights areas where Ireland's neighbours have been successful (especially through the carbon budgeting process within the UK Climate Change Act) and outlines opportunities for Irish policymakers to learn from the experiences of neighbouring countries.

Translating aspiration into action

In both the UK and Irish policy, there is substantial policy ambition for reducing emissions, particularly in the residential sector. Despite national plans for emissions reduction, there is a need for more specific information on the implementation of policies. This has been noted in the UK (UK Committee on Climate Change 2018) and Ireland and is especially pertinent as Ireland begins its journey with carbon budgeting following the Climate Action and Low Carbon Development (Amendment) Bill (Government of Ireland 2021a).

This policy uncertainty also plays a role in the adoption of technology. Although such an exercise can be fraught with uncertainty, it helps to serve as an important measure of progress towards the clearly established national-level targets. For Ireland, this exercise is already underway with SEAI, who are currently conducting a National Heat Study.

Tailored technology solutions for retrofit

In both Ireland and the UK, residential retrofit is a clear key pathway to lower energy demand for heating. This chapter restates the need for retrofits to be effective, future proof and targeted to households with the greatest need. Policymakers have clearly embraced opportunities to demonstrate leadership in this space, but more can be done.

One important learning from this study is that there is no one technology solution that is a silver bullet to solve the problem. Although future residential energy use must be sourced from low-carbon heating, work must be done to identify what technology suits each development. Examples or notable technologies include heat pumps for standalone rural dwellings, district heating for new developments, low-carbon gas network connections for urban dwellings. This is especially important when considering the existing technology mix for each country, for example - a majority of gas network dwellings in England, district heating dwellings in Denmark (IRBEA 2016) or oil-fuelled dwellings in Ireland (SEAI 2018a).

By demonstrating an awareness of the legacy heating infrastructure, realistic and tailored policy options can be devised for the relevant country. This sort of ‘steered technology adoption’ presents an opportunity to improve welfare while also achieving stated targets.

2 Residential Heating Technology Review

Understanding the context for the current mix of heating technologies is paramount to understanding the potential for future low carbon technology adoption. This chapter begins by briefly exploring the history of heating technologies in Ireland, and the transition to modern centralized heating systems. We also provide some relevant statistics on the current building stock and demographics which are critical determinants of current and future heating technology adoption. We then describe the heating technologies most applicable to the decarbonisation of the residential heating sector in Ireland.

2.1 Residential Heating in Ireland

2.1.1 Historical evolution of heating technologies in Ireland

For millennia, the primary domestic heating source in Ireland has been solid fuels in the form of locally available peat and wood, burned in open hearths and fireplaces for heating and cooking. Much of the naturally occurring forests were harvested both to clear land for agricultural use and as a source of raw materials and fuel (OCarroll 2004). By the 18th century domestic forests were almost entirely depleted,[10] and peat fires became an increasingly important heating method (Energy Institute 2020).

The industrial revolution, and the discovery and exploitation of local coal mines which began in the 17th century increased the prevalence of coal as a heating fuel.[11] While domestically mined coal was primarily used to fuel steam-powered equipment, smelting and later electricity generation, a substantial share of imported coal was used to produce coal-gas or

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[10] Records form the early part of the 18th century even suggest that iron works had to cease owing to the lack of timber for fuel (O'Brien 1918; OCarroll 2004). One early author remarked that "*the woods of Ireland might, with the help of Norwegian imports, last some 50 years from this date (1673)*" while another mentions: "*The woods finally gave out in 1765*" (OCarroll 2004).

[11] Coal mining took place in four main areas: the Leinster coalfield straddling counties, Kilkenny, Laois and Carlow; the Slieve Ardagh coalfield on the border of Counties Kilkenny and Tipperary; the Kanturk coalfield in northwest County Cork and the Connaught coalfield straddling Counties Leitrim, Roscommon, Sligo and Cavan. (EPA 2009).

"Town Gas" to be used primarily in public and private lighting applications (McCabe 1992). A bi-product of this process, known as coke, was used in the manufacture of coal-gas itself as well as sold on to domestic consumers to be used in fireplaces.

Source: (CSO, 2000)

Common to the rest of the world, fireplaces and stoves remained the dominant home heating technology in homes well into the 20th century. In 1922, Swedish Nobel laureate Gustaf Dalén invented the AGA cooker which combined cooking and water heating through the use of a heavy cast iron frame to absorb heat from a low intensity but continuously burning source. The heated water could then be distributed through pipework to provide heat to adjacent rooms. However, the uptake of such early central heating systems remained limited, and it wasn't until the 1960s that traditional fireplaces and stoves began being replaced en-masse in favour of centralised heating systems. Some earlier systems used "back boilers" which were fitted to back of fireplaces/stoves and were used to heat water to be distributed via pipework.

Records in 1974 indicate that only 25% of households in the Republic of Ireland had a centralised heating system (Energy Institute 2020). By 1981 this share had risen to 39% and by 2002 to 84% (McManus 2011). Findings from the Household Budget Survey confirm the continued rise of centralised heating systems, with 97% of surveyed households indicating that they have central heating in 2010 in comparison to just 52% 23 years earlier (Table 2.1).

Table 2.1 Evolution of central heating in Ireland

	Household budget survey		Census		
Central heating type	1987 (%)	2010 (%)	1981 (%)	1991 (%)	2011 (%)
Oil	12	41		18	44
Natural gas	4	39		10	34
Electricity	1	5		3	9
Solid fuel	31	4		24	11
Other central heating	4	6		4	1
No central heating	48	3		41	2
% With central heating	52	97	39	59	98

Source: (CSO 1991; McManus 2011; SEAI 2018a)

Aside from the overall move to centralised heating systems illustrated in Table 2.1, we also observe a significant switch from solid fuel to oil and natural gas fuelled systems in the 1990s and early 2000s. While the focus of this report is to analyse the potential for transitioning to future low-carbon heating technologies, it is clear that a remarkable energy transition has already taken place in Irish homes. Importantly, this transition happened over a relatively short period of time (20 - 30 years), and hence demonstrates significant capacity for rapid change in domestic heating systems.

2.1.2 Building Stock

The heating technology mix employed depends fundamentally on the existing building stock to be heated. Before looking at the current heating technology mix in more detail, we begin by illustrating some key features of the Irish building stock such as age and type, which have, and will, influence heating technology choices.

Table 2.2 Current building stock by year of construction

Period in which built	No.	%
Before 1919	141,201	8.3
1919 to 1945	109,671	6.5
1946 to 1960	126,111	7.4
1961 to 1970	116,046	6.8
1971 to 1980	213,475	12.6
1981 to 1990	171,045	10.1
1991 to 2000	240,813	14.2
2001 to 2010	431,763	25.4
2011 or later	33,440	2
Not stated	114,122	6.7
Total	1,697,687	100

Source: Census (2016)

From Table 2.2 it is clear the substantial shift toward centralised heating systems discussed earlier was at least in part driven by newly constructed dwellings, which highlights the interplay between housing supply and energy policy in the residential heating sector. As of 2016, over 64% of occupied houses were built on or after 1971.

The decade between 2001 and 2010 saw the largest increase in housing construction, with 25% of the housing stock in 2016 constructed over the period. The impact of the 2009 financial crisis is also evident in the number of dwellings constructed since 2010, with just 2% of the dwelling stock constructed between 2011 and 2016.

The fact that 25% of the current dwelling stock was constructed in 2001 to 2010 also has important implications for future heating technology adoption, since the average life expectancy for a heating system of this period is 15-20 years (Aste et al. 2013; CIBSE 2014). This means that a large of share of properties built during the construction boom of the early 2000's will need heating system replacements in the coming decade and highlights the importance of policies which will influence heating technology choices in the coming years.

2.1.3 Dwelling Type

An important determinant of heating technology choice is the type of dwelling which requires heating. The optimal heating technology for an apartment or multi-dwelling building may be very different when compared to a detached or semi-detached house. From Table 2.3 we see that detached houses are by far the most common property type in Ireland, followed by semi-detached houses, and terraced dwellings. Apartments and flats (both purpose-built and converted) make up just 12% of the entire housing stock.

Table 2.3 Frequency of dwelling type in Ireland

Type of private accommodation	No.	%
Detached house	715,133	42.1
Semi-detached house	471,948	27.8
Terraced house	284,569	16.8
Flat or apartment in a purpose-built block	172,100	10.1
Flat/apartment in a converted dwelling (including bed sits)	32,053	1.9
Not stated	21,884	1.3
Total	1,697,687	100

Source: Census (2016)

Figure 2.1 compares the Irish building stock to other European countries. It is clear that Ireland has the lowest share of population living in flats/apartments by a considerable margin, and a comparatively high share of semi-detached properties.[12] This is important in explaining the currently employed mix of heating technologies, and the opportunity for future low-carbon heating technology options. It also has important implications for comparability with other countries in terms of policies used to encourage low-carbon heating. The closest European neighbour in terms of domestic building types is the United Kingdom which has a broadly similar distribution of dwelling types and climate. This is one of the reasons why we focus on the UK as a comparison state for low-carbon heating policies in the previous chapter.

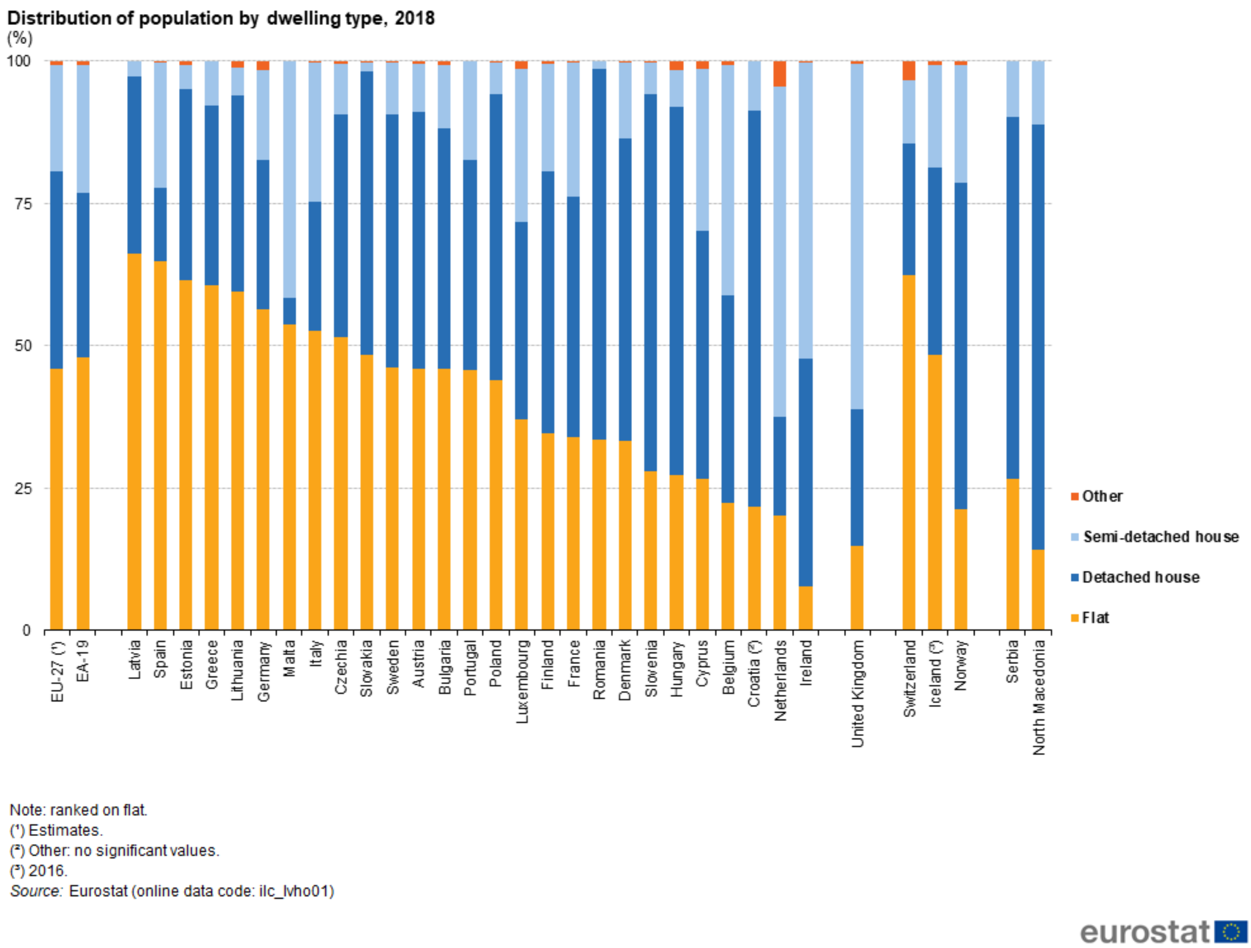

Figure 2.1 Distribution of population by dwelling type (Source: Eurostat, 2018)

12The census data describe the current dwelling stock by household, however households which live in apartments are typically smaller, which means that an even smaller share of the total population lives in apartments and flats. The figure from Eurostat compares the distribution of population by dwelling types across European countries and illustrates this point. Terraced houses are put in the same category as semi-detached houses in the Eurostat data.

2.1.4 Tenure Status

Ownership or the tenure status of building occupants can exert a significant influence on heating technology adoption. This is particularly true for cases where building occupants are not building owners, which can lead to principal-agent issues, typically known as the "*Landlord-tenant Problem*" (Gillingham et al., 2012; IEA, 2007, Petrov and Ryan, 2021). In the landlord-tenant problem, building owners (landlords) may under-invest in energy efficiency measures or heating systems improvements in cases where tenants are responsible for energy bills. Conversely, in cases where landlords are responsible for energy bills (i.e. utility bills are fixed and included in rental prices) tenants may over-consume energy since they do not face the marginal cost associated with energy use (Levinson and Niemann 2004). Both factors may lead to an over-consumption of energy in rental properties.

Table 2.4 Tenure status in Ireland over time

	2006	2016	Δ	%Δ
Owned outright	498,430	611,880	+113,450	+23%
Own with a mortgage or a loan	593,510	535,680	-57,830	-10%
Rent from a landlord	195,800	326,490	+130,690	+67%
Rent-free	21,700	27,440	+5,740	+26%
Rented from local authority	105,510	143,180	+37,670	+36%
Not Stated	47,340	53,000	+5,660	+12%
Total	1,462,290	1,697,670	+235,380	+16%

Note: Rent from a landlord includes renting from a voluntary/co-operative body. Source: Census (2016).

Overall, the total number of households in the Republic of Ireland increased by 16% over the period 2006 to 2016. As of 2016, the majority of households reside in properties which are owned outright, while households who own their property with a mortgage or a loan come in second. Interestingly this is a reversal of trends as ten years prior, and for census records dating back to at least 1991 the opposite was true. This reflects the changing nature of home ownership, which needs to be taken into account when designing policies which aim to encourage the adoption of low carbon technologies, and could present both opportunities and barriers.

On the one hand, a larger share of households which own their property outright could signal higher disposable incomes, since such households are not burdened with significant mortgage or rental costs. However, the demographics of households are also important, since these are likely to be older households (illustrated in Appendix Table 2.12), and older individuals may be less likely to engage in renovation or heating technology adoption with long payback periods or significant disruption (Mahapatra and Gustavsson 2008; Nair et al. 2010).

When combined, rental properties (from a private landlord, local authority or rent free) make up 497,110 households or roughly 29% of all households. Over time, privately rented accommodation has experienced the highest level of growth, with 67% more households living in private rental accommodation in 2016 when compared to 2006. Growth in the share of households in private rental accommodation has stagnated in recent years (RTB 2021), which is likely attributable to supply constraints and the global COVID-19 pandemic. However, in the absence of these constraints, and if pre-pandemic trends were to continue, the growth in demand for private rental accommodation is expected to rise. This will have significant implications for future low carbon technology adoption, if renters/landlords are less likely to undertake energy efficiency retrofits. In such instances, low carbon technologies which require less involvement or investment on the part of the household may become more attractive. Additionally, if renters are less likely to benefit from policies which aim to incentivise the uptake of low-carbon heating technologies, this raises questions about the distributional or inequality enhancing effects of such measures.

2.1.5 Occupancy

In addition to tenure status, occupancy can be a critical determinant of heating technology choice. Ultimately, both the heating and housing systems should satisfy the needs of the inhabitants. How occupants interact with their heating systems will have critical implications for heating technology choice and use. While newer heating technologies such heat pumps and district heating are more efficient both in terms of energy use and carbon emissions than existing options, they will still be inefficient if they are used to heat empty rooms or an empty dwelling. We explore dwelling occupancy using data from Census (2016) in Table 2.5 below.

Table 2.5 Number of occupied rooms in Irish private households

2016					2011	
Number of occupied rooms	All private households	All persons in private households	Persons per household	Persons per occupied room	Persons per occupied room	Δ
(A)	(B)	(C)	(D=C/B)	(E=D/A)		
1	23752	36348	1.53	1.53	1.45	0.08
2	88719	169591	1.91	0.96	0.88	0.07
3	172739	414481	2.40	0.80	0.75	0.05
4	179989	423608	2.35	0.59	0.56	0.03
5	378691	1011046	2.67	0.53	0.52	0.01
6	299371	854409	2.85	0.48	0.47	0.00
7	222308	699893	3.15	0.45	0.45	-0.00
8	137904	466918	3.39	0.42	0.43	-0.01
9	57900	207268	3.58	0.40	0.41	-0.01
10+	42239	156921	3.72	0.37	0.38	-0.01

Source: Census (2016, 2011). Occupied room defined as: "The *number of rooms* occupied by a private household is the total number used by the household. This includes kitchens, living rooms, bedrooms, conservatories you can sit in and studies, but excluding bathrooms, toilets, kitchenettes, utility rooms, consulting rooms, offices, shops, halls, landings and rooms that can only be used for storage such as cupboards (CSO 2017)."

The first column of Table 2.5 lists the number of rooms claimed to be occupied within a dwelling. An occupied room is defined as a room that is typically used by a household. As per CSO (2017) this includes rooms such as: kitchens, living rooms, bedrooms, conservatories and studies, but excludes rooms such as toilets, utility rooms and halls. These can therefore be thought of rooms which are typically occupied and may require heating. Columns (B) and (C) provide data on both the number of households and persons in dwellings with a given number of occupied rooms. From this, we can work out the number of persons per household which is presented in column (D). This illustrates that as the number of claimed occupied rooms increases (in A), the number of persons per household also increases (in D), meaning that bigger households reside in bigger dwellings.

However, the rate of increase in persons per household does not appear to match the rate of increase in the number of claimed occupied rooms. Column (E) illustrates this through the number of persons per occupied room. This suggests that properties with more claimed occupied rooms tend to have fewer persons per room. Larger homes therefore appear to be emptier.

2.1.6 Dwelling Size

The relationship between dwelling size and energy consumption is well understood – bigger dwellings require more energy for heating, construction and maintenance. Newly constructed dwellings in Ireland have increased in size (Appendix Figure 2.10), driven primarily by larger detached houses (Figure 2.2). At the same time, average household size has seen a persistent decline from 4.1 persons per household in 1971 to 2.7 in 2016 (CSO, 2016).

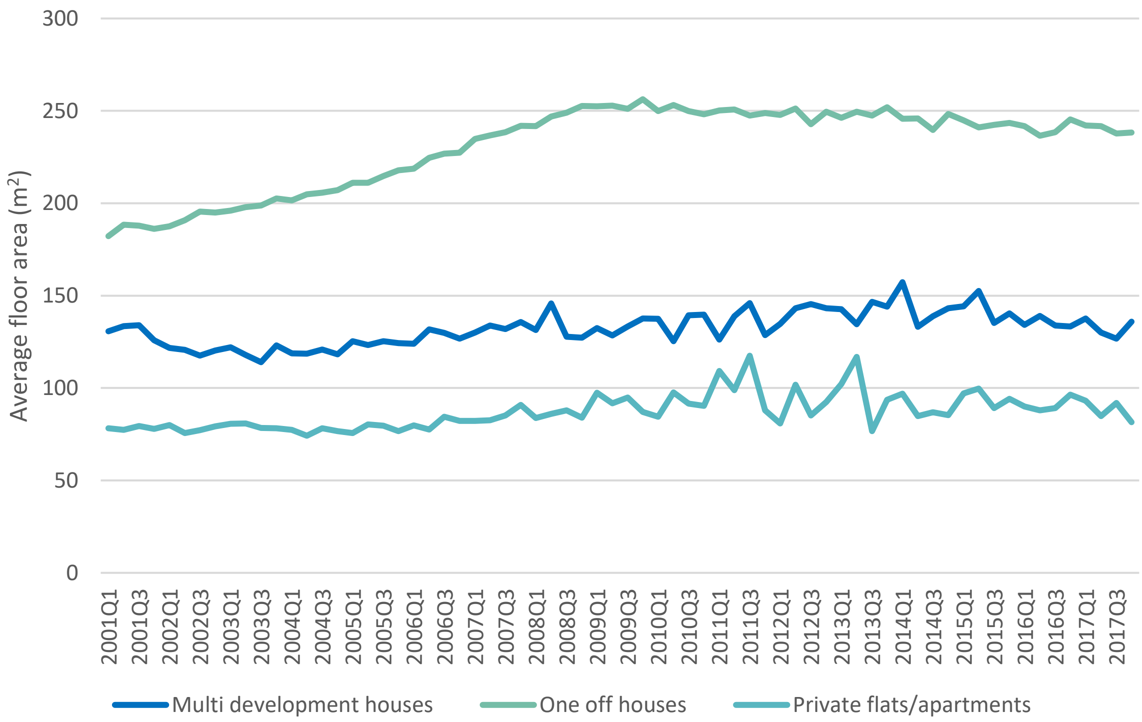

Figure 2.2 Average floor area per unit - planning permission data (2001 - 2017)

While downsizing to a smaller dwelling can offer significant energy savings, the option of downsizing depends on the number of occupants of the dwelling, their demographics, and the availability of other suitable accommodation. In a survey of mature homeowners with 1,213 households, IGEES (2020) find that only 4% of households aged 55 or over indicated that they were extremely or very likely to move their home in the future.

Over half respondents stated their opposition to moving was due to emotional attachment to the home. The authors estimate that between 15 and 20% of mature homeowner households would be willing to move if the option of selling their home and purchase a smaller purpose-built home in the same area for a lower price were available (IGEES 2020a).

In terms of the international literature, the savings possible from downsizing are illustrated by Huebner and Shipworth (2017), who, using a nationally representative sample of households in England find that building size alone accounts for 24% of the variability in energy consumption among residential dwellings. Household size (or number of occupants) on the other hand accounts for just 11% of energy consumption variability. The authors findings suggest that if single-person households living in dwellings with more than two bedrooms downsized to single-bedroom dwellings energy savings of 27% are possible. Similarly, earlier research by Wilson and Boehland, (2008) finds that a small house built only to moderate energy-performance standards uses substantially less energy for heating and cooling than a large house built to very high energy performance standards.

Embedded emissions in construction and the functional unit of expression for efficiency are also important when considering dwelling size and energy consumption. Stephan and Crawford (2016) show that larger dwellings have higher embedded emissions since the size of a dwelling is proportional to the materials required for its construction and maintenance. The authors also find that expressing energy efficiency per m^2 inadvertently favours larger dwellings, since lifecycle energy demand increases at a slower rate compared to house size.

2.1.7 Energy efficiency and consumption

The energy performance of the dwelling stock is a vital determinant of heating energy use and technology choice. A better insulated property can use significantly less energy for heating, irrespective of the heating technology applied. Dwelling energy performance however also influences the technology options available for heating a dwelling.

For example, in order to maximise the benefits associated with heat pumps, a home must be energy efficient to begin with, with a heat loss indicator of approximately 2 Watts/Kelvin/m^2 to qualify for a heat pump grant (SEAI 2020a). Improvements in dwelling energy performance are also necessary for fourth generation district heating systems (4GDH), which would work best with low energy, retrofitted and new properties (IrBEA 2016; Lund et al. 2014).

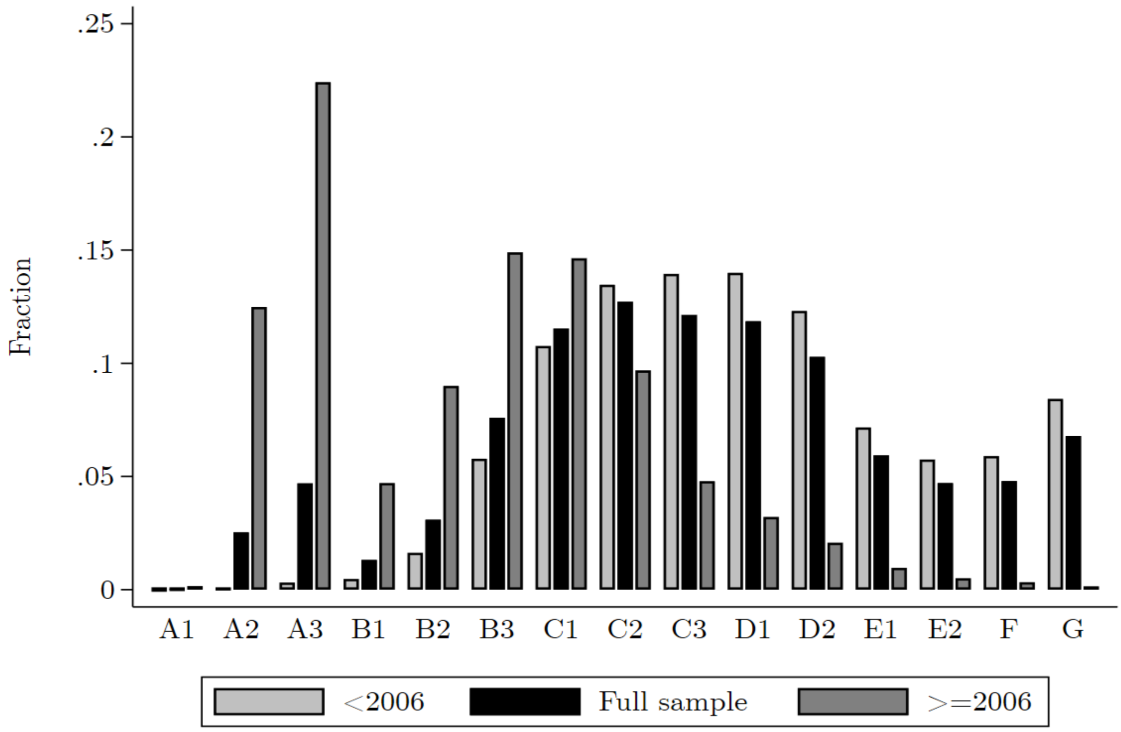

Figure 2.3 Distribution of BER grades

Figure 2.3 shows the distribution of energy ratings from the national BER database, for the entire sample (925,701 observations), and for properties built prior to, and after 2006.[13] Looking at the full sample (middle columns) we can see that the majority of properties which have undergone a BER assessment have a rating of B3 and below (817,706 or approximately 88% of the sample), with a mean BER value of 245kWh/m^2/yr which falls in the D1 category, and a median value of 214kWh/m^2/yr (C3).

We also see a significant grouping in the distribution of ratings at the A3 value. When looking at properties built after 2006 this grouping becomes even more pronounced. This is the result of building regulation changes introduced in 2011 (Building Regulations (Part L Amendment) 2011) which effectively required new dwellings to be A3 rated or better. Newer building regulation changes place an even more stringent requirement on the energy performance of new dwellings, with the introduction of the European Union (Energy Performance of Buildings) Regulations in 2019. Overall, newer properties are more efficient, however it is important to note that they represent a relatively small share of BERs. Approximately 20% of BERs issued are for properties built on or after 2006.

The Building Energy Rating (BER) provides an indicative measure of dwelling energy efficiency. It estimates energy used for space and water heating and does not account for appliance usage. Importantly, the methodology behind the BER makes several key assumptions regarding dwelling occupancy and heating behaviour. If these assumptions are violated, any difference between actual energy use and the level denoted by the BER has important consequences for policies that are based on measuring performance through BER attainment.

Research on a sample of gas-connected Irish homes presents two important takeaways (Coyne and Denny 2021b). Firstly - there is not much variation in actual energy use across households, when measuring gas and electricity consumed. When looking at sample averages of actual annual energy use (Table 2.6, Column 3-4), there is only a range of 457 kilowatt-hours (kWh) per year between households of differing dwelling energy efficiency. This is in

[13] The year 2006 was chosen for illustrative purposes since this is the cut-off for eligibility for insulation and heating control grants. 742,131 or approximately 80% of dwellings with a BER are built prior to 2006. https://www.seai.ie/grants/home-energy-grants/?gclid=Cj0KCQiA15yNBhDTARIsAGnwe0W0Ch-OFGm8kEU5YhpxFH3rdqiul1pONawvX63KxsGB0ZhR8Qjedx4aAoxGEALw_wcB&gclsrc=aw.ds

contrast to the range of theoretical energy use denoted by a simplified five-point BER, which is 17,391 kilowatt-hours (kWh) per year.

Table 2.6 Difference in actual and theoretical energy use

		Actual Annual Energy Use (AQ)		Theoretical Annual Energy Use (TQ)		T-Test of Equality of Means			
						Difference		SE	P-Value
	n	Mean AQ	Median AQ	Mean TQ	Median TQ	Mean	%		
Full Sample	19,251	10,869	10,167	13,148	11,402	- 2,279	- 17.33	61	0***
EPC Grade									
AB	2,601	10,569	9,661	7,571	6,620	2,998	39.60	122	0***
C	8,269	10,880	10,334	10,826	9,734	54	0.50	70	0.44
D	4,835	10,917	10,231	14,353	12,826	- 3,436	-23.94	104	0***
E	2,051	11,026	10,421	18,133	16,300	- 7,106	-39.19	173	0***
FG	1,495	10,964	9,853	24,962	22,466	- 14,000	-56.09	290	0***
Dwelling									
Apartment	1,674	8,115	7,211	11,595	10,983	- 3,481	-30.02	163	0***
Detached	2,316	13,712	13,150	19,385	17,184	- 5,673	-29.27	247	0***
Semi-detached	6,905	11,398	10,917	14,008	12,495	- 2,610	-18.63	99	0***
Terrace	8,356	10,197	9,712	11,020	9,490	- 823	-7.47	82	0***

***** P<0.01, **P<0.05, *P<0.10. Note: Source: Coyne & Denny (2021b). Units in kWh/year. Sample features 9,923 observations of one year of actual energy use and a further 9,328 observations from the same sample of houses with a second year of actual energy use. Medians reported.**

Results show large significant differences between actual energy use and the level denoted by the BER - even after accounting for appliance usage. On average, actual energy use is 17 per cent lower than the theoretical BER level. Occupants in the most energy efficient dwellings consume more energy than suggested by their BER (AB-rated average 39% above theoretical BER level). Conversely, occupants in less energy efficient homes consume far less energy than suggested by their BER (FG-rated average 56% below BER level).

2.2 Current Heating Technology Mix

2.2.1 Overview of heating fuels

The latest census records can give us perhaps the best picture of the current mix of heating technologies employed in the Irish residential sector. While more recent survey data is available, the completeness of census records at the population level gives the most accurate representation of the true overall mix of central heating technologies currently in place. Table 2.7 presents the distribution of central heating types, broken down by urban and rural environments.

Table 2.7 Current heating fuel mix in Ireland

Type of central heating	Total	(%)	Aggregate Town Area	(%)	Aggregate Rural Area	(%)
Coal (incl. anthracite)	86,611	5.1%	40,636	3.8%	45,975	7.5%
Electricity	146,302	8.6%	127,132	11.8%	19,170	3.1%
Liquid Petroleum Gas (LPG)	9,999	0.6%	4,390	0.4%	5,609	0.9%
Natural Gas	569,166	33.5%	555,475	51.4%	13,691	2.2%
No central heating	23,175	1.4%	13,779	1.3%	9,396	1.5%
Not stated	41,348	2.4%	32,248	3.0%	9,100	1.5%
Oil	686,004	40.4%	282,709	26.2%	403,295	65.4%
Other fuels	11,076	0.7%	3,895	0.4%	7,181	1.2%
Peat (incl. turf)	90,030	5.3%	14,074	1.3%	75,956	12.3%
Wood (incl. wood pellets)	33,976	2.0%	6,505	0.6%	27,471	4.5%
Total	1,697,687		1,080,843		616,844	

Source: Census (2016). Aggregate town area refers to towns with a total population of 1,500 inhabitants or more. https://www.cso.ie/en/releasesandpublications/ep/p-cp2tc/cp2pdm/bgn/

As of 2016, the most common type of central heating system is fuelled by oil, followed by natural gas. Together, oil and natural gas heating dominate the residential heating market and represent over 73% of residential heating systems. While electric heating appears to be the third most popular heating type overall, solid fuels (coal, peat and wood) together constitute a larger share of the domestic heating fuel mix (12.4%).

This highlights the significant challenge in place to electrify the heating sector in order to take advantage low-carbon electricity generation. In addition, the majority of electric heating currently in place is likely to be in the form of inefficient electric resistance heaters, however there are growing number of heat pump installations (Verma 2021), which will be discussed in more detail.

A significant dichotomy in central heating types exits between urban and rural environments. From Table 2.7 we can see that natural gas is favoured in more urban areas, whereas oil is by far the dominant technology of choice in rural areas. This reflects the limitations of the natural gas infrastructure currently in place, which is mostly confined to towns and cities. Importantly however, in addition to natural gas, there are also a substantial share of properties in urban areas which rely on oil. Electric heating appears to be more prevalent in urban areas and may be linked to a higher share of rental properties.

In rural areas oil-fired systems strongly dominate the residential heating market, capturing over 65% of the market share. Apart from oil, over 24% of rural properties depend on solid fuel systems, with peat being the most popular solid fuel choice. This split in heating technology choice based on an urban-rural divide means it is unlikely that we will be able to rely on a single low-carbon technology to decarbonize the entirety of the domestic heating sector. We discuss some of the low-carbon technology options which are already in place in the Irish market in the following section in more detail.

2.2.2 Existing Low Carbon Heating Technologies

2.2.2.1 Heat Pumps

One promising approach to decarbonise the domestic heating sector is the use of heat pumps, which can extract ambient heat from the air (or ground) and provide a stable and efficient source of low-grade heat. Heat pumps use electricity to operate, usually 25%- 40% of the heat output, implying that efficiencies of 250%-400% can be achieved (SEAI 2020b). This means that for one unit of electricity used, up to four units of heat can be delivered. In comparison, very efficient condensing oil and gas boilers have efficiencies of 85% to 97% (SEAI 2021a).

Despite electricity prices being higher per kWh relative to gas and oil, energy cost savings can therefore be achieved by switching to properly designed and installed heat pumps. Given that heat pumps operate using electricity, significant emission savings are expected in comparison to fossil fuel using boilers, particularly as the electricity generation mix moves towards renewable energy sources. In addition, relative to other renewable heating technologies such as biomass boilers, heat pumps require less maintenance and do not require fuel delivery.

The 2019 and 2021 Climate Action Plans (DCCAE 2019) set out a goal to install 600,000 heat pumps (400,000 heat pumps in existing buildings) by 2030. As of 2020, according to BER data there are currently 38,535 heat pumps installed in residential dwellings in Ireland. The trend in installations of the current stock of heat pumps is presented in Figure 2.4 below.

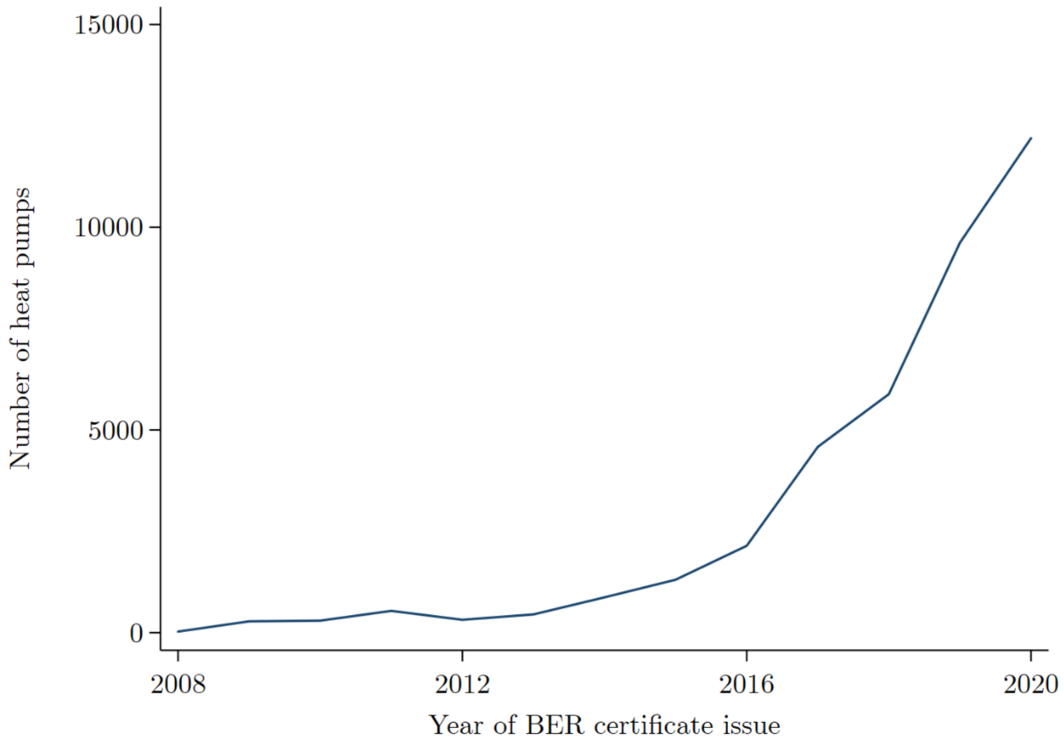

Figure 2.4 Number of heat pump installations per SEAI BER data[14]

[14] Note: we identify heat pumps in the BER database as heating systems which are categorized as `Electrical` from the variable `mainspaceheatingfuel` and have a main heating system efficiency greater than 101 (`hsmainsystemefficiency>101`).

It is clear that heat pump installations have experienced exponential growth over the past several years. Even in the face of a global pandemic in 2020 which imposed limits on construction work and renovation the number of heat pump installations grew by 12,195 units. However, SEAI (2020) outlines that meeting the targets set out in the Climate Action Plan requires the number of annual heat pump installations to increase significantly. While the growth rate in adoption has been impressive so far, further acceleration is necessary in order to achieve 2030 targets.[15]

Given the geographical distribution of properties and heating technologies discussed earlier, heat pumps may be a particularly attractive option in certain locations where access to the natural gas network is limited and where heat demand density is insufficient for district heating systems. However, heat pumps also may require substantial retrofit in order to be viable for older, inefficient dwellings (SEAI 2020c). As of 2020, it is estimated that there are in total roughly 200,000 homes in the Republic of Ireland which are "heat-pump ready". This suggests that a substantial share of homes that must be upgraded before being suitable for a heat pump. Aside from the costs of a deeper retrofit, a barrier to heat pump adoption is the higher upfront cost associated with the technology relative to fossil-fuelled equivalents.

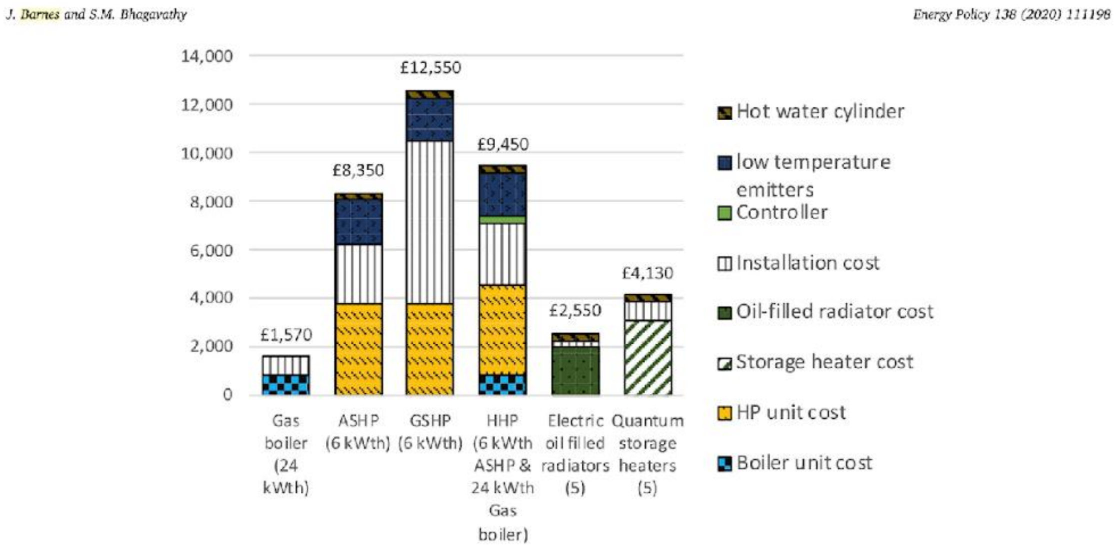

Figure 2.5 Upfront cost of heating system for UK semi-detached home (Source Barnes & Bhagavathy, 2020)

[15] In order to reach the target of 600,000 heat pump installations by 2030, it will be necessary to install on average in excess of 56,000 heat pumps per annum over the next decade.

Central cost estimates from Barnes & Bhagavathy (2020) compare the costs associated for air-source heat pumps (ASHP), ground-source heat pumps (GSHP) and hybrid heat pumps (HHP) with some gas and electric heating options for a typical UK semi-detached home. All types of heat pumps have significantly higher upfront costs, which are driven primarily by HP unit cost, installation costs and the costs associated with installing low temperature emitters. Electric Ireland (2021) provides similar cost estimates for heat pumps in the Irish market, with air source heat pump installations typically costing €8,500 – €14,500, depending on the size and power of the heat pump. Surveys of Irish heat pump installers find installation costs ranging from €8,000 - €16,000, depending on size and type of installation (Cronin 2021). Furthermore, suppliers indicate they believe heat-pump installation costs have risen slightly in the last 5 years and are likely to remain stable within the next five years. This is corroborated using evidence from an annual survey of heat pump installers by the Swedish Cooling and Heat Pump Association (2021), where heat pump installation costs have seen a steady increase in the last 10 years. It is of course important to note that these cost estimates relate to the heat pump installation itself, and not the likely necessary additional improvements in thermal performance necessary to accommodate the technology in existing dwellings.

Although heat pump installations have a higher upfront cost relative to conventional oil or gas boilers, due to their significantly higher efficiency, operating costs for the household are expected to be lower. Kelly et al. (2016) estimate that for some 60% of oil-fired heating system users in Ireland, investing in an air-source heat pump could deliver substantial cost savings in the region of €600 per annum. With a rising carbon price, and an increasingly decarbonised electricity system, the operational cost savings from heat pumps relative to fossil fuel technologies are expected to increase further. Savings will ultimately depend on dwelling insulation, previous heating technology, system size, type of emitters and occupant behaviour.

2.2.2.2 District / Localized Heating

District, and localised heating systems use a centralised heating source to distribute hot water via insulated pipework to households in an area. In a similar setup as the traditional electricity network, heat is produced (or captured) at a central location and is then distributed to individually metered buildings (IrBEA 2016). A significant advantage of such systems is that the original heat source can take many different forms including: natural gas systems, electrical heating, combined heat and power systems, and waste heat from electricity production or industrial process.

At present there are no large-scale district heating networks in Ireland. However, there are a number smaller scale localised projects in large apartment blocks, multi-building campuses and some community heating schemes (Lambe 2019). These may be defined as communal or localised heating systems (IrBEA 2016). Table 2.8 details some examples currently in place. Chapter 4 of this report focuses on larger-scale district heating networks and the role they could play in decarbonising buildings in Ireland in more detail.

Table 2.8 Existing examples of localised heating projects in Ireland

- Charlestown, Finglas. Mixed use development of shopping centre, retail park and apartments. Heating technologies: CHP biomass boiler using wood pellets with backup gas boiler. 285 apartments with a 18,800m^2 shopping centre.[16]
- Trimbleston, Goatstown. 160 apartments. Natural gas-based CHP system.[17]
- Forbes Quay, Dublin 2. 124 apartments. Natural gas boilers providing heat and hot water.
- Cathedral Court, Dublin 8. 112 apartment buildings and adjacent office buildings. Gas fired boilers.
- Smock Alley, Temple Bar. 54 apartments supplied with heat and hot water through a local heat network.
- Elm Park, Dublin 4. Mixed use development of offices and apartments. Heating technology – CHP, gas boiler, biomass boiler (Lambe 2019).
- Stewarts Care, Palmerstown. Healthcare campus with mix of high dependence residential units. Heating technology – CHP.
- The Glen, Cork. 58 housing units, a community centre, creche and youth centre. Powered by wood pellet, biomass boiler and gas boilers.

[16] http://www.kaizenenergy.ie/case-studies/
[17] https://www.mandpmechanical.ie/projects/district-heating-trimbleston

2.2.2.3 Combined Heat and Power (CHP)

CHP systems can deliver both thermal and electrical energy to a dwelling. These can be utilised as part of district/localised heating systems, or as standalone systems within individual buildings (micro-CHP). There is therefore significant variation in system size and fuel types. The total operational capacity of CHP systems in Ireland at the end of 2019 was 322MWe from 319 units (SEAI 2020d). These are primarily fuelled by natural gas (274 units, 93.2% of operational capacity) followed by biogas (21 units, 3.7% of operational capacity), biomass (3 units, 2.0% of operational capacity), solid fuel (1 unit, 0.8% of operational capacity) and oil (20 units, 0.3% of operational capacity).

By far the vast majority of these units are installed in the industrial and services sectors. There are just 55 CHP units in the industrial sector, however these units account for 87.2% of total operational capacity, reflecting their relative scale. By comparison, there are 264 CHP units installed in the services sector, however, these reflect just 12.8% of total operational capacity. Some of the CHP units in the services sector also supply residential customers, either through community heating schemes or through mixed-use developments. From the BER database we can identify cases where residential dwellings meet at least some of their heating requirements from CHP systems or waste heat.[18] In total, we identify 5,200 such cases in residential properties, the significant majority of which are apartments .

Table 2.9 CHP or waste heat by dwelling type

Dwelling type	Total	(%)
Mid-floor apartment	3,223	61.98
Ground-floor apartment	879	16.90
Top-floor apartment	843	16.21
Apartment	2	0.04
Basement dwelling	1	0.02
Mid-terrace house	73	1.40
End of terrace house	28	0.54
Semi-detached house	99	1.90
Maisonette	29	0.56
Detached house	23	0.44
Total	5,200	100

Source: BER data

[18] We identify these properties as cases where `chpunitheatfraction>0`.

Solar Thermal Collectors

Aside from photovoltaic panels, solar thermal collectors which use solar energy to provide hot water have enjoyed limited popularity in the Irish residential market. From BER data we find that there are 38,917 such installations.[19] These are presented over time in Figure 2.6. While there appears to be have been an initial growth in the adoption of such systems between 2008 and 2011, the number of installations plateaued in subsequent years and appears to be in decline, perhaps due to a substitution effect with increasingly cheaper solar photovoltaic systems.

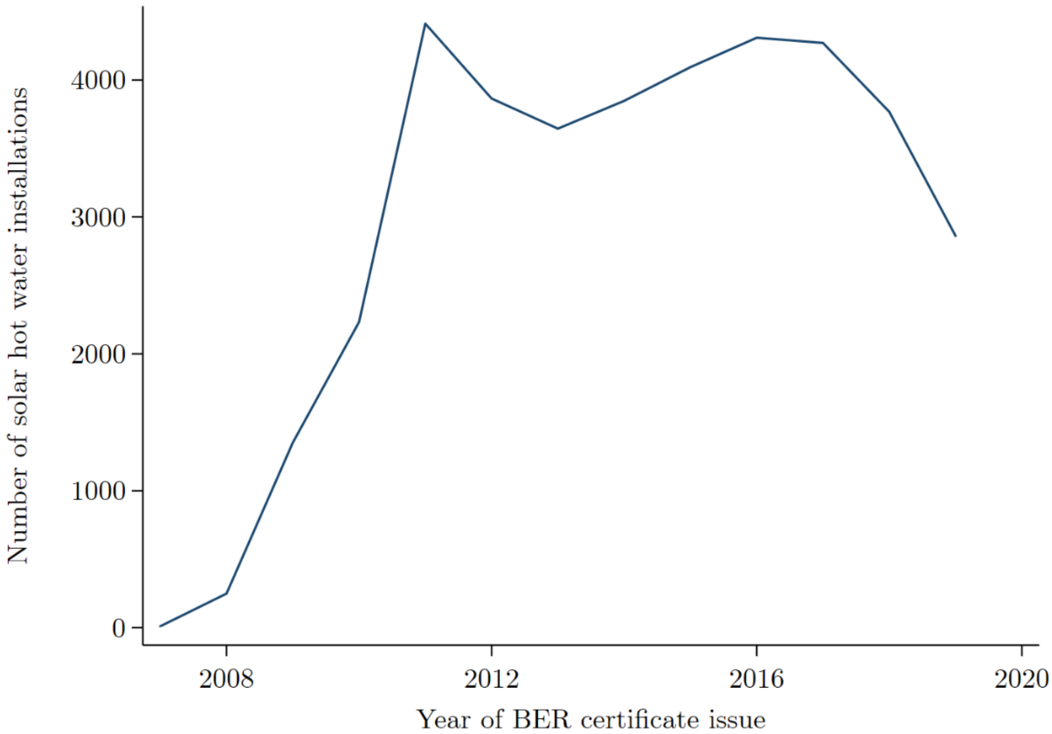

Figure 2.6 Annual installations of solar hot water in Ireland (Source: BER data)

2.2.2.4 Decarbonized Gas

Decarbonised or renewable gas can take the form of a range of gasses which replace natural gas in the existing gas network. This does not necessarily represent a new heating technology but rather a substitution of fuel for existing heating technologies (KPMG 2018). Biogas is produced through a process known as Anaerobic Digestion (AD), which places source material

[19] These are identified from the variable "`solarhotwaterheating`" in the BER database.

in an oxygen-deprived container. Bacteria is then introduced which break down the source material releasing methane. Biomethane is a purified form of biogas, has properties similar to natural gas and can be injected directly into the natural gas grid to be used in existing heating/cooking appliances. An additional benefit of biogas is that it can displace emissions associated with agriculture and can be produced from waste feedstocks such as food waste, municipal solid wase, and slurry/manure.

According to Ricardo Energy & Environment (2017) up to 28% of natural gas supply in 2015 in the Republic of Ireland could be met through biogas by 2050. This scenario is designed to show the maximum biogas/biomethane production which could be achieved through anaerobic digestion utilizing all feedstocks identified as available for AD. It would require significant use of grass silage accounting for 86% of feedstock. Waste-based and moderate grass silage use scenarios suggest that 5-8% of natural gas supply could be met using biogas and with a positive NPV. This is similar to O'Shea et al. (2017) who find that the total production by NPV positive plants in their optimization model is equivalent to 6.8% of energy use in transport, 7.2% of total natural gas demand, or 22% of industrial gas consumption.

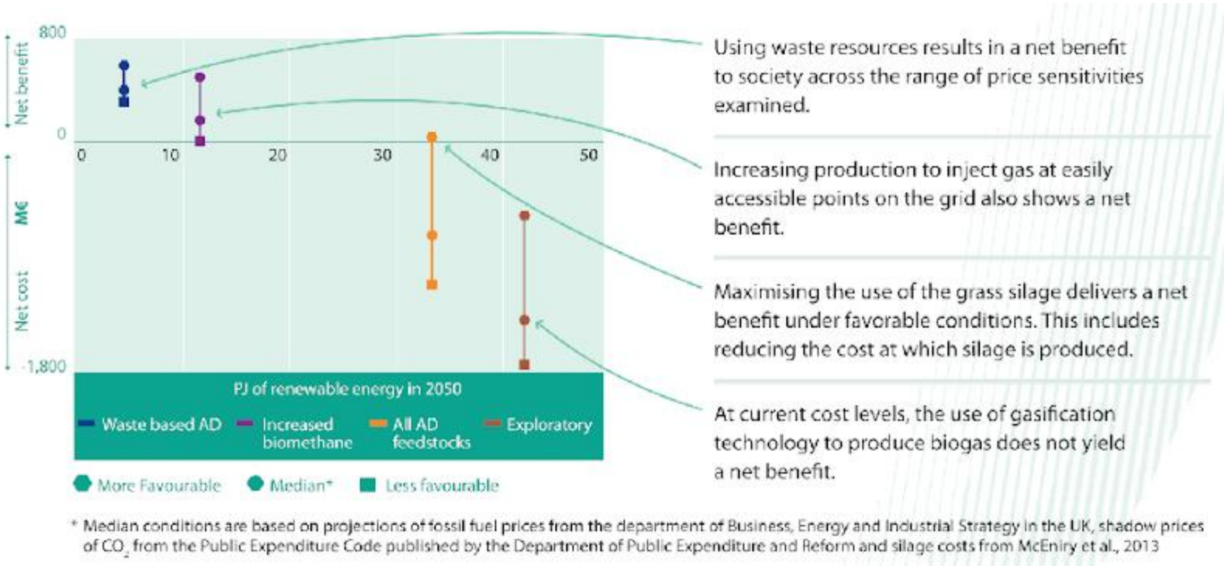

Figure 2.7 Biogas and biomethane scenarios (Source: SEAI (2017))

As of 2017, the vast majority of anaerobic digestion installations implemented in Ireland have been wastewater treatment plants, with only 14 plants using agricultural feedstock (O'Connor et al. 2021).[20] Expansion of renewable gas infrastructure is underway through the GRAZE gas project, which will include a Central Grid Injection Facility (CGI),[21] a renewable gas logistics operation, 2 Compressed Natural Gas (CNG) stations and support for circa 74 CNG vehicles.[22]

2.2.2.5 Biomass

Biomass is the oldest form of heating fuel, and yet it may be a viable alternative for decarbonising at least a portion of difficult to reach domestic heat demand. There are many forms of modern biomass fuel, ranging from wood from forestry bi-products to poultry litter from chicken farms and straw from tillage. Biomass fuel may also be produced from a variety of energy crops, such as willow, poplar and miscanthus.

The most popular biomass fuel type in residential settings is wood, either as dried wood for use in stoves or in the form of wood pellets and wood chips. From the 2016 census we see that there are in total 33,976 homes in the Republic of Ireland where heating is fuelled by biomass in the form of wood chips or pellets.[23] Renewable Energy Ireland (2021) estimate that biomass heating will meet roughly 10% of residential thermal energy consumption by 2030 under aggressive decarbonisation scenarios, however will play a bigger role in industrial applications. Biomass boilers typically have higher upfront and maintenance costs relative to oil and gas boilers. For a domestic property, the cost of a biomass boiler in Ireland ranges between €3,000 and €8,000, depending on type and size and units typically have an efficiency ranging from 80-90% (Selectra 2021).

The amount of domestically available biomass resource available in the Republic of Ireland will depend on the prevailing market price (Figure 2.8). Based on availability and existing

[20] A map of current and planned bioenergy installations in the Republic of Ireland can be accessed at: https://www.irbea.org/bioenergy-installations-map-ireland/

[21] Located in Mitchelstown, Cork the CGI facility will allow renewable gas to enter the gas grid. Gas will be transported by road, via tankers to the CGI facility. This is intended to be the first of 17 transmission connection facilities. When operational, this facility could output 8% of Ireland’s residential gas demand (56,000 homes).

[22] https://www.gasnetworks.ie/corporate/news/active-news-articles/major-step-forward-to-bring-renewable-gas-on-to-gas-network/

[23] Wood pellets have a higher energy density than wood chips and therefore are easier to store and transport. Wood chips are cheaper than wood pellets on a euro per kWh basis. However, they take up 3 times as much storage space, but are also less sensitive to moisture damage.

market prices, forestry and the by-products of the forestry industry currently have the largest source of biomass potential (SEAI 2021b).

With increasing market prices, energy crops can contribute an increasing share of biomass supply, since farming such crops needs to be a viable prospect. Current delivered energy costs for biomass fuel range from 5.94c/kWh for bulk delivery of wood pellets to 11.27c/kWh for bagged hardwood fuel with 20% moisture (SEAI 2021a).

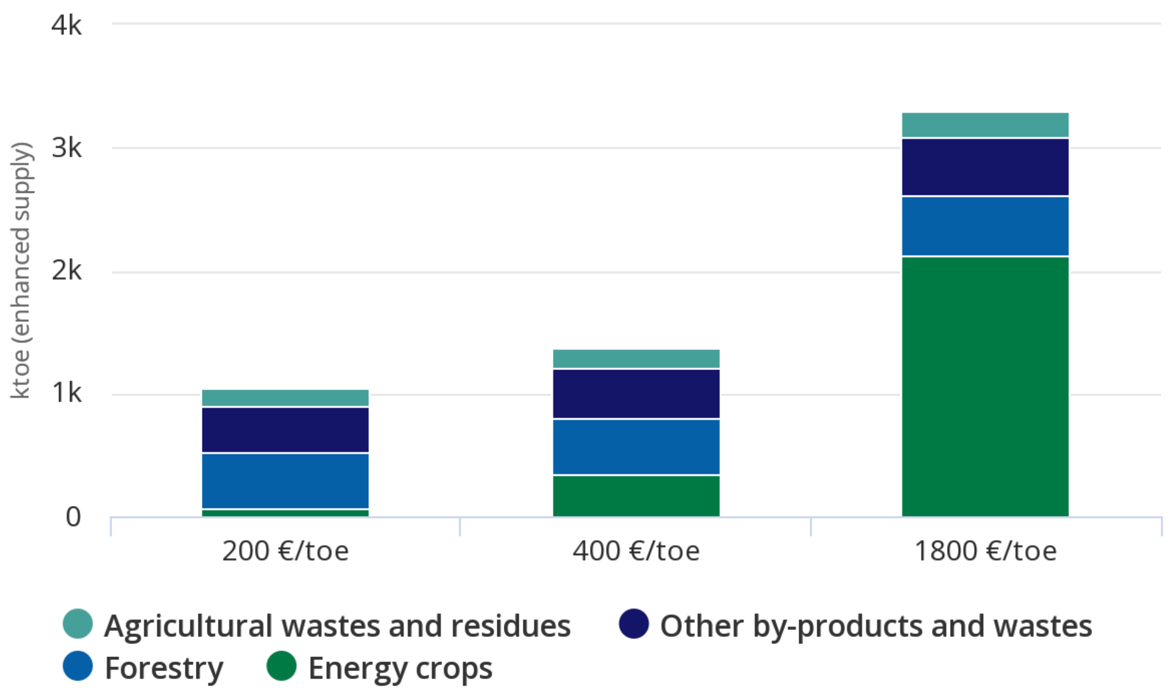

Figure 2.8 Biomass resources at different price brackets (Source: SEAI (2021))

A major limitation with both biomass and biogas fuels is that they must be procured in a responsible manner in order to ensure that they are indeed carbon neutral/reducing. Transporting, growing, harvesting and refining biomass and biogas is likely to be associated with additional emissions which are in excess of simply using the fuel. Taken together these supply chain activities can take back some of the benefit of using bioenergy (Clancy 2019). In addition, in order to produce increasing quantities of biomass, a substantial change in land-use from food production will be necessary, with sustainable use of fertiliser. Imported biomass, particularly from countries outside of the Europe may be associated with a high risk of causing greenhouse gas emissions (SEAI 2021b).

2.3 Heating Technologies in Neighbouring Countries

In this section, we explore heating technologies in a selection of European countries. IERC (2020) carry out a detailed comparison of heating technologies in countries with a similar temperature and climate to Ireland, and identify Belgium, France, Netherlands and the UK as being some of the closest comparison nations in terms of heat demand. Some statistics on heating requirements and technologies in these countries are presented in Table 2.10.

Table 2.10 Comparison of heating demand and fuel mix - selected EU countries (IERC, 2020)

	Ireland	UK	France	Belgium	Netherlands
Domestic heating/cooling fuel (%)					
Oil	40	9	18	36	<1
Gas	25	75	37	46	84
Coal	19	2	1	1	0
Electricity	14	10	19	10	5
Biomass	1	4	20	7	6
District heating	0	<1	3	<1	4
Solar thermal	<1	0	<1	<1	<1
Heat pump	<1	<1	2	<1	<1
Average annual temperature capital city	9.8	10.3	12.3	10.5	10.2
Average national HDD (2018)	2756	2936	2184	2514	2527
Average national CDD (2018)	0	1	65	33	31
Population density (p/km^2)	70	273	122	376	505
Population increase 1998-2018 (%)	27	13	11	11	9
% households with access to gas network	39	82	41	55	97
Gas reserves (trillion cubic feet)	0.4	6.2	0.3	0	28
Crude oil reserves (thousand barrels per day 2018)	0	842	16	0	16

Source: IERC (2020). HDD=Heating Degree Days, CDD=Cooling Degree Days.

A major difference between the distribution of domestic heating types in Ireland and this list of countries is that almost all comparison states have a lower reliance on oil for domestic heating and a higher reliance on natural gas. IERC (2020) find that all comparable countries have considered space heating an area that requires both short term and long-term policy action to encourage decarbonization.

Some of the key strategies being considered by these countries include: local authority engagement; consumer awareness and information campaigns; planning to ban fossil-fuel based boilers; building trust in new technologies through certification schemes; installer and developer training and creating and enabling an environment that is conducive to attracting investment. Longer term strategies are being developed in all countries and are necessary in demonstrating policy stability to attract investors, particularly for the deployment of low carbon heat network infrastructures and technical regulations and standards for low-carbon technologies. The findings of IERC (2020) also suggest that the availability of hydropower, natural gas and oil reserves have exerted a significant influence on historic heat policy.

Some other significant differences are identified between the Republic of Ireland and this list of countries. The Republic of Ireland had the largest population increase between 1998-2018 yet has the lowest population density overall, which is approximately half of the EU average population density. Ireland's dwellings also have a higher number of occupants on average as compared to other similar climate-countries at 2.6 persons per household, which is 20% higher than France and Netherlands, and 16% higher than Belgium and the UK. Coupled with differences in fossil fuel resources, it is important that national level renewable heat policy reflects specific domestic requirements and context.

As mentioned previously, the United Kingdom offers perhaps the closest comparison state to the Republic of Ireland in terms of its distribution of dwelling types. The two countries' close proximity, similar climate and socioeconomic conditions offer an opportunity for a comparative case study analysis based on heating technologies and policies used. This is why we focus on the United Kingdom in detail when analysing low carbon heating policies in Chapter 1. In Table 2.11 we explore the heating technologies applied to constituent countries in the United Kingdom in more detail.

Table 2.11 Heating types across United Kingdom

	England	Wales	Scotland	N. Ireland
Central heating fuel (%)				
Natural gas	85	82	79	24
Electricity	5	4	12	8
Oil	4	10	6	68
Heat networks	2	0	1	0
Other	4	5	2	0
	100	100	100	100
Population (million)	55.9	3.1	5.4	1.9
Dwelling stock (million)	24.7	1.4	2.6	0.8
Population density (p/km^2)	432	154	137	70
RHI accreditations				
Air source heat pump	39,273	2,621	9,888	373
Ground source heat pump	8,966	1,086	1,520	336
Biomass systems	7,478	1,171	3,748	1,073
Solar thermal	6,875	826	1,255	667
Per 100,000 population				
Air source heat pump	70.2	83.5	181.8	19.8
Ground source heat pump	16.0	34.6	28.0	17.9
Biomass systems	13.4	37.3	68.9	57.0
Solar thermal	12.3	26.3	23.1	35.4

Note: for Northern Ireland, the electricity category includes solid fuels and other types of heating. Data sources for central heating type distributions: England (Department for Business Energy and industrial Strategy 2018); Wales (Statistics for Wales 2019); Scotland (Scottish House Condition Survey 2017); Northern Ireland (NISRA 2020). Data for low carbon technologies for Great Britain sourced from Domestic Renewable Heat Incentive accreditations and includes accredited installations covering the period 2014-2020 (Department for Business Energy and industrial Strategy 2020). Data on Northern Ireland RHI accreditations sourced from Department of the Economy NI, (2021). RHI scheme in Northern Ireland was suspended on 29th February 2016.

From Table 2.11 it is clear that natural gas is by far the dominant heating fuel for mainland UK territories. While England is the most densely populated region, we see similar shares of natural gas domestic heating across both Wales and Scotland, which are comparatively much less densely populated. This reflects the significant coverage of the gas grid in Great Britain. By comparison, in Northern Ireland natural gas central heating systems make up just 24% of heating systems, with oil fired systems (68%) being the most popular form of heating. Similar to the Republic of Ireland, electric heating makes up a relatively small proportion of heating types across all four regions, with a larger share of electric heating in Scotland (12%). Heat networks are uncommon across all regions.

Low carbon heating technology uptake remains relatively low across the United Kingdom. As of December 2020, there were approximately 63,318 heat pump installations in Great Britain which were accredited by the domestic renewable heat incentive scheme. The majority of these installations are air source heat pumps, with most installation being in England. On a per capita basis however, Scotland appears to have the highest number of air source heat pumps and biomass installations.

Gross and Hanna (2019) study the underlying reason for the UK's high share of residential gas heating, by comparing the evolution of domestic heating in the UK to that of Sweden. The authors conclude that the remarkable divergence in outcomes can be attributed to path dependent processes whereby increasing returns are experienced when one technology gains an early lead. The economics of the technology paths in the UK and Sweden were different and led to different policy choices. Norwegian hydro electricity was cheap in Sweden whereas in the UK locked-in gas was cheap. Once gas became expensive, the expansion of the network stopped. The rollout of natural gas central heating in the UK was facilitated by the nationally coordinated programme to switch from towns gas to natural gas in the late 1960s and early 1970s. In contrast, in Sweden the oil crises of the 1970's and early climate change policy in the 1990's facilitated the transition to electric resistance heating, district heating and heat pumps. This highlights the importance of early policy intervention in the heat sector. Path dependence in residential heating will be explored in more detail in the subsequent chapter of this paper.

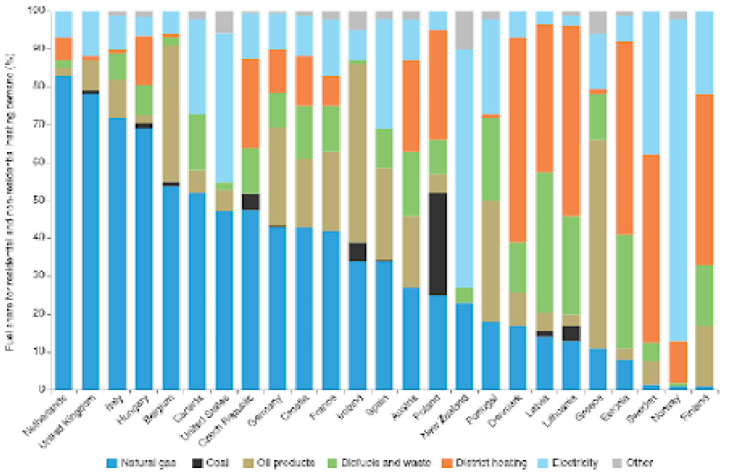

Fig. 1 | Fuel shares for residential and non-residential heating in selected countries. For the United States, data are only for residential fuel shares. Other includes wind, solar, geothermal and peat. Figure adapted from ref. [3], based on data obtained with permission of Vivid Economics and the Department for Business, Energy and Industrial Strategy.

Figure 2.9 Fuel shares for heating - Source (Gross and Hanna 2019)

2.4 Chapter 2 Appendix

Table 2.12 Age of household reference person and tenure status

	Total	≤29	30 - 44	45 - 64	≥65
State	1,697,665	126,963	537,741	637,439	395,522
Own with mortgage/loan	535,675	11,792	252,990	248,219	22,674
Owner occupied without loan/mortgage	611,877	6,020	37,968	248,238	319,651
Rented from Private landlord	309,728	80,533	162,337	57,557	9,301
Rented from Local Authority	143,178	13,183	51,354	55,455	23,186
Rented from Voluntary/Co-operative body	16,765	2,082	5,870	5,326	3,487
Occupied free of rent	27,440	3,526	8,292	7,542	8,080
Not stated	53,002	9,827	18,930	15,102	9,143

Source: Census (2016)

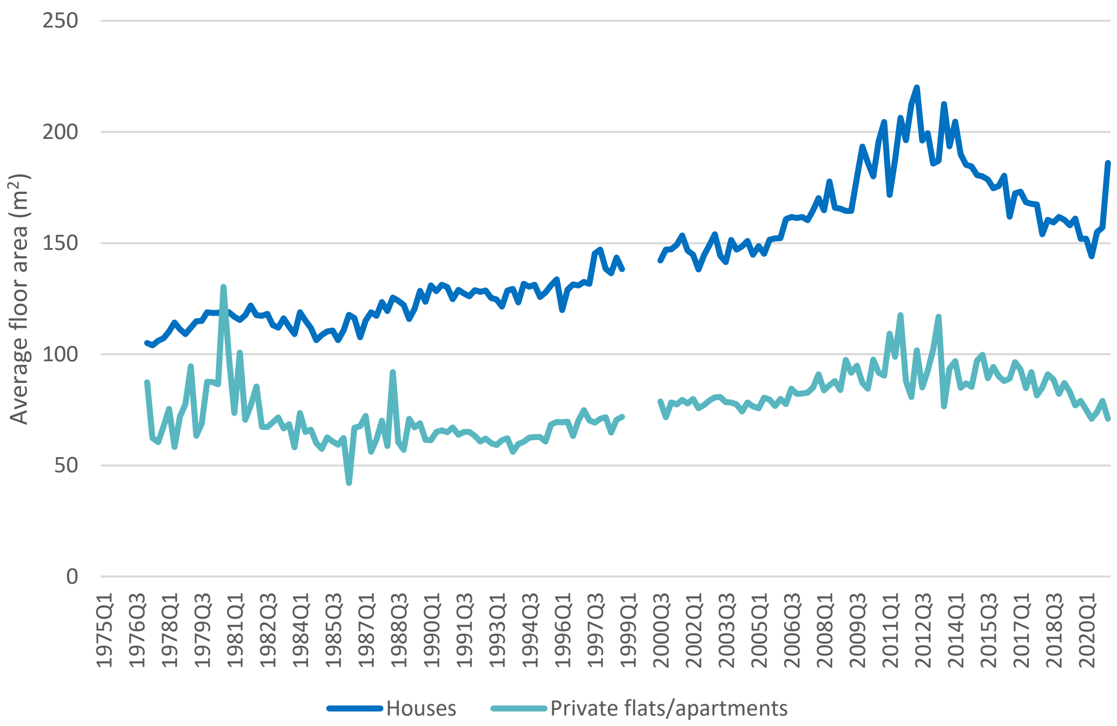

Figure 2.10 Average floor area per unit - planning permission data (1975 - 2020)

3 Technology Adoption

The purpose of this chapter is to identify the main drivers of heating technology adoption. We begin with a discussion of the factors influencing heating technology adoption as identified by the relevant literature. We then review some of the current modelling predictions for future heating technology adoption in Ireland, for some of the technologies identified in the previous chapter. Finally, we provide a discussion on the uncertainty surrounding future residential heating demand, stemming from the impacts of climate change itself as well as an increase in home working resulting from the global COVID-19 pandemic.

3.1 Factors influencing technology adoption

Following a review of the academic literature we identify several common factors which influence heating technology adoption in the residential sector. These are: (1) direct costs such as upfront costs and future energy costs (2) spatial and built environment factors such as dwelling type and location; (3) sociodemographic factors such as age, income and tenure status; and (4) behavioural factors such as time/risk preferences, heuristic decision making and social norms (Mukherjee et al. 2020). In what follows we discuss each of these in turn.

3.1.1 Financial costs

The direct financial costs associated with energy-using technologies and their adoption has long been studied in the economics literature. Since at least the 1970s economists have tried to explain the purchasing behaviour related to energy-using durable goods, and in particular the trade-off between immediate capital expenditure and future energy savings. It is well known that energy using durable goods typically require substantial initial capital investment, and also incur subsequent usage costs. More energy efficient appliances typically have higher capital cost and lower subsequent usage costs. This trade-off implies the use of discounting.

3.1.1.1 Implicit discount rates

Earlier studies on the trade-off between initial investment and subsequent usage costs estimate the implicit discount rates consumers place on the future costs associated with energy using appliances (Jaffe and Stavins 1994a). While these studies do not look at the underlying reasons for this trade-off, the findings suggest that consumers consistently and significantly undervalue future appliance use costs.

Hausman (1979) studies the substitution between higher capital costs associated with more energy efficient air conditioners and subsequent lower usage costs. The findings suggest overall implicit discount rates of 20% on the purchase of air conditioners. Implicit discount rates were also found to vary significantly with income – with higher income individuals having lower implicit discount rates. Lower income individuals were found to have implied discount rates of up to 89%. This suggests that a significant weight is placed by consumers on the initial capital outlay, and this is particularly true among low-income individuals.

> “Yet this finding of a high individual discount rate does not surprise most economists. At least since Pigou, many economists have commented on a "defective telescopic faculty." A simple fact emerges that in making decisions which involve discounting over time, individuals behave in a manner which implies a much higher discount rate than can be explained in terms of the opportunity costs of funds available in credit markets.”
>
> (Hausman, 1979)

Subsequent studies on implicit discount rates in other energy using durable goods report similar results (Table 3.1). Specifically, for household space and heating technologies, Dubin & McFadden (1984) find an implied discount rate of 20.5% at their sample mean income of $16,948, which declines with increased income. The authors offer a possible explanation for this result in that households with lower incomes may be credit constrained, and hence unable to make significant capital investments.

More recent studies on implicit discount rates observe similar results, with significant heterogeneity based on preferences, behavioural biases, external barriers and socio-demographic factors (D. Damigos et al. 2021).

Table 3.1 Early empirical estimates of implicit discount rates

Reference	Energy durable	Implicit discount rate
Hausman (1979)	Air conditioners	20%
Gately (1980)	Refrigerators	45 - 300%
Houston (1983)	Hypothetical energy saving device	22.5%
Dubin & McFadden (1984)	Space and water heating	20%
Ruderman et al. (1987)	Heating, cooling, and residential appliances	18 - 825%

However, other authors have argued that high implicit discount rates associated with energy using durables may be justifiable on the grounds of the risk, transaction costs and the illiquid/irreversible nature of such investments (Hassett and Metcalf 1993; Sutherland 1991). This may be particularly true for technologies such as central heating systems and insulation – where capital investments cannot be easily liquidated. Future payoffs may also be uncertain due to the uncertain nature of future energy prices (Sutherland 1991). In addition, if appliances convey when the occupant moves home (are left behind in the dwelling) this may discourage investments in efficiency, if these investments are not fully capitalized in home prices. Sandler (2018) finds evidence that consumers purchase less expensive refrigerators and clothes washers when these appliances convey to new owners.

3.1.1.2 Upfront costs and liquidity constraints

The earlier literature on implicit discount rates suggests that when it comes to energy-using durable goods, consumers tend to significantly undervalue future energy costs – and hence place more emphasis on short term or immediate costs. The upfront and immediate nature of heating system expenditure itself is also a significant barrier to adoption. For example, for Ireland, Mukherjee et al. (2020) find that the initial cost associated with heat pump installations was a major barrier cited by non-adopters. Findings from Italy by Troiano et al. (2019) mirror this, with initial system cost proving to be the most important factor in determining adoption. Using an agent-based modelling approach Meles & Ryan (2020) find that altering upfront costs through subsidies influences the adoption of heat pumps substantially. Higher grants encourage more consumers to purchase heat pumps.

The significant upfront costs of energy-using durable goods require that households have liquid assets (cash) which can be invested in such appliances. For example, the average heat pump in the Republic of Ireland as of 2021 costs between €8,500 – €14,500 for the heat pump installation alone (Electric Ireland 2021). If households do not have cash on hand to cover upfront costs, they will need to borrow to finance investment. Lack of access to credit may therefore hinder investment, particularly among lower-income groups or those who have poor credit histories (Gillingham and Palmer 2014). The extent to which liquidity constraints hinder the uptake of low-carbon heating technologies remains relatively unexplored, however some studies have suggested that loan programs have reached only a small subset of eligible property owners (Palmer et al. 2012).

3.1.1.3 Heterogeneity in energy consumption

If a given technology is profitable on average, it does not mean that it will be profitable for the entire distribution of energy users. Significant heterogeneity in energy consumption may imply that for some households, investments in energy efficiency and low-carbon heating technologies may be un-profitable. For example, McCoy & Kotsch (2018) find that returns to energy efficiency investments are much smaller for households in more deprived areas, and for certain measures the savings erode more quickly over time. For Ireland, Coyne et al. (2018) find that lower income households obtain lower returns to energy efficiency investment. This is driven in large part by substantial under-heating by occupants pre retrofit, which deviates significantly from the assumed heating behaviour that is used to model the Building Energy Rating (BER) for the household. Additional systematic differences between current and future adopters of energy efficiency and low-carbon heating technologies may further bias projected future energy savings upwards (Gerarden et al. 2015).

3.1.1.4 Household energy prices and expenditure

Energy prices are an important determinant of heating technology adoption. Low fossil fuel prices hinder low carbon heating technology adoption by lengthening payback periods. While household electricity prices in the Republic of Ireland were fourth highest in the EU[24] in terms

[24] The weighted average price of electricity to households in Ireland for the first half of 2021 was 7% above the EU average and 1% above the Euro Area average. Gas prices for the same period were 5% below the EU average and 10% below the EU Area average (https://www.seai.ie/data-and-insights/seai-statistics/key-statistics/prices/).

of total household expenditure, electricity and gas costs represent a relatively smaller share. Energy prices have risen substantially in the previous 3 years up to 2022 and may drive consumers to invest in more efficient heating technologies. However, this is offset by reduced real disposable income caused by rising inflation and therefore consumers have less capacity to invest in retrofits or heating technologies with higher upfront costs even if the operational costs are lower than other technologies.

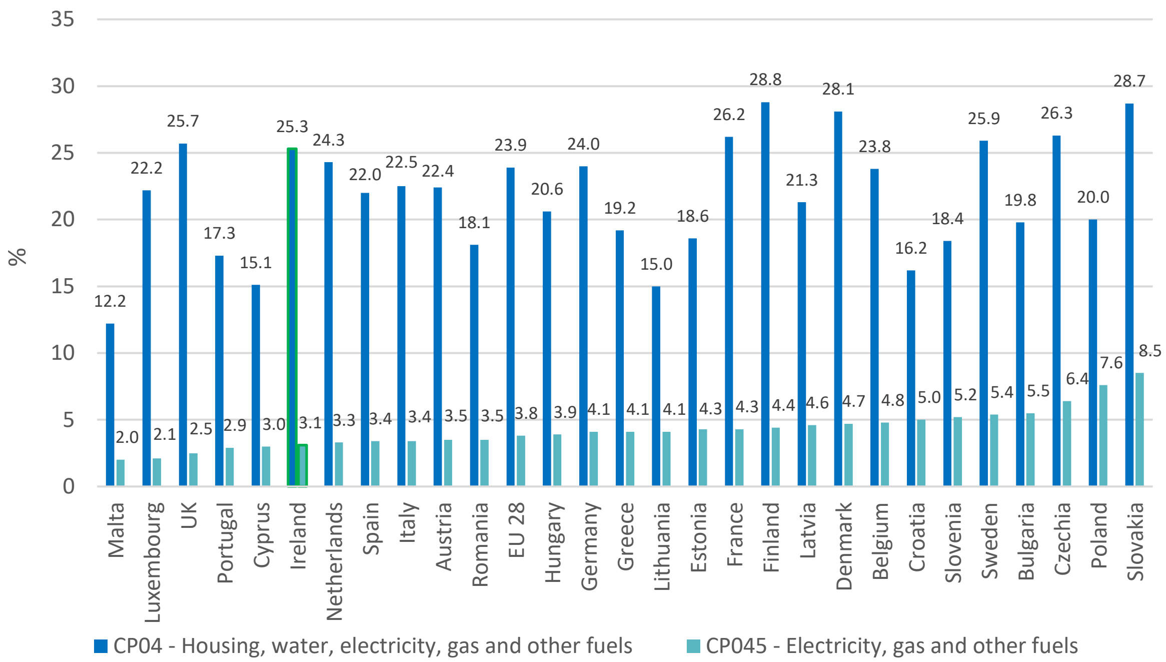

Figure 3.1 Share of household consumption expenditure for housing, water, electricity gas and other fuels 2019 (Source: Eurostat, 2021) [25]

Figure 3.1 illustrates that Ireland ranked 6th lowest in terms of share of total household expenditure allocated towards energy costs in 2019, more recent data is not yet available. When included with other housing costs however, we see a reversal in trends, with Ireland ranking as the country with the 8th highest spend on total housing costs (inclusive of energy). This illustrates that while total housing expenditure is relatively high, total energy expenditure

[25] Eurostat (2021) Table [nama_10_co3_p3: Final consumption expenditure of households by consumption purpose (COICOP 3 digit). Accessed February 2022. https://appsso.eurostat.ec.europa.eu/nui/show.do?query=BOOKMARK_DS-423035_QID_2E5A46AA_UID_-3F171EB0&layout=COICOP,B,X,0;GEO,L,Y,0;UNIT,L,Z,0;TIME,C,Z,1;INDICATORS,C,Z,2;&zSelection=DS-423035INDICATORS,OBS_FLAG;DS-423035TIME,2019;DS-423035UNIT,PC_TOT;&rankName1=TIME_1_0_-1_2&rankName2=UNIT_1_2_-1_2&rankName3=INDICATORS_1_2_-1_2&rankName4=COICOP_1_2_0_0&rankName5=GEO_1_2_0_1&rStp=&cStp=&rDCh=&cDCh=&rDM=true&cDM=true&footnes=false&empty=false&wai=false&time_mode=NONE&time_most_recent=false&lang=EN&cfo=%23%23%23%2C%23%23%23.%23%23%23

has historically been relatively low in comparison with other European countries. Given the reliance of domestic heating on fossil fuels however, and the recent increases in energy prices this ranking may be altered.

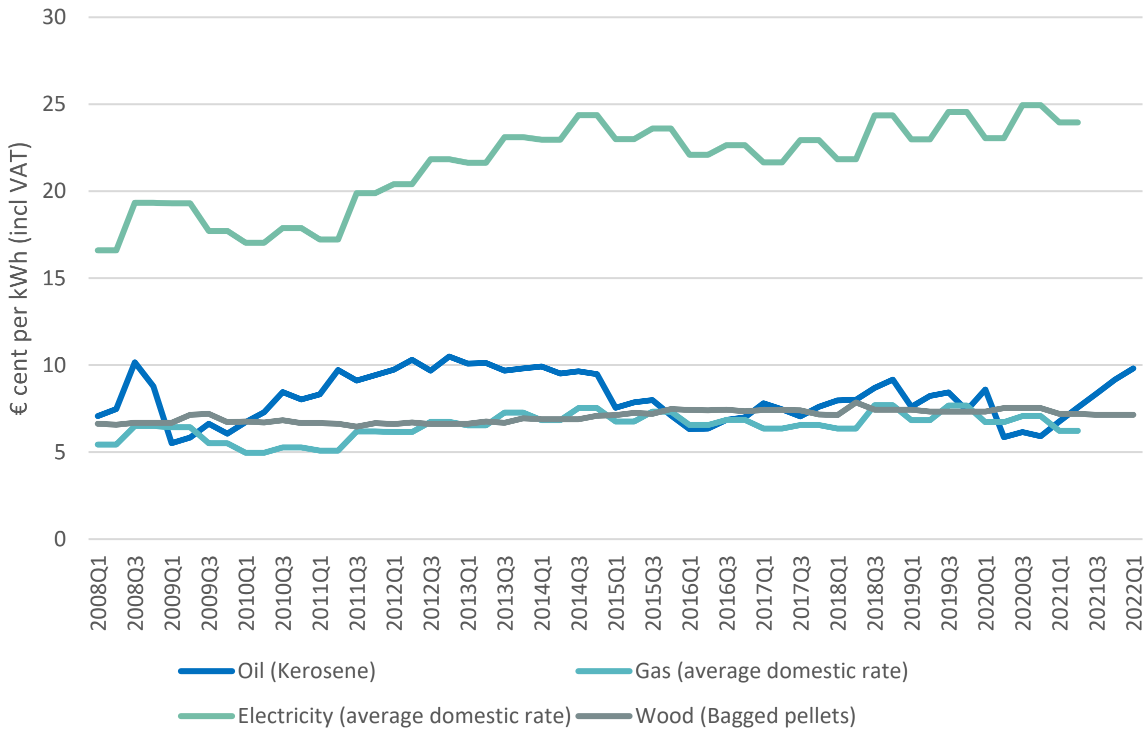

Figure 3.2 Irish household fuel price comparison (Source: SEAI)[26]

From Figure 3.2 it is clear that the per kWh prices of fossil fuels such as natural gas and oil (inclusive of VAT) are significantly lower than electricity prices. In addition, while in the long-term electricity prices appear to be increasing,[27] fossil fuel prices remained stagnant over the decade between 2008 and 2018. In the case of heating oil, prices in 2020 were at their lowest since 2009, however have since seen an increase beginning in 2021.[28] The continuing divergence of prices between electricity and fossil fuels may act as a barrier to electric heating system uptake, and comparatively lengthen electric heating payback periods.

[26] Source: https://www.seai.ie/data-and-insights/seai-statistics/key-statistics/prices/
[27] https://www.rte.ie/news/business/2021/0401/1207389-price-hikes-from-energy-suppliers-take-effect-in-april/
[28] https://www.irishexaminer.com/news/politics/arid-40699799.html

3.1.2 Spatial and built environment factors

As illustrated in Chapter 2, dwelling characteristics such as type, size and location are important predictors of heating technology adoption. The current distribution of dwelling types has undoubtedly influenced the heating technologies currently in place. The high share of detached and semi-detached houses, coupled with significant geographic dispersion has dictated that each individual dwelling has its own, separate heating system. This is the likely reason why we see a historically low uptake of localized or district heating systems (such as earlier generation district heating systems). In addition, the menu of heating technology options is often constrained by location characteristics and in particular by access to the gas grid. Other dwelling characteristics which have been found to be important in influencing low carbon heating technology adoption are listed in Table 3.2.

Table 3.2 Spatial and Built Environment Factors

Factor	Impact on low-carbon technology adoption
Current heating system type/path dependency	Current heating type may be a significant predictor of future heating system. In addition, there may be significant path dependency in residential heating (Gross and Hanna 2019). Heat pumps are more likely to be adopted by households which have oil or electricity (Caird and Roy 2010, Michelsen and Madlener 2011; Jensen 2015).
Current heating system age	End of life heating systems more likely to be replaced for existing dwellings. Typical lifetime of a gas/oil boiler 15 – 20 years (Aste et al. 2013; CIBSE 2014).
Size of dwelling	Larger dwellings significantly more likely to adopt heat pumps (Caird and Roy 2010; Meles and Ryan 2020; SEAI 2020c).
Building energy rating	A minimum level of energy performance is required in order to install heat pumps (SEAI 2020a) and 4GDH (IrBEA 2016; Lund et al. 2014). Those unaware of their own BER less likely to adopt heat pumps (Mukherjee et al. 2020).
Location	Significant heterogeneity in current heating systems in urban and rural environments (due to limitations of the gas infrastructure) (Curtis et al. 2018). However not all dwellings currently within range of the gas network are connected.

Note: adopted and expanded from (SEAI 2020c)

The current heating system type may be a strong predictor of the future heating system a household will choose. In addition, country level differences in outcomes in terms of heating technology distribution may be the result of path dependent processes. Path dependence can occur where a series of often incremental changes lead to a large divergence in outcomes. Gross & Hanna (2019) find significant path dependencies when comparing residential heating in the UK and Sweden. While in Sweden oil heating has largely been replaced by district heating and heat pumps, the residential heating market in the UK is largely dominated by natural gas.

The authors argue that this incredible divergence in outcomes may be the results of increasing returns to particular technologies or systems. As a particular technology gains an early lead (e.g. gas in the UK), its cost or performance attributes accelerate leading to further uptake and the coevolution of supporting infrastructures or networks. This increasing returns effect may make other technologies comparatively much less favourable, leading to the proliferation of one particular technological solution.

There are three categories of increasing return which Gross and Hanna (2019) identify as relevant to heating technology uptake: scale and learning economies; adaptive expectations and network externalities.

- **Scale and learning economies** arise where increasing production leads to a fall in the unit price or improvement in quality of a technology, either through scale economies or through learning by repetition and experience.
- **Adaptive expectations** occur where the uncertainty of performance or reliability of a particular technology is diminished as more consumers adopt a leading technology – further leading to further uptake.
- **Network externalities** occur where technologies are linked and need to be compatible with a wider network of constituent technologies and supporting infrastructure. These are sometimes referred to as co-ordination effects.

Gross and Hanna (2019)

A comparable example comes from the transport sector, where the dominance of the internal combustion engine (ICE) can be seen as a path-dependent process. At the turn of the 20th century electric vehicles represented a larger market share than ICE in the United States, however a lack supporting infrastructure (few private homes even in cities at the time had electricity (Woolf 1987)) and several technological developments in internal combustion engines (such as the elimination of the hand-crank by the electric starter motor) established the dominance of ICEs which further accelerated their technological development (Foster et al. 2021; Kirsch 1997). More recently Aghion et al. (2015) also find significant path dependence in the automobile market today, with firms which face higher tax-inclusive fuel prices tending to innovate more in clean (and less in dirty) energy technologies.

The implications for policymakers interested in altering heating system adoption is therefore that early intervention can have significant impacts on future outcomes through path dependence and increasing returns. It is therefore vital that socially optimal heating technologies are targeted, and perhaps it can be argued that policies which are technology neutral may be favourable in order to avoid unintended future outcomes.

3.1.3 Sociodemographic factors

Sociodemographic characteristics can also substantially influence heating technology adoption. For example, as discussed in the previous chapter young, and old age may be a barrier to retrofit or heating system upgrade. While these factors may or may not be linked to market or behavioural failures, they can give us an insight into the types of individuals who may be more/less likely to adopt low carbon heating technologies. We list some of these factors and their influence on adoption below:

Table 3.3 Sociodemographic factors and technology adoption

Factor	Impact on low-carbon technology adoption
Income	Higher income individuals more likely to adopt efficient appliances (Allcott et al. 2015). Middle class households more likely to be early adopters of low-carbon heating technologies (Caird and Roy 2010)
Age	Younger (under 35) more likely to adopt in a hypothetical setting (Mukherjee et al. 2020). Older for actual early adopters (Caird and Roy 2010)
Education	Higher education correlated with adoption (Michelsen & Madlener; Mukherjee et al., 2020)
Residence period	Longer residence periods associated with increased probability in adoption (Mukherjee 2020)
Home ownership	Owner occupiers significantly more likely to adopt renewable energy technologies (Mukherjee et al. 2020). Rental properties are found to be less energy efficient than comparable non-rental counterparts (Petrov and Ryan 2020)

As mentioned previously, a growing lack of home ownership in particular may be significant barrier to low carbon heating technology uptake. In the energy economics literature, this is typically referred to as the "*Landlord-tenant problem"* and is considered to be a market failure.[29] There are two components to the problem – split incentives and information asymmetries. Split incentives arise from the fact that the party responsible for energy efficiency investments or energy conservation does not necessarily obtain a direct return from such actions. This comes about from the energy bill-paying arrangement between landlords and tenants (Figure 3.3). Information asymmetries arise when one party in the transaction holds more information that the other party. In the case of the landlord-tenant problem, the landlord will typically have more information on the efficiency of the property than a prospective tenant. Energy performance certificates such as the Building Energy Ratings (BER) were introduced in order to correct for information asymmetries, by providing objective information on the efficiency of the property to prospective buyers.

[29] A market failure occurs where markets do not lead to the optimal/efficient allocation of resources.

	Occupant OWNS dwelling	Occupant RENTS dwelling
Occupant PAYS for energy use	(1) No split incentives	(2) Efficiency problem
Occupant DOES NOT PAY for energy use	(4) Both	(3) Usage problem

Figure 3.3 Taxonomy of landlord-tenant problem split incentives

Figure 3.3 illustrates the split incentive problem. In cases where tenants are responsible for energy related utility bills, landlords have an incentive to underinvest in energy efficiency, since the returns to such investments accrue to the tenant(s) in the form of reduced energy bills. In the absence of significant rental premiums to efficiency landlords will not invest in significant energy efficiency improvements. This is typically referred to as the "*Efficiency problem". *Petrov and Ryan (2021) find evidence of the efficiency problem in Ireland using BER data – rental properties are less efficient than their comparable non-rental counterparts, and this difference appears to be bigger in cities. This might suggest that low-carbon heating options which require less investment/involvement by the landlord or tenant may be preferable to decarbonize heating for rental properties.

On the other hand, if energy bills are included in rental prices and are fixed (scenario (3) in Figure 3.3) this may lead to an overconsumption of energy, since tenants do not face the marginal costs associated with energy use (Levinson and Niemann 2004).

3.1.4 Behavioural factors

Earlier studies which look at implicit discount rates merely observe this as an empirical phenomenon, however more recent behavioural economics literature has provided numerous explanations as to why consumers may substantially undervalue future energy costs. Gillingham et al. (2009) highlight that energy efficiency investments may be hindered by consumer behaviour, which is inconsistent with utility maximization, or in this context, energy cost minimization. As summarized by Schleich et al. (2016) behavioural patterns which may explain this under-investment include time/risk preferences, bounded rationality, rational inattention and various other behavioural biases. While these factors may not necessarily represent market failures, they at least in part explain consumer behaviour in relation to energy using technology adoption. In a behavioural insights paper SEAI (2020a) carry out a more complete review of behavioural factors linked specifically to heat pump technology adoption for Ireland. Some behavioural factors which can be linked to low carbon heating technology adoption and investments in energy efficiency in general are presented in Table 3.4 below.

Table 3.4 Literature of behavioural factors on technology adoption

Factor	Impact on low-carbon technology adoption
Present bias	Decreases the emphasis placed on future costs – may partly explain observed excessive implicit discount rates.
Bounded rationality/heuristic decision making	Decision making based on "rules of thumb". May contribute to undervaluing of future energy savings, and or overvaluing of upfront costs.
Loss aversion/prospect theory	Loss averse individuals are less likely to undertake investments in general and are also found to be less likely to invest specifically in energy efficiency upgrades (Heutel 2019).
Awareness	Lack of awareness or trust in heat pump technology may be a significant barrier to uptake. (Charistas and Chronopanitis 2017; Michelsen and Madlener 2016) A lack of informed suppliers may be contributing factor.
Administrative burden/"Sludge"	Lades et al. (2021) find that administrative burden in obtaining grant supports is one major reason for low levels of uptake of economically beneficial energy investments, particularly when coupled with present bias preferences.
Functional reliability of the system/perceived reliability/trust	Mahapatra and Gustavsson (2008) find this to be an important factor for households considering a new heating system in Sweden. Sopha et al 2015 also find functional reliability to be an important consideration for wood-pellet heating in Norway.
Disruption/peak-end rule	Significant disruption due to retrofit or heating system upgrade may be a barrier to adoption. In addition, negative experiences during the installation process may bias consumers perceptions of the technology (Owen et al. 2013), and therefore their likelihood to recommend it to others.

3.2 Technology Adoption Modelling Predictions

In this section, we briefly explore some of the modelling predictions for low-carbon heating technology adoption which have been carried out specifically for the Republic of Ireland. We explore studies in relation to heat pumps, decarbonized gas and district heating systems.

3.2.1 Heat pumps

Meles & Ryan (2020) develop an agent-based model to analyse the adoption process of heat pump systems and their potential underlying diffusion factors. An agent based model is a computer simulation of a number of decision-making units (agents) and institutions which interact through a set of prescribed rules (Farmer and Foley 2009). Heterogenous agents are created using data from a nationally representative sample survey (Mukherjee et al. 2020). Each agent is characterized by several attributes that are assigned from survey data and secondary data (e.g. building characteristics, location, pro-environmental behaviour, risk-taking behaviour and the number of energy peers). The model comprises 933 agents in total, which are separated into 8 distinct regions. Financial aspects, psychological factors, and the influence of social networks are considered.

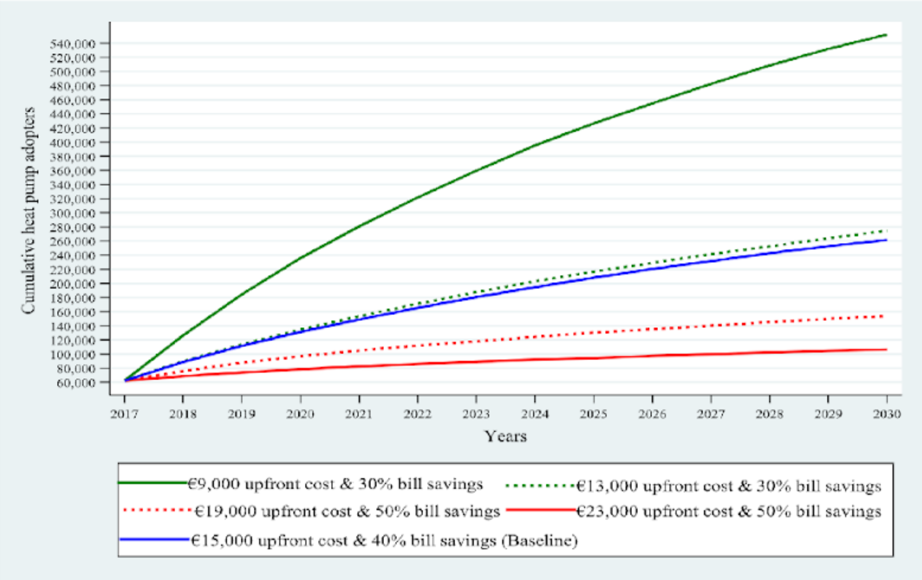

Figure 3.4 Sensitivity analysis of heat pump adoption to changes in upfront costs (Source: Meles & Ryan, 2020)

The results suggest that homeowners, households in Dublin County, households with higher education and a larger number of bedrooms are more likely to adopt a heat pump. Sensitivity analyses also show that adoption is highly sensitive to changes in upfront costs (e.g. Figure 3.4) suggesting that upfront grant support may be an important determinant of uptake.

3.2.2 Decarbonised gas

A report carried out on behalf of Ervia by KPMG (2018) analysed several decarbonization scenarios for homes connected to or in range of the gas network (approximately 1m homes in Ireland). The three scenarios analysed were: gas decarbonization using biomethane only (100% biomethane); gas decarbonization using biomethane and hydrogen (90% biomethane, 10% hydrogen) and electrification of heat (100% electrification using heat pumps). The findings suggest that the biomethane only, and biomethane and hydrogen blend solutions may be less expensive on a cost per household basis, however significant investments in new anaerobic digestion plants would be needed with associated policy support mechanisms. This work builds on an economic assessment of Biogas and Biomethane for Ireland (SEAI 2017) which suggests that up to 28% of Ireland's gas supply (in 2015) could be met by biogas by 2050, with the majority coming from grass silage resource.

A recent study by O'Connor et al. (2021) surveys Irish cattle farmers to assess the potential for on-farm anaerobic digestion uptake. The study finds 41% of the 91 survey participants were interested in installing AD on their farms in the next five years. The major barriers to uptake cited were the significant upfront investment and a lack of information regarding the technology, while potential improvement in farm profitability was considered to be the greatest perceived benefit.

According to a report carried for the European Commission, Ireland has been identified as the market with the highest potential for growth in biogas production to 2030, primarily due feedstock availability (European Commission 2017). However, due to the relative lack of dedicated studies, further work is necessary to determine the potential for biogas specifically for the heating sector in Ireland, and whether or not it may be strategically better suited to reduce emissions in other difficult to decarbonize sectors (e.g. transport and industry).[30]

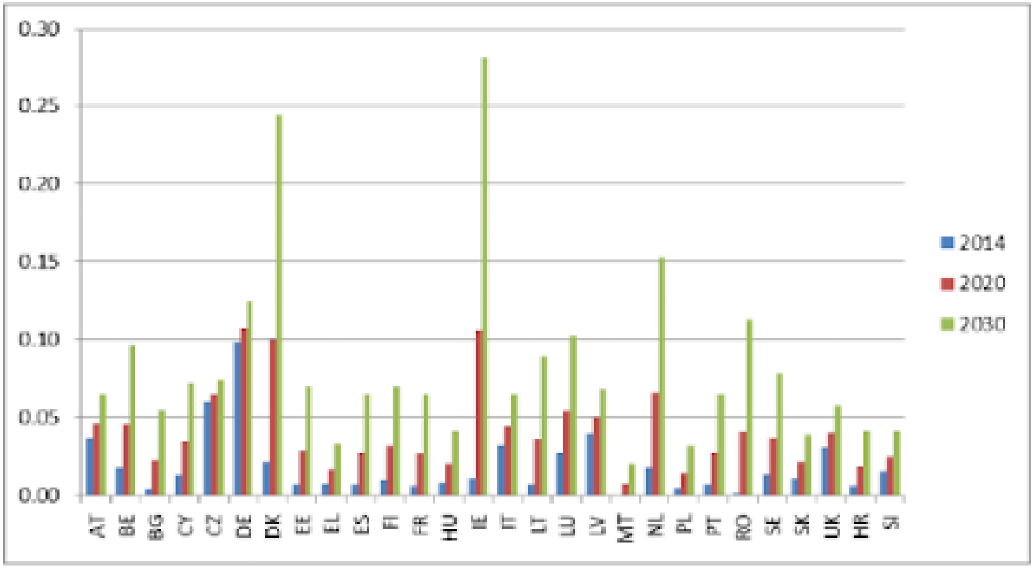

Figure 3.5 Growth of biogas production per Member State in ktoe/1,000 inhabitants (Source: European Commission (2017))

3.2.3 District heating

A recent report published by Renewable Energy Ireland (2021) has outlined an ambitious agenda to achieve emissions reductions through the use of established renewable heat technologies. Their analysis notes that Ireland could achieve a realistic and practical milestone of 40% of heating being attributed to renewable sources. This would provide greater energy independence (through lower reliance on imported fossil fuels) and contribute towards achieving the economy-wide target of an annual 7% reduction in CO_2 emissions (DECC 2020).

A key pillar of this initiative is the widespread use of district heating, which would conservatively meet 10% of national heat demand in 2030, despite 56% of heat demand being feasible with current district heating or the latest 4GDH (Renewable Energy Ireland 2021

[30] https://www.gasnetworks.ie/corporate/news/active-news-articles/irelands-first-journey-biogas-bus/

p.29). Of this 56%, 35% is in urban areas, with the remainder in suburban spaces. In their analysis, district heating would meet over half of the heat demand in high heat density areas in Dublin, Cork, Limerick and Drogheda (Co. Louth) (Renewable Energy Ireland 2021). Importantly, this implies that almost 44% of heat demand requires a different low carbon solution.

District heating networks could be powered with high-temperature surplus heat from waste-to-energy, power plants, data centres and industry. Currently, power plants do not harness substantial volumes of waste heat as a by-product, which has been estimated at roughly 40% of their fuel input (Renewable Energy Ireland 2021 p.26). Figure 3.6 highlights how points of excess heat from industry, waste-to-energy and power plant could supply areas across the entire country. There is also a role for medium-temperature district heating networks using data centre waste heat that is boosted by electric heat pump. Remote locations with sufficient heat demand could be met by a biomass-fuelled network. Chapter 4 of this report will look at district heating potential in more detail.

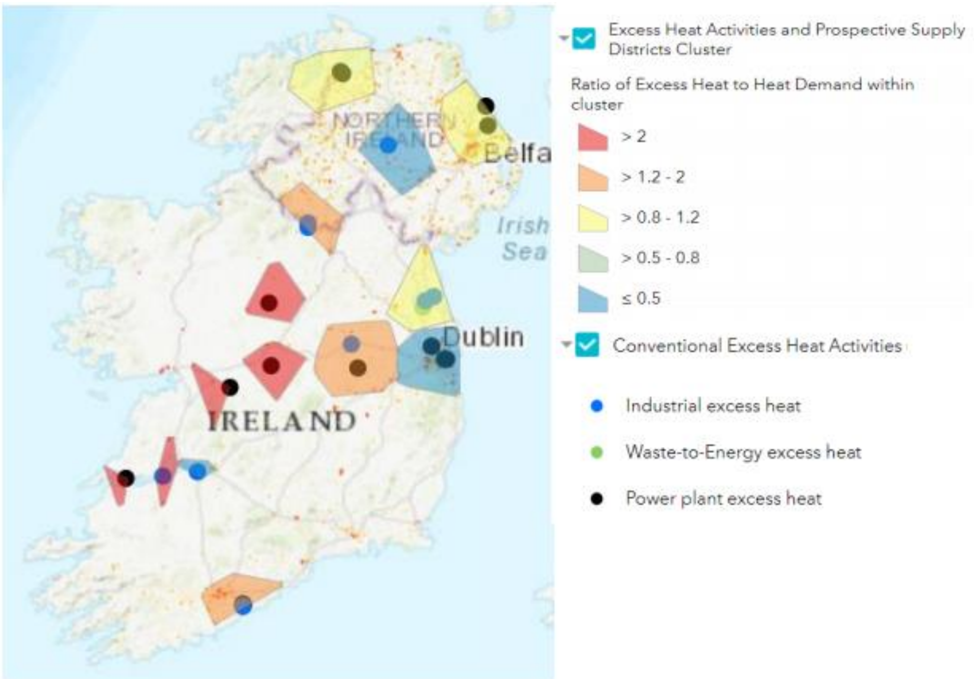

Figure 3.6 Points of industrial excess heat activity and potential supply areas (Renewable Energy Ireland, 2021)

3.3 Changing nature of future heating demand

Residential heating (and cooling) demand is closely related to local climate conditions. Ireland's relatively mild year-round climate and lack of extreme cold (or hot) weather historically has dictated both building construction and heating demand. However, climate change itself will likely alter residential energy demand for heating and cooling – with subsequent impacts on technology adoption. In addition, residential heat demand is fundamentally shaped by dwelling occupancy patterns, which have been influenced by the COVID-19 pandemic and the associated increase in home working. We discuss both of these forces and their potential impact on residential heating demand in turn.

3.3.1 Impact of climate change on heat demand

There appear to be two main ways in which climate change will impact heat demand in Ireland. Firstly, due to increasing average temperatures it is expected that overall heat demand will fall. Liu & Sweeney (2008) forecast that if temperatures increase by 1° Celsius this will correspond to a decrease in energy demand for space heating of 8% in the greater Dublin region, with insulation standards held constant to 2008 levels. However, with improved insulation standards this figure increases to between 15 and 28%. Findings by Semmler et al. (2010) for the entirety of Ireland confirm this, with predicted decreases in heating degree days of 10±3% for 2021-2060 and 22±3% for 2061-2100 relative to 1961-2000. In addition, the authors find that the increase in cooling degree days may intensify a currently weak demand for air conditioning in the summer.

The second way in which climate change will likely influence heating demand is through increase in the frequency and severity of extreme weather events. Extreme weather events may take the form of heatwaves such as the recently observed one in July 2021.[31] [32] However,

[31] https://www.irishexaminer.com/news/arid-40344335.html

[32] https://www.gov.ie/en/press-release/d4897-irelands-weather-in-2020-indicates-further-evidence-of-climate-change-says-met-eireann/

climate change is also expected to bring about increased rainfall and changes in wind speeds and storm tracks that increase disruptions to both transport and electricity supply.

One particular extreme weather event in recent history which caused significant disruption was storm "Emma" which occurred in early March of 2018 and coincided with a cold spell driven by a Sudden Stratospheric Warming (SSW) event dubbed "the beast from the east" (Met Eireann 2019).[33] This combination of events caused temperatures to fall to record lows and brought about widespread snowfall across the country. Coupled with strong winds it effectively brought the country to a standstill with closures of schools and businesses and significant disruption to transport. At its peak, 117,000 premises were without power.[34]

While it is still unclear whether cold spells caused by SSW events will become more frequent or severe as a result of climate change in the future, increases in the number of severe storms will likely continue to cause disruptions to electricity supply. According to ESB Networks (2019) the number of unplanned outages is already experiencing a steady increase (Figure 3.7), primarily due to an increase in the number of storm days. This may present a challenge to the electrification of heat in the future, since heat demand is likely to be correlated with such events. Ensuring that the electricity network is resilient to the effects of increased storm activity will be necessary to convince consumers to electrify both heat and transport.

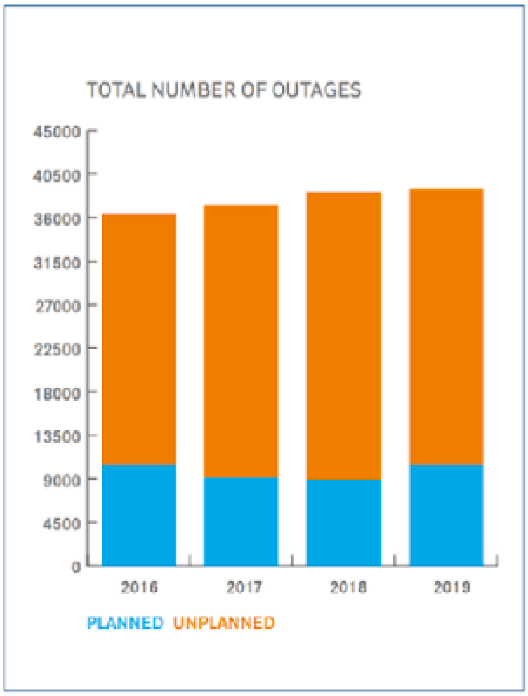

Figure 3.7 Power Outages (Source: ESB Networks 2019)

[33] Conclusive evidence as to whether or not the frequency or severity of SSWs will be affected by climate change is still unavailable, though some scientists suggest that it may be linked to arctic amplification https://www.carbonbrief.org/explainer-polar-vortex-climate-change-and-beast-from-the-east

[34] https://www.thejournal.ie/storm-emma-power-update-3880853-Mar2018/

3.3.2 Impact of transition to working from home

The transition to working from home (WFH) as a result of the COVID-19 pandemic appears to have had an overall negative effect on total energy demand, driven primarily by a reduction in transport/commuting. However, residential energy demand for heating may increase if people continue to spend significantly more time at home – particularly during winter months. In a commentary, IEA (2020) estimate that a day of working from home could increase household energy consumption by between 7% and 23% compared to a day working at the office, depending on regional differences, the size of homes, appliances and efficiency.

While it is unclear exactly how, when and whether the global COVID-19 pandemic will end, one of its legacies is likely to be a significant and persistent shift to remote working. In a recent paper titled: "*Why working from home will stick*" Barrero et al. (2021) explore this issue using survey data from the US over multiple waves.

The findings suggest that 20% of full workdays will still be supplied from home after the pandemic ends, compared to just 5% beforehand. The authors develop evidence on five reasons to explain this persistence, which include: new investments in physical and human capital that enable working from home (WFH); better-than-expected WFH experiences; greatly diminished stigma associated with WFH; lingering concerns about crowds and contagion risks, and a pandemic-driven surge in technological innovations that support WFH.

In a survey carried out by Mccarthy et al. (2020) which looks at the impact of remote working due to COVID-19 specifically for Ireland, the vast majority of respondents (94%) indicated that they would like to continue to work remotely after the crisis. In a survey of European countries by Eurofound (2020) Ireland had one of the largest shares of employees working from home in April 2020 (48%). The National Remote Work Strategy published by Department of Enterprise, Trade and Employment (2021) has indicated a right for employees to request remote work from their employers.

Exactly how the transition to working from home has, and will, affect Irish residential heat demand is still relatively unexplored. However, findings from the UK (Mehlig et al. 2021) suggest that domestic gas demand did not change during the first national lockdown (March-June 2020) however increased by 6% for the second national lockdown (November 2020). The daily pattern of electricity demand changed in both lockdowns, with weekday demand shifting to a patten which resembled a pre-pandemic weekend. Findings from Poland mirror this, with an increased, but smoother electricity demand profile during the day in lockdown (Bielecki et al. 2021).

While these studies focused on electricity, if heat demand follows a similar pattern throughout the day, this may have significant implications for heating technology choice. A longer and smoother heating demand profile is very suitable for a heat pump – which is typically designed to run for long periods of time and responds slowly to temperature changes (CSE 2021; SEAI 2019b).

A secondary effect of the transition to home working on energy demand and technology adoption may come from the relocation of workers. A significant portion of respondents in McCarthy et al. (2020) indicated that they would relocate (23%), may consider relocating (16%) and have already relocated (7%) due to their experience of remote working. This appears to be primarily driven by respondents from Dublin and surrounding counties with the intent to move to more rural areas and may already be reflected in house price inflation.[35] This may shift heating demand away from the capital and into more rural areas, with corresponding implications for the mix of low carbon technology option available.

[35] Property prices have been rising faster outside the capital city:
https://www.irishtimes.com/business/economy/house-prices-rise-at-fastest-rate-in-2-years-1.4620239

4 District Heating

This chapter features a review of progress to date in the use of low-carbon district heating. It considers policies and operational systems in other countries and highlights some of the most effective policies, with a view towards their ability for Ireland to deliver on 2050 climate goals.

4.1 Understanding District Heating

District energy is an inclusive term for the provision of heating and cooling in urban settings through a network of insulated water pipes. District heating encompasses a variety of systems that vary in size, thermal capacity, technology, network length and are subject to local design requirements (Sayegh et al. 2018). This broad definition encompasses almost 6,000 networks across Europe (Connolly et al. 2014). This chapter focuses on current district heating applications and future prospects.

In principle, a network provides space and water heating to buildings, while being fuelled by a diverse range of low-carbon and renewable heat sources, including conventional generation, heat pump, biomass, waste-to-energy and waste heat (Renewable Energy Ireland 2021; State of Green 2018). This diversity can provide security of supply while also improving the efficiency of the energy system by capturing waste heat. Figure 4.1 illustrates potential examples, including power generation, industrial processes, data centres and wastewater treatment. This can meet heat demand in residential, commercial and public buildings.[36]

[36] See: HeatNet NWE (2020): https://guidetodistrictheating.eu/about/what-is-district-heating/

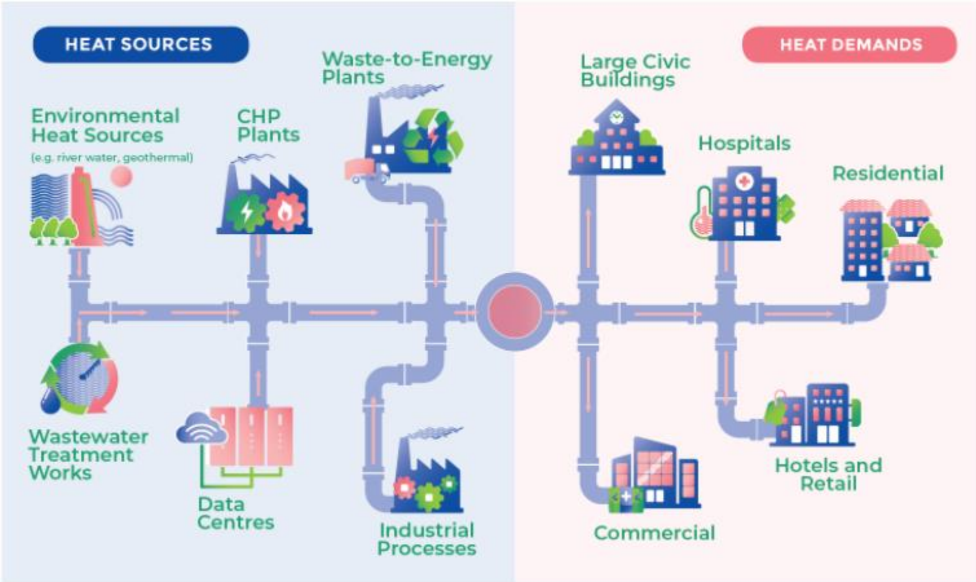

Figure 4.1 District Energy Infographic (Source: HeatNet NWE)

Capturing waste heat is a substantial opportunity for district heating. As part of the Heat Roadmap Europe project, Persson et al. (Persson et al. 2014) identified areas of excess heat from fuel combustion for district heating. They estimate that 46% of waste heat in the EU27 region across 63 strategic heat synergy regions could be reused, provided that correct incentives are in place. This equates to almost a third of total building heat demands in identified regions. The authors note that availing of this opportunity requires a high recognition of the heat sector in policy and a proper valuation of the benefit of waste heat reuse. From this standpoint, the value of waste heat is intrinsically linked to the price of emissions.

The rest of this chapter presents an overview of district heating across Europe, details the development of district heating technology, including the latest fourth generation. It outlines Ireland's position on this journey, including a description of projects underway and potential for expansion. Finally, this chapter focuses on the lessons for success from countries where district heating has been implemented.

4.1.1 District Heating across Europe

In 2012, district heating accounted for 9% of EU heating (European Commission 2016). As part of the Heat Roadmap Europe project, Connolly et al. (2014) explore the potential for district heating to achieve EU-level climate targets in comparison with electrification strategies outlined in *Energy Roadmap 2050* (an initiative to attain an 80% reduction in annual greenhouse gas emissions in 2050, compared to 1990 levels (European Commission 2011)). They note that roughly 6000 separate district heating systems account for 13% of total heat supply for final consumption in EU27 residential and service sector buildings.

A technical and economic feasibility study notes that district heating (fuelled by recyclable heat from thermal power plant, waste-to-energy facilities and industrial processes) could help achieve the EU *Energy Roadmap 2050* target while costing roughly 15% less for heating and cooling, compared to the high electrification scenario (Connolly et al. 2014). More recent work focused on the residential sector has noted that although district heating provides an average of 24.5% of heat supply in the EU (Figure 4.2), it masks significant country-level differences where countries like Denmark source almost sixty per cent of their residential heat from district heat, while countries like the Netherlands, UK and Ireland lag far below the average for EU countries with district heat, with shares of 4.1%, 2.1% and 0.1%, respectively (Sayegh et al. 2018).

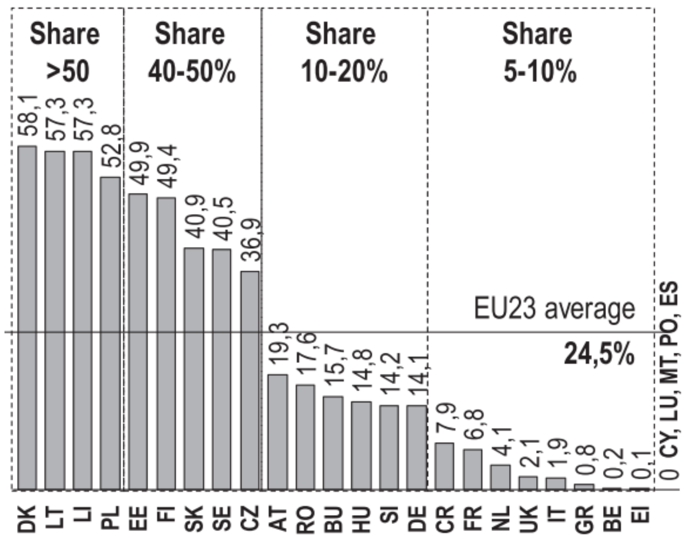

Figure 4.2 2012 Share of residential heat supply from district heating (Sayegh et al. 2018)

4.1.2 A Timeline of District Heating

District heating has been used for meeting the space and water heating needs of buildings networked in urban settings for more than a century. However, historical systems have often required high-temperature input and featured substantial heat losses. Table 4.1 presents an overview of the key features of past and current district heating networks (Lund et al. 2014). Improved technology in modern systems feature far lower temperature heating requirements and lower heat losses. This is aligned with the objectives of a net-zero carbon economy and allows more suppliers to contribute to the network.

Table 4.1 Taxonomy of District Heating networks (Adapted from Lund et al. (2014))

Generation	1 - Steam	2 - In situ	3 - Prefabricated	4 - 4GDH
Period	1880-1930	1930-1980	1980-2020	2020-2050
Heat production	Coal steam boilers	Coal, oil-based CHP	Large scale CHP, biomass, fossil fuel boilers	Low-temperature heat recycling and renewable sources
Heat carrier	Steam	Hot water (>100°C)	Hot water (<100°C)	Low-temperature water (30-70°C)
Building efficiency	N/A	200-300 kWh /m^2	100-200 kWh/m^2	New build: <25 kWh/m^2 Existing: 50-150 kWh/m^2
Radiator temperature	High (>90°C)	High (>90°C)	Medium (70°C)	Low (50°C)

The first generation of district heating dates back to the early twentieth century, where steam was channelled through steel pipes to service high-temperature radiators and hot water tanks in urban buildings. The second-generation district heating network used pressurised hot water (mostly over 100 degrees Celsius) as the heat carrier, circulated using centralised pumps. More recently, the third generation of district heating has been available since 1980 and features pressurised hot water often below 100 degrees Celsius, with an ability to service more energy efficient buildings by heating medium temperature radiators. The latest generation of district heating uses lower grade heat and represents a tectonic shift in the integration of district heating across the energy system.

The latest generation of district heating (4th Generation - '4GDH') represents a step-change in the ability of networks to operate with low-temperature supply. It is able to operate using low-temperature (30-70 degrees Celsius) water, channelled through pre-insulated pipes. One major advantage of this system is the ability to recycle waste heat and to operate with renewable energy sources, due to lower temperature requirements (Sorknæs et al. 2020). Until now, systems have largely relied on fossil fuel combustion or combined heat and power.

The improved system efficiency has several notable benefits. With a lower operational temperature, there is less heat loss in the network. This also allows more industrial sources to supply lower grade waste heat to support the network. This can help to abate needless additional energy generation. Secondly, improvements in the energy efficiency of buildings mean that a lower temperature level of heating is required to achieve comfortable occupancy. As an example, it can operate with new dwellings (A-rated) and existing buildings if the dwelling is at least C1 BER-rated, based on the guideline building efficiency.

Table 4.2 What does Ireland need to increase presence of 4th Generation District Heating? (Adapted from Lund et al. 2018)

- Provide space and water heating to existing, renovated and new buildings
- Distribute low-temperature heat in networks with low grid losses
- Recycle heat from low-temperature and renewable heat sources
- Integrate with smart energy system for intermittent renewables and storage
- Suitable planning and incentive structures required to unlock investments

There is much work required to adapt current networks to be future-proofed to feature low-temperature networks that supply low-energy buildings (Connolly et al. 2013). The 4th Generation district heating network features several important prerequisites. Lund et al. (2018) note that it requires a connection to energy efficient buildings as part of a smarter energy system that can accommodate renewable energy resources. Analysis shows that the benefits of 4GDH, including lower grid losses, low-temperature heat sources (including intermittent renewables and biomass) and its function as a source of energy storage outweigh the additional costs such as upgrading existing heating systems and installing and operating distribution grids (Lund et al. 2018). However, the challenge of upgrading legacy networks is a complex challenge, involving substantial refurbishment of the network.

Perhaps fortunately, Ireland stands to benefit from its relative lack of district heating to date, as large-scale pilot district heating networks seek to realise the benefits of the latest 4GDH networks without the challenge of renovating legacy systems. Ireland's district heating journey is the focus of the next section.

4.2 District Heating and Ireland

This section considers recent evidence on the potential for the latest district heating technology to be used in Ireland - which has featured relatively little district heating to date. It also considers barriers towards the implementation of such technology that are relevant to Ireland, details the two key pilot schemes that are underway and outlines the potential for industrial waste heat from data centres to serve a role as a source of supply to the network. The chapter concludes with an overview of district heating in other countries and some key takeaways for consideration.

4.2.1 Potential for District Heating

In Ireland, district heating is at a pivotal junction. In response to high emissions in the residential sector (relative to EU counterparts) driven in large part due to the use of high carbon fossil fuels, ambitious policies to decarbonise the sector are starting to be put into action. Compared to other countries, Ireland has been slower to adopt district heating, with less than one percent of Ireland's heat demand being met through district heating. This has been attributed to a lack of policies, frameworks and standards which creates investment uncertainty (IrBEA 2016).

Large scale district heating[37] has not been implemented in Ireland, with estimates that only 0.8% of 2013 heat demand is covered by district heating, relative to an EU-28 average of

[37] Similar to IRBEA (2016a), the definition of district heating in this chapter considers a central heating supplier over a managed network across multiple buildings and end-users at the municipality level. This is different to communal or localised heating systems, which are smaller in scale and wholly managed by the site developer.

11.7% (Colmenar-Santos et al. 2016; IERC 2020). This lack of heating contrasts with evidence that almost three quarters of Dublin City would have sufficient heat demand to be met by district heating (CODEMA 2015). Upcoming evidence suggests that 83% of total heat demand in Dublin City could be feasible for district heating.[38] The business case for district heating has improved with greater building energy efficiency and advances in low-carbon heating networks. This section details the extent of district heating in Ireland and outlines the potential for such systems to contribute towards the national net zero target.

An important first step on the district heat journey is to understand its viable potential in Ireland. The publication of the Irish Heat Atlas (Figure 4.3) is an important milestone in spatially quantifying residential and commercial heat demand in Ireland. It presents heat demand and network investment costs in line with the approach used in the Heat Roadmap Europe study of 14 EU countries.[39]

Analysis notes that 35% of Ireland's total heat demand found in cities, towns and villages is currently suitable for district heating. Additional government supports (fuel taxes, grants etc.) would unlock a further 21.3%, while 4th Generation systems could meet an additional 8.4% of residential and commercial heat demand. This suggests that almost two thirds (65.2%) of Ireland's total heat demand could be met by district heating, with the correct policy and technical supports.

Evidence has shown that many urban areas in Ireland have sufficient demand for district heating. In order to understand why the rollout of technology lags behind its perceived potential, the next section focuses on several of the noted barriers facing the implementation of district heating in Ireland. This follows Chapter 3, which discussed issues related to technology adoption.

[38] See Codema https://codema-dev.github.io/map/district-heating-viability-map-v2/
[39] See https://www.districtenergy.ie/heat-atlas

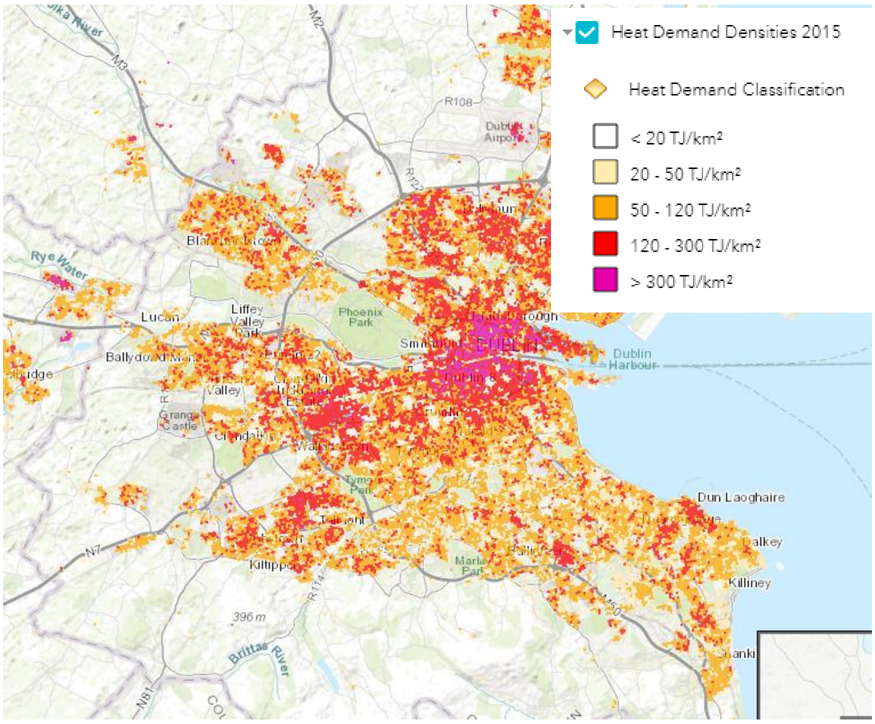

Figure 4.3 Sample of Irish Heat Atlas (Source: districtenergy.ie)

4.2.2 Barriers Towards Implementation

A case study considering the barriers to implementation of district heating in Ireland notes that many of the challenges facing district heating are unrelated to the technology itself and are more in line with issues prevalent across many emerging industries (IrBEA 2016).

As a relatively **new industry**, there is a general lack of knowledge surrounding district heating as a utility. This lack of awareness is not just present among consumers, as it is also evidenced throughout the domestic supply chain. A related barrier that is frequently observed across emergent industry is the need for a suitably skilled workforce. For Ireland, realising potential for district heating requires expertise to plan, coordinate and deliver projects. Given the relative lack of district heating to date in Ireland, it is crucial for policymakers to understand what supports (if any) are needed to develop the human capital expertise required to deliver change at the local level (O' Shea et al. 2019).

Engaging consumers is a key part of technology adoption (discussed further in Chapter 3). Any type of fuel switching requires consideration for consumer behaviour, which may often lag behind policy ambition due to factors including cost, time, dwelling status (owner / tenant) and any prior investment in energy efficiency. In particular, some customers might be dissuaded by losing their ability to switch energy provider when they join a centralised district heating network (that operates as a monopoly). There will have to be promotion to convince customers to make the switch. Other countries have applied both mandatory and voluntary methods in order to stimulate the uptake of DH schemes.

> "Public bodies are identified as key enablers of district heating; particularly where larger scale co-ordination of projects is required among diverse stakeholders. The development of district heating will require coordinated, local-level action to effectively plan for successful wide-spread district heating implementation." (IrBEA 2016)

A scoping report highlighted a **policy and planning** environment that did not accommodate district heating (IrBEA 2016). These limitations were evident in the Part L building regulations, the lack of recognition of district heating in the Building Energy Rating (BER) and the lack of any exemption for district heating network piping from planning permission, as is the case for most other infrastructures under the Planning and Development Act. The differences in regulatory environment facing district heating networks could hinder its competitiveness with other fuel sources.

District heating networks tend to last longer than typical energy generation infrastructure, so should be viewed as suitable candidates for long-term financial instruments (e.g. public private partnership, long-term bond) which have been used for similar long-term investments. From a theoretical perspective, the lack of investment to date may stem from differences in public and private investment outlooks, where private sector investments often require a higher discount rate (Solow (1963), Arrow & Lind (1978)).

Table 4.3 Barriers to Ireland realising its district heating potential (Persson et al. (2014))

- Landscape related aspects (e.g. proximity of heat demand and supply)
- Thermo-dynamical factors (e.g. excess heat temperature levels)
- Seasonal factors (e.g. annual heat demand variations)
- Site-specific factors (e.g. unique plant configurations)
- Contextual factors (local strategies, enterprise willingness)

Many of the barriers to district heating in Ireland have also been observed for potential fuel sources, including geothermal energy. Recent evidence has highlighted that geothermal energy could be a secure, cost effective and effectively carbon neutral source to potential district heating network. Despite this potential, the lack of any district heating geothermal projects in Ireland is attributed to a lack of public awareness, the capital cost of geothermal projects and a lack of appropriate geological data (Department of the Environment Climate and Communications 2020). The next section focuses on two large-scale pilot projects that seek to serve as an exemplar for the Irish context that could support change.

4.2.3 Irish District Heating Pilot Projects

Two district heating pilot studies seek to overcome the barriers associated with district heating in Ireland. Pilot studies help to increase knowledge sharing, human capital, gain regulatory support and overcome operational concerns which may have hindered development to date. By providing examples of the technology in operation while developing leadership and human capital, it is hoped that this technology can be adopted across Ireland, where appropriate.

At this point, the groundwork for district heating has been laid by key local and national stakeholders. This work has involved careful consideration of international best practices, modelling of Ireland's potential for district heating and applications for pilot schemes. The Irish government Climate Action Plan aspires to have 60,000 homes connected to district heating by 2040 (Government of Ireland 2019). As part of this, two projects, both led by local authorities, have received grant support from the Climate Action Fund:

4.2.3.1 Tallaght District Heating Scheme

This scheme will reuse data centre waste heat with a heat pump to supply space and water heating for 1,962 homes, 16,250m^2 of commercial space and 47,000m^2 of public buildings in South Dublin (CODEMA 2018). The scheme is expected to reduce carbon dioxide emissions by just under 1,900 tonnes per year. Public buildings that will benefit include SDCC's County Hall, the Civic Centre, the Technological University Dublin, and Tallaght County Library.[40] The project features a roughly €8 million capital cost over the ten-year energy supply contract, 61% of which is grant supported (CODEMA 2020).

The project was made possible by the 'HeatNet' project, funded by the EU Interreg North-West Europe programme. This funding covered staff costs to develop the project and provided funding towards infrastructure. Progress on this scheme has followed the pathway established in other countries. This has included the scoping of potential heat demand and supply sources, the establishment of Ireland's first publicly owned, not-for-profit energy company (Heat Works) to manage the venture (Fortum) (CODEMA 2020). Civil works are underway, with pipes laid for the network in June 2021, with pipelaying started for the network in June 2021 and operation expected in early 2022 (Data Center Dynamics 2021). This scheme has been noted as an exemplar for leadership at the local council level, which is a vital factor for success (IERC 2020).

[40] See https://www.datacenterdynamics.com/en/news/aws-dublin-data-center-contribute-new-district-heating-scheme/

4.2.3.2 Dublin District Heating System

This system is planned for the central Dublin area of the Docklands and Poolbeg Peninsula. It has received grant funding of up to €20 million as part of the Climate Action Plan and aims to be operational as a joint venture by early 2025. It is expected to be mainly powered by excess waste heat from a waste-to-energy plant in Poolbeg, but will accommodate other industrial sources, including data centres and electricity plants. Although initial estimates suggest that the network could heat 50,000 homes, increasing building energy efficiency suggests there is potential to heat up to 80,000 homes.[41] This change is supported by the fact that homes built in the Docklands region since 2014 are compatible with the network.

> "This is effectively a start-up utility, so it is important that we get it right so district heating can continue to grow across the city,"
>
> James Nolan, District Heating Project Manager[5]

4.2.4 Irish District Heating Targets

The national 2019 Climate Action Plan aims for 60,000 homes to be connected to district heating by 2030 (Government of Ireland 2019). If these two pilot schemes are successfully implemented, this national target could be achieved in Dublin alone. In one sense, the national policy may not be ambitious enough. However, policy targets often serve as a reminder of how reality can often fall short of goals, especially as homeowner behaviour (in terms of willingness to adopt) can differ from the policymaker ambition. A policy target for district heating that appears conservative may not stimulate action. However, the counterpoint is that the target appropriately reflects the non-trivial matter of delivering change. A more conservative target may be warranted for the early adoption of an established technology that is new to the Irish market, as is the case here.

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[41] See https://www.irishtimes.com/news/environment/ringsend-incinerator-to-supply-heat-for-30-000-more-homes-1.4547219

In addition to grant funding supports, the 2019 Climate Action Plan also demonstrates an awareness within government on the need for additional supports, including a stated need for a roadmap for delivering on the potential of district heating in Ireland. Building on experience from other countries, the Climate Action Plan (2019) has noted that spatial and planning policy needs to be steered towards supporting district heating (Government of Ireland 2019). In particular, new developments of multi-storey and terraced buildings should be located in closer proximity to reduce network costs. Focusing on the Irish residential sector, there is a clear need to renovate a largely standalone dwelling stock (noted in Chapter 2) to a centralised heating network. District heating can play a role in providing low-carbon heat across the built environment, including commercial and public buildings.

As new dwellings will be highly energy efficient, they require less energy and will be compatible with district heating. Compared to other energy efficiency technologies (such as external wall insulation or heat pump), a connection to the district heat network is not disruptive for the homeowner. It can almost eliminate emissions for space and water heating, which is responsible for 79.2% of residential energy use on average in the EU (Eurostat 2019). Other planning regulations have been introduced to support the transition towards district heating. In the Dublin docklands region, all new buildings since 2014 were required to be compatible with district heating.[5] However, the myriad of options available to consumers suggests a need for a district heating policy framework, which is expected for publication in 2021 according to the Interim Climate Actions government publication (Government of Ireland 2021b).

Pilot projects seek to introduce district heating to the Irish market in a robust and sustainable manner. Although networks could be powered by a variety of fuel sources, the next section considers the role of data centres as one possible industry that is ready to contribute to district heating networks in Ireland.

4.2.5 Data Centres

In many economies, district heating is fuelled by thermal power generation, industry and manufacturing processes. Recent analysis for Ireland has considered how waste heat from power generation, waste-to-energy and industry waste heat could fuel district heat (Renewable Energy Ireland 2021). One possible explanation for the lack of district heating to date in Ireland might be due to the lack of established fuel supply sources. This section elaborates on just one of the many potential sources of supply - the data centre sector.

The Irish data centre sector represents a major opportunity for complementary development with district heating networks. Ireland has become the centre of the digital economy, conducting 14% of global trade in ICT services in 2016 (OECD 2017), the highest of any country. In Ireland, the Tallaght District Heating Scheme seeks to leverage waste heat from a commercial data centre. Data centres are an appealing option for a modern district heating network due to their proximity to the network and the constant heat output that could provide security of supply, especially with the presence of intermittent renewable sources that also contribute to the network. Combined with storage and heat pumps, it allows the use of electricity at times when there is high renewable penetration on the electricity grid, helping with balancing through large-scale demand response.

Leveraging opportunities to increase energy efficiency and reuse within data centres is an important outcome, especially since data centres are expected to dominate the Irish electricity grid. The sector is expected to comprise 75% of the growth in Irish electricity use from 2017-2026 (Oireachtas 2017). By 2028, centres are projected to use between 25% and 37% of national electricity demand (EirGrid 2019).

The ability for data centres to contribute to the low-carbon economy is reflected in their presence as a source of energy supply in the Tallaght District Heating Scheme (IERC 2020). In this scheme, it is expected that waste hot air from the data centre will be collected, run through a heat exchanger and boosted by heat pump to supply the district heat network (Data Center Dynamics 2021).

Internationally, data centres have been able to contribute to the local district heating network, with an Apple hyperscale data centre in Viborg, Denmark as a prominent example (Euroheat & Power 2021).[42] The large presence of data centres in Ireland provides a similar opportunity to harness the waste heat to integrate into a future energy system. Although estimates vary based on site-specific technologies, it is estimated that data centres in 2030 will have electricity demand of 1400MW. Considering the substantial electricity used for cooling, it is estimated that data centres could have surplus heat from cooling of 6.1 TWh/year by 2030 (Renewable Energy Ireland 2021). Combined with the fact that data centres are located primarily in Dublin, these facilities could contribute to district heating networks.

Unlike the uncertainty inherent in forecasting technology adoption behaviour for millions of households, it appears that data centre operators are aware of the positive contribution they could make. A recommendation paper by Euroheat & Power (2021) outlines this view, connecting industry ambition to achieve climate neutral status by 2030 on the pathway to making Europe climate neutral by 2050. This commitment has been stated by many key industry operators as part of the voluntary Climate Neutral Data Centre Pact (CNDP).[43] Table 4.4 outlines the commitments as part of the Pact, which includes targets for the procurement of renewable electricity to exploring the potential to contribute to heat networks.

Exploratory analysis based on 2019 forecasts suggest that data centres could play a substantial role in the national decarbonisation effort (Coyne and Denny 2021a). In this analysis, it is assumed that data centres could transition to zero-carbon cooling, which is a departure from conventional cooling which consumes electricity intensively. Results suggest that technology adoption could lower national electricity demand by 0.81% if adopted by data centres built from 2019 to 2028. Savings rise to 3.16% over the same period if adopted by new and existing data centres. Although the analysis was limited by the lack of detailed plant information, it illustrates the potentially key role of data centres in the low carbon economy.

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[42] See https://www.apple.com/mu/newsroom/2015/02/23Apple-to-Invest-1-7-Billion-in-New-European-Data-Centres/

[43] See https://www.climateneutraldatacentre.net/self-regulatory-initiative/

This commitment is conditional on only new build data centres if it is “practical, environmentally sound and cost effective” (Euroheat & Power 2021). Notably, this commitment does not include the existing stock of data centres, which is a considerable omission. Examples of data centres contributing to the heat sector in Ireland have been partly grant supported, it remains to be seen if the cost-effective criteria can be met without further policy supports.

Table 4.4 Actions under voluntary Climate Neutral Data Centre Pact (Source: CNDP)

- **Energy Efficiency -** Set high standard for facility energy efficiency. 2025 for new build, 2030 for existing plant. Improve metrics for facility energy efficiency.
- **Clean Energy -** Data centres will match electricity supply through the purchase of clean energy (renewable or hourly carbon-free). 75% by 2025, 100% by 2030.
- **Water -** Aim to conserve water, develop annual target for water conservation. Target to be met by new build data centres from 2025, existing plant by 2030.
- **Circular Economy -** Commit to assessing all used server equipment for reuse, repair or recycling. Set targets by 2025.
- **Circular Energy System -** Explore potential connection for new data centres with district heating. Consider if practical, environmentally sound and cost effective.

There is scope to develop metrics that reward data centres for their support for decarbonisation outside of the facility. Currently, the capture of waste heat for third-party use is not included in facility energy efficiency metrics. Issues related to community acceptance of renewable energy sources close to homes has been noted in Ireland for other generation technologies (Bertsch et al. 2017) and could pose issues for future data centre construction. A deeper understanding of these issues might improve relations between data centres and the communities they are based in.

4.2.5.1 The conflict facing data centre growth

The looming forecasts for growth in the data centre sector (among others) raises an important point about ensuring that policymaking consistently reflects a hierarchy that is mindful of national climate commitments. Ambitious targets for decarbonising the energy system bear consequence for every end-use and sector. The latest headline policy guidance is that the Irish government "endorses, supports and promotes the appropriate and timely delivery of data centres across regions" (Government of Ireland 2018).

However, a conflict between stakeholders is apparent in a recent Commission for Regulation of Utilities (CRU) consultation on data centre connection policy (CRU 2021). Faced by the challenge of excess electricity demand at peak times, the CRU proposes that upcoming data centre connections are prioritised based on their location and their ability to use onsite generation to support security of supply during times of system constraint.

> "The CRU notes that there are a range of technologies, and behaviours, that can be adopted by data centres and data centre developers in Ireland which can mitigate some of the challenges that this sector brings. The CRU is aware that in other jurisdictions, Data Centres are examining options to manage their load and peak demand on the system. One such example is data centres matching their energy use to the availability of renewable sources."
>
> (CRU, 2021)

However, a recent submission from IDA Ireland to the CRU consultation has noted that although grid instability would create substantial reputational damage to the Irish economy (IDA Ireland 2021), they assert that any burden of adjustment lies on the supply side (i.e. electricity generation), rather than the demand for a particular sector (e.g. data centres). This view is partly based on earlier analysis that data centres are critical infrastructure that provide economic benefit to Ireland (IDA Ireland 2018). This benefit is estimated at €0.9 billion per annum (direct and indirect benefit from 2010 to 2018), with a data centre presence serving as an anchor for foreign direct investment in Ireland.

Although previous research noted the economic benefit of data centres and their willingness to source energy from renewable sources (IDA Ireland 2018), it does not tackle the latest question of whether the marginal benefit of future data centre capacity outweighs the marginal cost of additional renewable energy generation (and system stability) and emissions, especially in light of new EU targets. This conflict is just one example of how policymakers must be in harmony on decarbonisation targets and the pathway to achievement. It also emphasises the need to consider solutions that can help foster decarbonisation while also harnessing the enthusiasm from private sector to participate in the green transition. In this sense, leadership in district heating with private industry waste heat input could help serve as a catalyst.

4.3 District Heating Across Europe

Building on the discussion of the barriers facing Ireland and how it is seeking to implement district heating, this section will highlight the substantial evidence on the use of district energy in other countries, with a particular focus on Denmark as an exemplar and the UK as a closer comparison to Ireland.

4.3.1 Denmark

Denmark is a pioneer in the area of district heating. By 2018, almost two thirds of all Danish residential homes received their space and water heating from a district network. This network has been underpinned by the use of combined heat and power, which is more efficient than separate heat and electricity generation. One advantage of a district heating network is the flexibility of input sources (State of Green 2018). This is evident in Denmark's ability to incorporate increasing shares of renewable electricity sources, which accounted for over 65% of Denmark's gross electricity consumption in 2019.[44]

[44] See Eurostat (2020): https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Share_of_energy_from_renewable_sources_in_gross_electricity_consumption,_2004-2019_(%25)-v2.PNG

In Denmark, the first district heating system was a combined heat and power (CHP) plant built in 1903 with a waste incinerator providing electricity and heat to a nearby hospital. This was expanded to harness excess heat from local electricity production. By 1970, around 30% of all homes in Denmark were supplied by district heating. The enthusiasm for district heating networks was supercharged during the energy crisis in 1974, with a renewed desire to decrease dependence on imported fossil fuels and to avoid fuel-specific price shocks. This remarkable growth in district heating networks was supported by key legislation, which features several considerations for other countries attempting to foster district heating. In 1979, Denmark passed a heat supply law that regulated the form and type of heat planning.

This landmark legislation tasked local authorities with approving new heat supply projects with the highest socio-economic benefit (using a methodology from the national Danish Energy Agency), generated by CHP where possible. It also established specific zones of heat networks around the country, where individual zones were earmarked for a specific type of heat supply (individual, natural gas, decentralised district heating, centralised district heating).

A key feature of the Danish setting is that heat supply companies are legislated as not-for-profit entities. This means that although the price of heat varies nationwide, the method for setting the heat price is legislated as covering the necessary costs to supply heat. Finally, legislation endowed a natural monopoly on the district heating system, in order to avoid several cost ineffective heating networks. This has required thorough planning to create a reliable investment environment while also keeping consumers protected.

Political agreement has been a core feature of Denmark’s district heating policy, with subsequent legal amendments to improve the opportunity for wind and other renewable energy sources in 2008, ambitions investments in energy efficiency pursuant to 2020 targets. District heating infrastructure has proven to be future proofed as energy systems transition towards lower carbon sources. Table 4.5 notes how Denmark is developing legacy systems as part of the transition towards 4GDH networks:

Table 4.5 Steps to transition to 4GDH (State of Green 2018)

- Transition CHP plant from fossil fuel (coal, gas) to biomass (straw and wood)
- Increase heat storage capacity to accommodate intermittent renewables
- Develop more district cooling systems with seasonal storage
- Connect large heat pump and electric boilers to use wind energy in network
- Replace steam and high-temperature systems with low-temperature water
- Renovate buildings in the network to lower the required supply temperature and to minimise heat losses in the return temperature.

As an example of real savings, the Copenhagen district heating network (where 98% of heating is supplied through district heating) represents substantial savings for consumers. Annual energy bills through district heating cost roughly half (€1,400) of what they would if they were oil fuelled.[45] Such savings are likely to be comparable to those in the Irish context, where previous research has found that the capital and maintenance costs of a district heat network in Ireland are comparable to those in Denmark and Sweden, based on publicly available data (IrBEA 2016).

4.3.2 United Kingdom

In addition to Denmark, there have been recent examples of district heating networks present across the United Kingdom which perhaps serve as a more appropriate inspiration for Ireland as a country with little district heating to date. In 2013, district heating served only 2% of UK citizens (Colmenar-Santos et al. 2016). This section will provide a brief overview of key examples from the UK, with a focus on situational factors that have helped to drive progress.

Islington council operates the publicly owned Bunhill Heat and Power Network. The first phase (2012) is powered by a gas-fuelled 1.95 MWe combined heat and power engine that serves 820 dwellings, two leisure centres and four office blocks with 1.4km of pipework.
The second phase (2019) expands the network by an additional kilometre to connect a further six hundred dwellings. Importantly, the network is also being fuelled by waste hot air from

[45] See https://www.c40.org/case_studies/98-of-copenhagen-city-heating-supplied-by-waste-heat

local manufacturing industry and the London Tube network of underground railways. Exhaust air is typically in the range of 18-27 degrees Celsius, which is boosted by a heat pump to 80 degrees Celsius.[46] The Bunhill project is an important demonstration of how waste heat can be integrated into heat networks to decarbonise urban heat supply. Furthermore, the ability to provide low-carbon, low-cost heat to urban residents is a vital social good.

Figure 4.4 Bunhill Heat and Power Network (Phase 1 Green, Phase 2 Blue)[47]

[46] See https://www.energyadvice.islington.gov.uk/bunhill-heat-and-power/bunhill-2-how-does-it-work/
[47] See https://www.energyadvice.islington.gov.uk/bunhill-heat-and-power/bunhill-heat-and-power-network/

In pursuit of a net zero carbon economy, the UK Committee on Climate Change in 2019 suggested that new homes should not be allowed to connect to the gas grid from 2025 (UK Committee on Climate Change 2019). This illustrates an awareness of the need to avoid lock-in of fossil-fuel based infrastructure.

This report has already noted many of the legislative and administrative challenges facing the development of a district heating network. In the UK, such challenges were also present, driven largely by the dominant use of natural gas in residential heating (IERC 2020). A key resource provided by policymakers is the formation of the Heat Network Delivery Unit in 2013. This has helped to provide over £17 million in grant support to over 200 projects across England and Wales.[48] This initial commitment has been bolstered in 2018 by a further provision of £320 million in grants and loans to develop district heat networks as part of the Heat Networks Investment Project. The intention of this funding is to overcome the initial hurdles on this journey and to secure additional private investment towards network construction.[49]

Table 4.6 Barriers addressed through the Heat Networks Investment Project[12]

● Lack of information on risk profile of heat network investment ● Subsidise funding gap between hurdle rate and project internal rate of return ● Address lack of understanding of technology by end users ● Support the development of supply chains to enact change

In addition to grant support, policymakers have provided a toolkit of resources for communities to develop heat network projects. Since 2014, government has also legislated for heat suppliers to install meters and correctly monitor their customers.[50] It is clear that the UK government has embraced the opportunity to decarbonise their heating sector, while also demonstrating a keen awareness of the need to overcome the myriad barriers that would prevent the effective adoption of technologies.

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[48] See https://www.gov.uk/guidance/heat-networks-delivery-unit

[49] See https://www.twobirds.com/en/news/articles/2018/uk/bird-and-bird-and-heat-decarbonisation-policy-in-the-uk

[50] See https://www.gov.uk/guidance/heat-networks

4.4 Chapter 4 - Key Findings

This chapter has provided an overview of district heating technology and its potential as a force for positive change in the context of reducing emissions, particularly in the residential sector in urbanised areas. The latest district heating technology presents a new opportunity for Ireland, with greater compatibility to accommodate waste heat from industry and power generation and to function with a diversity of fuel sources, including renewables. The review of evidence from Ireland and abroad surfaces several key insights for consideration:

No shortcuts to achieving change

It is clear from the current evidence that district heating is a viable low carbon heating technology. However, there is no replacement for experience - which has contributed to countries such as Denmark being leaders. However, time is of the essence and other countries must get up to speed. Fortunately, it appears that Ireland has commenced this journey, including an identification of the scope for heat demand and supply and the development of a policy framework for district heating (Government of Ireland 2021b).

A major milestone has been the development of pilot schemes in recent years - one of which has commenced works on the pipeline (Tallaght) and another which is submitting a Business Case to the Department (Government of Ireland 2021b). In a sense, the main technological challenge associated with district heating has been solved. The remaining issues relate to public willingness to implement change and to convincing private stakeholders (government, firms and consumers) that this is a change worth investing in.

A greater role for policymakers in avoiding mismatch

Much of this report centres on the delicate balance of several different energy sources, many of which end up in competition with each other at the household level. In order to provide clarity to consumers and firms, consideration should be given to the design of information and supports to encourage households to make the right switch.

In urban areas, competition is expected between existing gas networks and a possible district heating network. In this instance, customers are spoiled for choice, with a risk that consumers may make the wrong choice (to a more carbon intensive technology) or no choice at all. Both options would be counterproductive to reaching stated national targets. In Ireland to date, many solutions have focused on improving information to consumers and providing subsidies for positive change for a range of technologies. This conflict is present across several areas related to the low carbon transition and is explored in Chapter 6.

Leveraging national expertise on public-private collaboration

As part of the development of major pilot schemes in Ireland, significant expertise has been developed in securing the cooperation and collaboration of private industry to supply heat to a district heat network (Data Center Dynamics 2021). This support has required significant effort on public and private stakeholders. In order to build on the experience in Ireland to date, it is important to develop stronger ties between heat supply sources and their local networks. This will help to understand whether potential waste heat sources are economically viable. For Ireland, this collaboration may be made easier by industry, particularly data centres, that are willing to play a role in the green transition (Euroheat & Power 2021).

However, this enthusiasm should be supported with the resources to achieve change, rather than to be viewed as wasted potential. Such collaboration could help to fuel district heating while providing other benefits to society, including the storage of renewable energy, the balancing of the electricity grid (Renewable Energy Ireland 2021) and by realising the benefits of foreign direct investment (IDA Ireland 2021).

5 Overview of Multiple Benefits and Trade-offs

Greenhouse-gas emissions reductions and energy cost savings are the most obvious and commonly discussed benefits associated with the adoption of low carbon heating and energy efficiency improvements. However, there are a host of other benefits which may arise from such actions which accrue directly to dwelling occupants or indirectly to society as a whole. In this chapter we explore some of the multiple benefits and costs associated with improvements in energy efficiency and the adoption of low-carbon heating technologies (IEA 2019b; Ryan and Campbell 2012). In addition, we provide a brief discussion on how these multiple benefits/costs can dictate the rationale for policy aiming to improve energy efficiency and low carbon heating uptake.

5.1 Co-benefits and Trade-offs

5.1.1 Health

A major benefit of improving the thermal integrity of a dwelling is the associated reduction in cold related illnesses and cold stress for occupants. Maidment et al. (2014) carry out a meta-analysis on 36 studies which look at the health impacts associated with energy efficiency upgrades, covering approximately 30,000 participants. The findings suggest that household energy efficiency interventions led to a small but significant overall improvement in the health of residents, with newer studies in the sample finding larger effects. Improvements in health outcomes however were much more pronounced for low-income groups, which supports the inclusion of energy measures to help tackle social issues like fuel poverty and health inequity.

In a more recent review, Fisk, Singer, and Chan (2020) find that in almost all studies subjective health measures such as non-asthma respiratory symptoms, general health and mental health improved following retrofits. For asthma symptoms the evidence of improvement slightly outweighed the evidence of worsening. The authors warn that published research in the area has serious limitations, particularly due to a lack of data on objective health outcomes.

One recent study which aims to address this concern by Fyfe et al. (2020) uses linked hospital admissions data with data from a New Zealand insulation subsidy program. The findings suggest that post intervention, hospitalizations in the treatment group (those who participated in the efficiency program) increased less (11% lower post intervention), representing 9.26 fewer hospital admissions per 1000 in the intervention group. Effects were found to be more pronounced for respiratory disease (15%), asthma in all age groups (20%), and ischemic heart disease in those older than 65 years (25%).

Table 5.1 Summary of health benefits

Benefits

- Improved indoor temperatures associated with decreases in mortality and morbidity from cold-related illnesses (Clinch and Healy 2001).
- Reduced dampness/mould growth can significantly improve respiratory health (Mendell et al. 2011).
- Improved indoor air-quality if moving away from solid fuels (Chakraborty et al. 2020).
- Improved self-reported physical and mental health measures.
- Higher productivity from employees taking fewer sick days (U.S. EPA 2018).
- Improvement in health inequity.

Risks

- Indoor air quality may be reduced due to increased airtightness, if lacking sufficient natural/mechanical ventilation (Collins and Dempsey 2019).
- Mould growth may increase as a result of increased condensation.
- Choice of materials such as sealants and insulation may emit volatile organic compounds (VOCs).

For Ireland in particular, the number of deaths during the winter has historically been far greater than during any other season – denoted as *"excess winter mortality"* (Clinch and Healy 2000, 2001). Despite a relatively mild winter climate, this winter surplus accounts for a rate of seasonal variation in mortality of 15%, which is among the highest in Europe (Clinch and Healy 2000).[51] Improvements in thermal performance of the residential building stock may therefore offer substantial potential for improving public health.[52] Despite this, research on

[51] By comparison Denmark and Norway have 5% seasonal mortality variation.

[52] In addition, Collins and Curtis (2017b) find that significant asymmetries in information regarding health outcomes of retrofits exists between adopters and non-adopters.

the health outcomes associated with retrofit specifically for Ireland has been limited. To address this knowledge gap, a pilot program, the *Warmth and Wellbeing Scheme* was launched whereby free energy efficiency upgrades are provided to individuals with chronic respiratory diseases conditions living in energy poverty (SEAI 2018b). Research in collaboration with the London School of Hygiene and Tropical Medicine is underway to evaluate the public health outcomes of the scheme (Straton 2018).

In order to ensure positive health outcomes and to avoid unintended consequences, energy efficiency retrofits need to be carried out using quality materials and best practice. In particular, when the air-tightness of the building is improved, adequate ventilation is required in order to prevent higher levels of indoor pollutant accumulation and mould growth (Collins and Dempsey 2019). Examples of indoor pollutants include volatile organic compounds, carbon dioxide, carbon monoxide, formaldehyde and radon (WHO 2010). Fisk, Singer, and Chan (2020) report that several studies find radon and formaldehyde concentrations tend to increase after retrofits that did not add whole-house mechanical ventilation.

The incidence of condensation, dampness and mould is generally believed to be alleviated by retrofit. Fisk, Singer, and Chan (2020) find that mould and dampness, based on occupant reports almost always decreased after retrofit. However, some studies have reported new mould formation following retrofit, with inadequate ventilation suspected as the confounding factor (Willand et al. 2015).

Overall, it appears that energy efficiency retrofits and low-carbon technology adoption have the potential to significantly improve both self-reported and objective measures of health. However, retrofit needs to be carried out using best practices – particularly in terms of ventilation and material use in order to maximize health outcomes. The health benefits associated with retrofit may be of particular importance given the current global pandemic and the transition to home working, which has increased the time spent indoors and in residential dwellings. Some recent research has already linked ambient air pollution (PM10) with the severity of COVID-19 outcomes (Isphording and Pestel 2021). Future research needs to explore whether a link between indoor air quality and the incidence and severity respiratory diseases like COVID-19 exists.

5.1.2 Comfort

One of the most often cited benefits following energy efficiency retrofits is an increase in thermal comfort levels for occupants. Specifically for Ireland, findings by Aravena, Riquelme, and Denny (2016) suggest that increased comfort is one of the primary motivators for household investments in energy efficiency measures, second only to monetary concerns. In fact, a change in thermal comfort is likely the first benefit experienced by households following retrofit (Motherway and Halpin 2010), and communicating this experiential benefit may encourage individuals to start their journey towards whole house retrofit (UK Green Building Council 2021). It may therefore be prudent for messaging to convey the qualitative improvement in thermal comfort following retrofit.

> "Messaging needs to convey the full extent of experiential benefits that can be experienced after measures are undertaken. It is not just a case of being able to keep warm for less but that the comfort experience is qualitatively improved e.g., by not having to wait long for the house to warm up, by staying warmer for longer after heating has gone off, and by banishing unpleasant draughts." UK Green Building Council (2021)

Findings from Ireland are mirrored by the international literature. Using data from the US, Cole et al. (2018) find that comfort is among the top three most important benefits to consumers considering energy efficiency investment. In a meta-analysis of empirical studies which look at comfort and retrofit, Fisk, Singer, and Chan (2020) find that in virtually all studies considered, self-assessed thermal comfort increased post-retrofit. Additionally, where studies assessed measures of thermal discomfort, all results show reductions in thermal discomfort following retrofit, with many studies reductions in excess of 40%.

These findings may have significant implications for messaging and the communication of energy-efficiency improvements and the uptake of low-carbon heating. It is important to highlight both improvements in thermal comfort and the reduction in thermal discomfort post retrofit. In a survey of social housing tenants, Coyne, Lyons, and McCoy (2018) find that households experienced significant improvement in comfort post retrofit, primarily driven by the fact that low-income tenants were underheating their properties prior to retrofit.

5.1.3 Poverty Alleviation

Energy poverty can be broadly defined as an inability to provide enough heating or lighting to one's home. A recent social impact assessment on programmes targeting energy poverty (IGEES 2020b) outlines some of the more recent estimations of energy poverty in Ireland and the measures used to alleviate it. There are many ways in which energy poverty can be measured/defined and estimates of the proportion of households that experience energy poverty vary widely. This is illustrated in Table 5.2 which summarizes some of the different estimates presented in IGEES (2020). These range from 4% - 28% of households, depending on the method used.

Table 5.2 Estimations of energy poverty in Ireland (IGEES 2020)

- **Expenditure method:** proportion of household income spent on energy needs (>10%) (after housing costs) – share of households in fuel poverty in 2019 = 17.4%.
- **Objective method:** level of fuel expenditure required by a typical household to keep their home heated to levels recommended by WHO. Estimated share of households in energy poverty at 10% threshold in 2015 = 28%.
- **Subjective methods:** SILC data – 7.1% of individuals in Ireland surveyed went without heating at some stage in 2018, while 4.4% of individuals surveyed reported that they were unable to keep their home adequately warm.

There are two main grant schemes in the Republic of Ireland which aim to reduce energy poverty through the provision of grants for retrofit. These are the *Better Energy Warmer Homes* and *Better Energy Communities* schemes. The former targets individual homeowners in receipt of certain welfare payments, while the latter provides funding to community-based partnerships. In total 124,345 homes have received funding for energy efficiency works under the *Warmer Homes Scheme* between 2009 and 2019, while 12,940 homes have been retrofitted as part of the *Communities Scheme* between 2012 and 2019.

Expenditures on the *Warmer Homes* and *Energy Communities* schemes have risen by 323% and 263% respectively over these periods. The number of works per year under each scheme has decreased over time however the depth of retrofit has increased (IGEES 2020b). In addition, the *Warmth and Wellbeing* pilot scheme aims to provide free energy efficiency retrofits to those with chronic respiratory conditions, however it is currently only limited to applicants in the Dublin region (SEAI 2021c).

Energy-poor households by their nature will be less likely to invest in energy efficiency improvements or low carbon heating systems, given that they are likely to be low-income households and energy efficiency improvements typically require significant capital investment. Vulnerable households are also more likely to be prone to the so-called "discounting gap", whereby future energy costs are undervalued significantly (Dimitris Damigos et al. 2021). This can come about from a lack of savings, lack of access to credit, and a need to focus on immediate financial costs. Given that energy costs constitute a larger portion of expenditure in such households, these households are also likely to benefit the most from a reduction in future energy bills.

This highlights the need for policy intervention in order avoid an energy poverty trap, whereby households struggling to meet energy costs are unable to benefit from energy efficiency improvements and low-carbon technologies. The targeting of fuel poor households with subsidies for energy efficiency improvements and low-carbon technology adoption can also have a significant additional benefit in offsetting the regressive nature of increasing carbon and fuel taxes (Callan et al. 2009; O'Malley et al. 2020) – which will be necessary in meeting climate goals.

There are some limitations to providing targeted subsidies for energy efficiency improvements to fuel poor households. The first of these is figuring out who to target. As illustrated in Table 5.2 energy poverty rates vary significantly depending on the metric used to identify energy poor households.

Expenditure methods focus on energy spend as a share of income, which means that they do not capture potentially substantial inequalities based on assets and wealth.[53] In addition, households living in deprivation who can't afford to spend 10% of their income on energy and thus live in inadequately heated dwellings might not be captured (IGEES 2020b). On the other end of the spectrum, affluent households that choose to live in large and inefficient dwellings could be spending in excess of 10% of their income on energy costs. Arbitrarily chosen threshold values (10%, 15%, 20%) can also result in significant variation in identified poverty rates.

Currently, the *Warmer Homes Scheme* is administered to households that receive one of a number of social welfare payments.[54] While this captures fuel poor households by primarily targeting those in receipt of fuel allowances, it may miss energy-poor households who are not in receipt of any welfare payments. Only homeowners are eligible to make an application to the scheme, which may exclude a large number of energy-poor households living in rental accommodation (SVP 2015).[55]

5.1.4 Improved asset values

Investing in energy efficiency and low-carbon heating technologies is likely to improve homeowner asset values. A clear consensus has emerged from the property sales literature – more efficient properties are sold at a premium.

Earlier studies in the area try to establish a link between specific energy efficiency improvements or energy bills and sales prices, with the majority of studies from the US (Kholodilin et al. 2017). Findings suggested that more efficient houses and those with lower energy bills consistently command higher sales values (Dinan and Miranowski 1989; Horowitz and Haeri 1990; Johnson and Kaserman 1983; Laquatra 1986; Nevin and Watson 1998).

[53] As discussed by Roantree (2020) it is understood that wealth is much more unequally distributed than income.

[54] These include: fuel allowance, job seekers allowance, working family payment, one-parent, domiciliary care allowance and carers allowance. For a full list of eligibility criteria refer to SEAI (2021).

[55] Only homeowners and those living in local authority/approved association housing area also eligible for the *Warmth and Wellbeing* pilot scheme (SEAI 2021c).

For example, Nevin and Watson (1998) find that a $1USD reduction in annual fuel bills results in an incremental increase of home values of between $10USD - $25USD. With the introduction of Energy Performance Certificates (EPC) globally, much of the recent literature in the area focuses on establishing a link between EPC ratings and dwelling prices. In a recent meta-analysis of the literature which covers 66 studies Cespedes-Lopez et al. (2019) find a clear trend of premiums to more efficient properties, in cases where EPCs include a graduated grading system.[56]

Studies focusing specifically on Ireland using BER data find similar results. Stanley, Lyons, and Lyons (2016) observe a 1% sales price premium for a 1 point improvement in the BER scale, holding all other property characteristics constant. Hyland, Lyons, and Lyons (2013) find that relative to D rated properties, A rated properties are sold at a premium of 9%. Self-reported data for Ireland from SEAI (2010) also suggests that 65% of respondents also believe that the value of their home has increased as a result of retrofitting. Significant rental premiums for more efficient BER grades are also present in the residential rental market (Hyland et al. 2013; Petrov and Ryan 2021), suggesting efficiency is capitalized in rental prices also.

Of course, improvements in asset values will only benefit housing asset owners, and therefore do not necessarily represent a net benefit to society. In addition, this may contribute to both intergenerational and intragenerational wealth inequality based on housing (Blanden et al. 2021; Fuller et al. 2020).

5.1.5 Information spillovers and improved consumer awareness

Imperfect information is a classic example of a market failure, which may bias consumers towards purchasing less efficient technologies (Howarth and Andersson 1993). Engaging households in energy efficiency retrofits and low carbon technology adoption might improve awareness of energy consumption and emissions reducing technologies, both for the

[56] The authors note that it is difficult to compare premiums for ABCDEFG grades between studies due to variation in grading schemes and reference categories. However, a global premium of 4.2% is found for properties that have an energy performance certificate in comparison to those that do not.

households that adopt such measures and for their immediate network. For example, for Ireland Collins and Curtis (2017) find limited evidence that advertising the benefits of retrofit increases the number of *Better Energy Homes* scheme applicants.[57]

However, the authors find strong a spillover effect between the *Better Energy Communities* scheme (described earlier) and the *Better Energy Homes* scheme where applications are made privately on an individual basis. For every four buildings retrofitted within the community scheme (both private and community buildings), one additional retrofit is subsequently carried out under the *Better Energy Homes* scheme. This illustrates a significant additional benefit arising from the communities scheme, and suggests that community involvement could be an important resource in encouraging retrofit and low-carbon technology adoption. Spillovers from existing individual scheme participants or from early adopters of low-carbon heating technologies such as heat pumps may produce similar effects, and this may be a fruitful area for future research.

5.1.6 Energy Security

Ireland depends on imports to cover most of its primary energy demand. Import dependency has decreased in recent years (Figure 5.1) primarily due to indigenous production from the Corrib gas field which came into operation in 2015, however remains higher than the EU average.[58] The main primary energy import is oil, which accounted for 73% of total energy imports in 2018, followed by natural gas (17%), coal (8.2%) and renewables 1.4% (Ó Cléirigh 2020). Import dependence is likely to increase again in the coming years, with declining indigenous natural gas resources.

[57] Six types of advertising were considered in the study: outdoor advertising, local print advertising, national print advertising, local radio advertising, national radio advertising and online advertising. Significant effects were found only for national print advertising and online advertising.

[58] Supply from the Corrib gas field has already peaked and GNI anticipates that by 2026 or 2027 the supply form Corrib will be less than 30% of initial peak production levels. (Ó Cléirigh 2020).

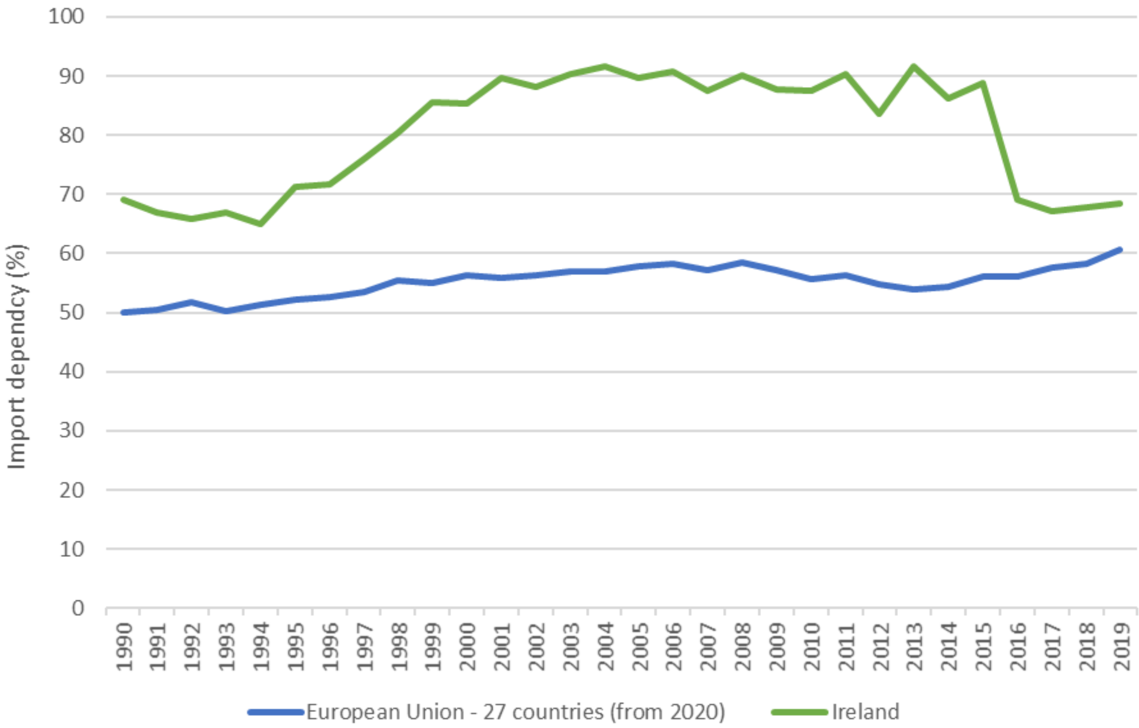

Figure 5.1 Energy import dependency - Ireland vs the EU[59]

Uptake in energy efficiency measures and low carbon technologies can reduce import dependency by reducing overall energy demand and by diversifying the primary energy mix. For example, the substitution of oil or gas boilers with heat-pumps or other low carbon technologies can reduce the demand for imported fossil fuels. This may provide more stable energy prices for households moving forward due to lower exposure to international fuel price fluctuations. Improvements in efficiency can also reduce the likelihood of supply interruptions and shortfalls in electricity generation (IEA 2019b; Ryan and Campbell 2012), in addition to reducing the reserve capacity required in the Irish electricity market.

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[59] Source: https://ec.europa.eu/eurostat/databrowser/bookmark/83eed004-a9f1-4a20-b8bd-440bf718fd39?lang=en

5.1.7 Employment Opportunities

Energy efficiency improvements can create direct, indirect, and induced employment effects (Brown et al. 2020; Ryan and Campbell 2012; Stavropoulos and Burger 2020). Direct employment opportunities arise from the manufacture and installation of energy efficient technologies. Since retrofit is a labour-intensive process, direct employment effects from investment in energy efficiency and low carbon heating technologies can be larger relative to investments in other industries (ACEEE 2011). SEAI estimates suggests that up to 60% of total installation costs associated with energy efficiency improvements are attributable to labour costs (Scheer and Motherway 2011).

Indirect employment effects from investments in energy efficiency refer to the jobs that are created in the industries that support the expansion of the retrofit industry (Stavropoulos and Burger 2020). For example, sectors that supply raw materials, tools and support services will also experience employment growth as a result of a growing retrofit industry.

Finally, induced employment effects include the jobs created when workers employed directly or indirectly by the retrofit industry spend their earnings in the local economy. Induced employment may also include income effects for households that observe energy cost savings as a result of retrofit, as well as other economy-wide effects, such as decreasing investments in fossil fuel plants and changes in electricity prices. While such effects can be difficult to quantify, Stavropoulos and Burger (2020) highlight the need for studies to include induced employment effects since they can be either positive or negative and therefore significantly influence the estimated overall net employment effects of policies.

Studies on the employment effects of retrofit and low-carbon heating uptake for Ireland are limited, and findings from other settings may not be applicable given differences in domestic industry make-up. However, in a study of the supply chain impacts of sustainable energy investment in Ireland, SEAI (2014, p. 14) find that Irish firms are well positioned to capture a large share of investments in energy efficiency improvements and renewable heat technologies. The construction sector in particular is well positioned to capture such investments, due to a large share of costs being attributable to installation and maintenance contractors. It is important to note however that employment effects of retrofitting existing dwellings may not necessarily be additional since they can compete with employment requirements in new dwelling construction. This is particularly true given the current acute shortage in new dwelling construction to meet housing demands (DAFT 2021; Finn 2021). Skills shortages are currently being experienced in the construction sector, whereby 91% of engineering leaders list this as a barrier to growing their workforce (Department of Business, Enterprise and Innovation 2020).

5.1.8 The Rebound Effect

Energy reduction claims from engineering estimates of improvements in energy efficiency and/or new technologies are often not realized in practice due to changes in occupant behaviour following retrofit (Sorrell 2007). Since improvements in energy efficiency decrease the cost of energy services for the household, this may lead to an increase in the amount of energy services consumed. For example, improving the thermal integrity of a home may lead its occupants to heat the home to a higher temperature, more often or for a longer duration of time. This phenomenon is often referred to as the *direct rebound effect.*

In addition to direct rebound effects, reductions in energy costs can lead to increased demand for other goods and services - a phenomenon referred to as the *indirect rebound effect* (Gillingham et al. 2016). For example, savings from reduced energy costs might be spent by households on flights. These effects occur where consumers purchase goods whose provision necessarily involves energy use at different stages of their global supply chains (Chitnis and Sorrell 2015; Dütschke et al. 2018).

Finally, macroeconomic rebound effects may also be present, whereby changes in energy demand in response to efficiency improvements lower energy prices, which in turn encourage increased energy consumption within national and global energy markets. Macroeconomic effects may also occur where investments in efficiency improvements lead to new products, applications of even new industries (Dütschke et al. 2018). These effects are typically very difficult to quantify and may not have much relevance for a small open economy such as Ireland.

In a review of empirical estimates of direct rebound effects for residential heating Sorrell, Dimitropoulos, and Sommerville (2009) find the mean value of direct rebound to be approximately 20%, with studies providing estimates in the range of 1.4-60%. Some more recent literature which looks at direct rebound effects such as Hediger, Farsi, and Weber (2018) find similar results (12%). Chitnis and Sorrell (2015) find total rebound effects (direct and indirect) of 41% for measures that improve the efficiency of domestic gas use. Specifically for Ireland, Scheer, Clancy, and Hógáin (2013) find a shortfall of approximately 36±8% between technical potential and measured energy savings following Home Energy Saving (HES) scheme retrofits, which can in part be explained by rebound effects.

5.2 The Rationale for Energy Efficiency/Low Carbon Heating Policy

The rationale for energy efficiency/retrofit policy can be framed in terms of a variety of different benefits, and interestingly, different countries may have different rationales for the same policy response. Kerr et al. (2017) explore this phenomenon by comparing rationales for retrofit policy in the UK, Germany, New Zealand and Ireland, assessing what the key perceived benefits of such policies have been, and how they have changed over time. The authors conclude that the recognition of multiple benefits associated with retrofit policies does not necessarily equate with multiplied policy support, and instead it is more likely that different rationales will have relevance at different times and for different audiences. The findings by Kerr et al. (2017) based on analysis of policy impact assessments and expert interviews are presented in Table 5.3 below:

Table 5.3 Summary of policy rationales (Kerr et al. (2017))

Country	Rationale
UK	Primary rationale: carbon and energy poverty
Germany	Primary rationale: carbon Supporting by employment/economic activity
New Zealand	Primary rationale: health Supported by employment and carbon
Ireland	Primary rationale: carbon and energy poverty Supported by employment

For example, the authors argue that the primary rationales in UK retrofit policy have been carbon emission reductions and fuel poverty elimination, with a growing focus towards fuel poverty over time. Health and employment effects have received comparatively less attention. In New Zealand on the other hand, health appears to be the primary rationale for retrofit policy, with media coverage focusing more on these rather than environmental or economic arguments, and a separate distinct impact assessment report focusing specifically on health (Kerr et al. 2017).

For Ireland, initially a fuel poverty rationale preceded any other rationale with the introduction of the Better Energy Warmer Homes scheme in 2002 (IGEES 2020b). Later rationale evolved to focus on reducing carbon emissions and meeting EU mandated carbon targets. Importantly, despite a significant economic recession, funding for retrofit schemes grew in the 2009 - 2010 period with the introduction of the Home Energy Saving Scheme, helped by an employment creating narrative.

These findings highlight how different multiple benefits are targeted in different countries despite a common policy response. They also illustrate how policy rationales can change over time in response to changing economic climates and public opinion. Different rationales may also be more relevant for different audiences. It is therefore important to consider how retrofit policy is framed, as framing effects may influence its design, delivery and level of policy support (Kerr et al. 2017).

5.3 Trade-offs in Subsidising Efficiency and Low-carbon Heating Technologies

Subsidizing energy efficiency improvements and low carbon heating technology implies trade-offs for policy makers, both in terms of the opportunity cost of using public funds elsewhere, and regarding the choice of individuals and technologies to target. Ensuring that subsidies reach those who need them or would benefit from them the most is essential for maximizing societal welfare gains from heating policy. Allcott, Knittel, and Taubinsky (2015) find that targeting subsidies at certain individuals (or "tagging") can produce larger efficiency gains than uniform subsidies. This arises from the fact that some consumers may be more affected by market failures or distortions, such as imperfect information, credit constraints, landlord-tenant problems, and behavioural biases. Uniform subsidies may fail to reach these individuals and instead accrue to wealthy homeowners who are not subject to these market distortions. For example, the authors find that three major energy efficiency subsidies in the US (for air conditioning, insulation and hybrid cars) are preferentially adopted by consumers who appear to be *less* affected by market distortions – i.e. wealthy environmentalist homeowners.[60]

Low income households are more likely to be affected by market distortions such as credit constraints, lack of information and landlord-tenant principal-agent issues, and at the same time also stand to benefit the most from the multiple benefits described in this chapter. This is particularly true where households reside in very inefficient housing (i.e. E, F and G ratings on the BER scale), where investments in efficiency are likely to deliver the greatest benefits in terms of health, poverty alleviation and comfort improvements.

In addition, targeting specific technologies with subsidy support also involves trade-offs, since many of the low-carbon technology options described in Chapter 2 may be substitutes. For example, providing subsidies for electric heat pumps to households within an area of where future district heating is also likely to be subsidized may lead to double funding. Denmark

[60] In the extreme this may lead to "free-riding" whereby subsidies are taken up by households who may have undertaken improvements regardless of the subsidy. Rivers and Shiell (2016) find substantial free riding on grants for high efficiency gas furnaces in Canada, whereby simulations suggests that 50% of subsidies were received by homeowners that would have adopted the technology even without the subsidy.

currently prohibits heat pumps in some 'collective heat zones', but there is increasing support for them outside these areas (Kerr and Winskel 2021). Careful consideration needs to be given to ensure that the correct technologies are targeted given the menu of options available for a given setting.

5.4 Chapter 5 - Summary

This chapter has explored some of the multiple benefits and costs associated with energy efficiency improvements and low-carbon heating technology uptake. A brief summary of these and the likely impacts for Ireland are presented in Table 5.4 below.

Table 5.4 Summary of multiple benefits and costs

Multiple benefit/cost	Summary
Health	Improved subjective and objective health outcomes expected as a result of low carbon heating policy. Larger benefits likely to accrue to those living in the worst performing dwellings. Retrofit needs to be carried out according to best practice, particularly in terms of ventilation and material choice to maximize health benefits.
Comfort	Significant improvements in occupant comfort expected post retrofit. Reductions in thermal discomfort expected for low-income groups. Comfort is one of the main experiential benefits for households following retrofit, and hence may be important to target when communicating the benefits of retrofit and low-carbon technology adoption.
Poverty alleviation	Significant opportunity for heating policy to alleviate energy poverty and offset the regressive impacts of carbon taxation. Identifying and reaching households in energy poverty is challenging.
Improved asset values	Housing asset values will improve as result of energy efficiency upgrades and low carbon heating technology uptake. Hower this benefit accrues only to asset owners.
Information effects	Imperfect information regarding energy use is a barrier to energy efficiency investment. Information spillovers likely to arise from early adopters and between subsidy schemes.
Energy security	Improvements in energy efficiency and the uptake of low carbon heating can reduce import dependence of fossil fuels, leading to less exposure to international fuel price fluctuations.
Employment	Direct, indirect and induced employment effects likely to arise from low-carbon heating policy. Skilled worker shortages and competition with new dwelling construction likely to be a significant barrier for retrofit policy.
Rebound effect	Direct rebound of up to 30% can be expected following energy efficiency retrofit. Indirect rebound effects are difficult to measure, however warrant further investigation.
Trade offs	Targeting or "tagging" consumers most affected by market distortions such as credit constraints, imperfect information and landlord-tenant problems is important in ensuring efficient outcomes. Targeting of low carbon technologies applicable to relevant settings is also necessary to avoid funding competing technologies.

6 Insights on decarbonising Irish residential heating

Many aspects to the challenge of decarbonising the residential heat sector in Ireland are outlined in this report including the ambition of future decarbonisation targets, the technologies to achieve change, building stock characteristics, household energy behaviour, and the multiple benefits of energy efficiency that may help drive policy design and technology uptake. In this chapter, we highlight key considerations for Irish low carbon residential heating policy that emerged from the analysis. These considerations could increase the effectiveness of policies required to meet national decarbonisation targets. They are outlined briefly in Table 6.1 and presented in more detail in the rest of this final chapter.

Table 6.1 Five key considerations for low carbon heating in Ireland

A multi fuel future	No one fuel source is a silver bullet to residential decarbonisation. Electrification of residential heating can support a transition from fossil fuel use - particularly for standalone dwellings. New developments in urban settings should seek to leverage economies of scale through district heating.
Matching technologies with users	The current suite of policy supports for residential energy efficiency should be reviewed to ensure efficient and equitable allocation of funds and effectiveness of policy instruments. Nationwide guidance on the optimal heating technology choice based on type of dwelling, location, and circumstances would facilitate better matching.
Behaviours and barriers	Behavioural change will be critical in lowering overall energy demand and increasing the uptake of low-carbon heating technologies. Multiple barriers such as high upfront costs and liquidity constraints, sociodemographic characteristics (such as age and income), landlord-tenant principal-agent problems and other behavioural patterns hinder adoption and require policy intervention.
Leveraging multiple benefits	Decarbonisation policies have additional multiple benefits and costs which accrue both to individuals and to society as whole. Such benefits (e.g. health, comfort, fuel poverty alleviation, energy security) and costs (i.e. rebound effects) should be quantified, promoted and considered in analyses of policy impacts, as some are priorities for households and society.

Resource constraints	Achieving targets is conditional on having adequate factors of production - especially skilled labour – that are required for both new build and retrofit targets. Policies such as the B2 retrofit target will likely exacerbate competition for limited resources. Decisions may be needed on allocation and prioritisation of resources for new housing versus retrofit targets. There are trade-offs between new residential developments that are highly efficient with low carbon technologies and retrofit of the existing poor quality building stock. The timing of rollout of new heating technologies and related policies should factor in carbon budget constraints, as well as costs and uptake readiness.

6.1 A multi fuel future

Chapter 2 provides an overview of the legacy heating technologies in Ireland and lists some of the low-carbon heating technology options implemented and available today. A significant dichotomy is identified in the distribution of current heating technologies. Natural gas heating dominates in urban environments while oil is the dominant fuel choice in rural settings. Given the geographical dispersion of properties it is apparent that a variety of low-carbon technologies will be needed to decarbonise the stock of existing dwellings. This geographical dispersion will limit the options available to some households, particularly rural settings, with heat pumps and biomass being perhaps the two main low-carbon heating options available. Policy information and supports should reflect the hierarchy at the household level to improve information for consumers.

Mindful of existing Irish policies, heat pumps and district heating are identified as two promising heating technologies for residential buildings in the low carbon future. Additionally, biogas may have a role in decarbonising heating in homes currently on the gas network, building on the legacy gas network infrastructure in place. Similar to biogas, biomass is often viewed as part of the low carbon future. However, careful consideration must be given to the optimal application of limited biogas resources, especially if greater emissions savings can be obtained through the use of biogas in transport. For biomass, sustainability practices in countries outside of Europe may be associated with a high risk of causing greenhouse gas emissions (SEAI 2021).

The need for change is clear - an international comparison suggests that Ireland has one of the lowest shares of renewable residential heating in Europe (IERC 2020). A review of census data on central heating for the Irish dwelling stock suggests that change is possible - with a previous dramatic shift in heating systems achieved from a majority of dwellings using solid fuel / no central heating in 1991 to a majority of dwellings with oil and gas central heating in 2011 (SEAI 2018). The latest challenge is in linking existing dwellings with the best low-carbon option to achieve change.

A multi-fuel future requires important consideration of the menu of choices and policy supports available to consumers. Much of this report centres on the delicate balance of several energy sources, which often compete with each other at the household level. To provide clarity to consumers and firms, consideration should be given to the design of information and supports so as to encourage households to make the switch to the right heating system for their situation. It should be anticipated that a range of fuels and technologies will be needed in the future to decarbonise residential heating.

A prime example of this conflict is in urban areas, where competition is expected between existing gas networks, heat pumps, and a possible district heating network. In this instance, customers are spoiled for choice, with a risk that consumers may make the wrong choice (to a more carbon-intensive technology) or no choice at all. Both options would be counterproductive to reaching national decarbonisation goals. In Ireland, supports should focus on improving information to help individual consumers navigate the different fuel systems and provide subsidies for a range of low carbon solutions to drive positive change.

Additional regulation could help to direct change in a direction that the market may not deliver in a timely manner. Other countries feature more tailored regulations, including a recommendation to forbid new homes from connecting to the UK gas grid from 2025 (UK Committee on Climate Change 2019) and policy supports in Austria that only subsidise a heat pump where connection to the district heating system is not possible (Austrian Government 2021). This direction would send a clear signal to the market.

Evidence from the Netherlands has shown how countries can rapidly incorporate the use of low-carbon fuels and divest from incumbent energy sources such as natural gas. Overwhelming public outcry there in the aftermath of geological disruption due to fracked gas activity has resulted in a transition towards low carbon renewables, with district heating as an enabling technology for many high-density urban agglomerations. This demonstrates that change can be achieved in a relatively rapid manner, despite the legacy infrastructure investment. It also highlights the vital role of local government in rolling out district heating in urban areas.

6.2 Matching the right technology with the right user

This report has explored the key technologies, behaviours and conditions to reduce emissions in the residential sector. One key insight is that there is scope to improve policy effectiveness through better matching of technologies and end users.

Chapter 3 details how understanding key socioeconomic variables (e.g. age, income, ownership status) and behavioural factors are crucial to determining the market for low carbon heating and energy efficiency upgrades. It notes the need to correctly align the right policies and supports with the right target audience. Failure to do so could result in an Energy Efficiency Gap where individuals fail to adopt energy efficient technologies with a positive net present value (Jaffe and Stavins 1994b). Without targeting policy measures and technologies to suitable users, public funds may be spent less effectively and lead to uptake of expensive technologies, such as heat pumps, in unsuitable dwellings.

Survey research has suggested that factors such as rental status, disposable income, fuel poverty and demographic factors play an important role in determining consumer demand for improving heating systems (Curtis et al. 2018). Importantly, the same study suggests that environmental concerns do not influence the decision to upgrade a heating system (or the specific choice of system) and that homeowners do not always rely on independent energy consultants for guidance to ensure they have the right technology for their situation (Curtis et al. 2018; Mukherjee et al. 2020). These factors play an important role in understanding the scope for achievable change.

As a barometer for the scope for change, a national survey of mature home owners (aged 55 or over) has noted that there is little appetite for downsizing to a smaller dwelling that is big enough for their current needs, a potentially more efficient use of housing resources (IGEES 2020a). Results suggest that 20 per cent of mature homeowners would be willing to downsize, but only if there is a smaller, purpose-built home in the same area for a lower price.[61] There is an inverse relationship between age and openness to downsizing, with relatively younger homeowners with less tenure in their dwelling more receptive to downsizing and to potential policy measures (IGEES 2020a). From the 2016 Census data we note that roughly 30 per cent of owner-occupied households (approximately 600,000 dwellings) had a respondent over 55 years old and this cohort is growing. It is reasonable to expect that the same preferences against downsizing could also oppose substantial home refurbishments.

Aside from the important socioeconomic and demographic considerations, more observable factors are the heterogeneity in dwelling type and heating system. **Chapter 2** highlights the importance of dwelling type and heating system type in designing low carbon heating options, while **Chapter 4** presents district heating as a key enabler for low carbon heating at scale. Optimal matching of technology for dwellings and regions across the country could help to provide a clearer menu of policy options.

As an example - rural areas have significantly more one-off housing, heated by oil and/or solid fuels, than urban areas and therefore often require dwelling-specific measures to decarbonise heating supply. The lack of a gas or district heating network implies that a heat pump is most likely to be the most appropriate technology to decarbonise heating in this type of dwelling. Conversely, urban areas should give priority to creating a district heating network and connecting local dwellings. Proximity to industry and the denser agglomerations of dwellings in urban areas lead to reduced network investment cost per household.

[61] The construction of new, smaller scale and affordable housing in urban areas is a significant challenge. For more, see https://www.irishtimes.com/business/economy/50-000-new-homes-needed-every-year-to-solve-housing-crisis-industry-report-1.4645408

In addition, considering the limited capacity of individuals experiencing fuel poverty in urban areas to afford to make substantial energy efficiency investments, a connection to a low-carbon district heating network might serve as a viable option. Upcoming district heating pilot projects aim to supply space and water heating for urban developments, with the capital network cost spread across all end-users. Connecting to social housing and urban developments would increase the penetration of low-carbon heating technologies for cohorts that might have limited means to join the low-carbon transition. Those individuals are most at risk of being locked into carbon intensive fuel sources that will become more expensive in line with future increases in the carbon tax. District heating offers a way to provide cost-effective low-carbon heating at scale in urban areas to support those in most need.

6.3 Behaviour, Barriers and Timing

Much of this report considers heating technologies and the current policy landscape to stimulate adoption. However, consumer behaviour and buy-in are critical factors for adoption. Put simply - real change can only occur when there is a demand for as well as supply of low carbon technologies. Without appropriate action, change may be delayed and result in failed targets. Recent legislative changes in carbon budgeting highlight the need for timely change.

Chapter 3 has explored some of the main barriers to low carbon heating technology uptake. Well-established barriers such as high implicit discount rates, high upfront costs and liquidity constraints are likely to prevent individuals from investing in low carbon heating. Market failures, or instances where markets fail to allocate resources efficiently due to underlying issues such as imperfect information or landlord-tenant problems are partly responsible for lower-than expected take up of energy efficiency measures. Where market failures are identified there is clear rationale for government intervention to improve societal welfare. This intervention can range from information campaigns to improve awareness of low carbon heating to financial supports and mandates for minimum energy performance standards. In addition, behavioural factors such as present bias, bounded rationality, loss aversion, perceived reliability and administrative burden (or "Sludge")[62] are also likely to hinder adoption (SEAI 2020). Such barriers can be overcome with targeted policy action. For example, the administrative burden associated with applying for grants and uncertainty around the right technology are expected to be alleviated with the introduction of "One-stop-shops" for retrofit. The goal of one-stop-shops is to offer all the services needed to carry out the retrofit of a home – finance, technical, administrative – in one place for the homeowner. It is expected that improved access to low-cost finance may reduce the interaction of present bias and high upfront costs.

The significant upfront costs associated with investing in new heating technologies provide one of the most important barriers to take-up of low carbon heating systems. As demonstrated in Chapter 3, the costs associated with the purchase of heat pump technology can range from €8,000 to €16,000 (Cronin 2021). This does not include the cost of other retrofit measures that are required to upgrade a dwelling to an A or B-rating for efficient heat pump operation, such as underfloor heating and building envelope insulation, which can add significant expense depending on the size, type and initial energy performance of the building. For example, the SEAI deep retrofit pilot programme found that the average total capital cost required to upgrade a home from an average BER rating of F to an average A3 rating is €60,229.[63] Recent estimates compiled for the Department of Environment, Climate and Communications offer similar total cost ranges of between €14,000 and €66,000, depending on the level of works required.[64] These significant upfront costs mean that the payback time for the private householder in terms of the energy saved in the absence of subsidies could be long, and is a function of multiple factors such as future energy prices, and occupant energy behaviour.

The private benefit in terms of energy savings to the individual household is thus likely to be lower than the significant public good associated with the reduced carbon emissions immediately and into the future. This situation justifies policy intervention in the form of a

[62] See for example Sunstein (2020).

[63] Source: https://www.seai.ie/grants/home-energy-grants/deep-retrofit-grant/key-findings/

[64] Source: https://www.gov.ie/en/press-release/government-launches-the-national-retrofitting-scheme/. For example cases of retrofit costs see: https://assets.gov.ie/215293/ff8c1d23-c2fd-4d0c-ba80-3bdd4081c226.docx

subsidy of the costs. The recent National Retrofitting Scheme has taken important steps in assisting homeowners with the upfront costs of retrofitting, paying 50% of costs, and offering free upgrades to homes at risk of energy poverty. The latter scheme is very important to ensure equitable distribution of public funds, as even with substantial grants on offer, households will need to pay a significant sum of their own funds to decarbonise their heating systems. Many households will not be in a position to do this and therefore other financial mechanisms and programmes are needed to ensure not only homeowners with capital can take advantage of subsidies to improve their homes.

Although the uptake of low-carbon technology is important, the behaviour of end-users plays a critical role in how technologies are used once they are installed and whether CO2 emissions savings are realised. Chapter 2 highlights recent evidence from a sample of gas-connected Irish households of statistically significant differences between occupant energy usage and the level expected by the Building Energy Rating (Coyne and Denny 2021b). It finds relatively little difference in kilowatt-hour energy use across the entire sample of houses with different BERs. Analysis of the energy use of different dwellings found over-consumption in the most efficient dwellings and under-consumption in the lowest efficiency dwellings relative to the dwelling BERs (Coyne and Denny 2021b).

- On average, actual energy use for the sample of dwellings is 17 per cent lower than the theoretical BER level.
- Occupants in the most energy efficient dwellings consume more energy than suggested by their BER (AB-rated average 39% above theoretical BER level).
- Conversely, occupants in less energy efficiency homes consume far less energy than suggested by their BER (FG-rated average 56% below theoretical BER level).

Source: Coyne & Denny (2021b)

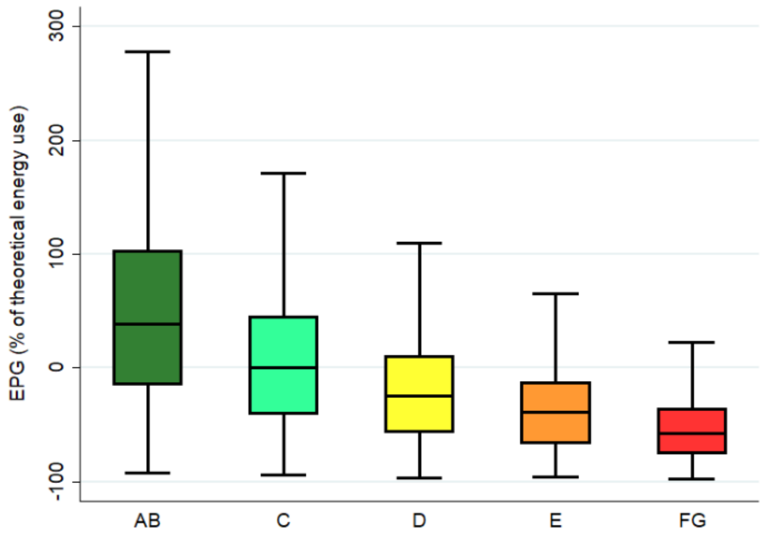

Figure 6.1 Comparison of Energy Performance Gap (EPG)

Source: Coyne & Denny (2021b). Note: Figure presents the EPG as the difference between actual and theoretical energy use as a percentage of theoretical energy use. Each box reflects the interquartile range of EPG, with whiskers denoting the adjacent value. Sample includes 19,251 observations with 9,923 observations of one year of actual energy use and a further 9,328 observations featuring a second year of observed actual energy use. Figure reflects the relative appliance adjustment.

6.4 Leveraging multiple benefits

Chapter 5 notes that there are significant 'multiple benefits' associated with low-carbon heating systems and often relate to occupant wellbeing. Primary goals from a climate action perspective behind residential low carbon heating policy is to lower energy demand, increase energy efficiency, and decarbonise the remaining energy demand. However, an equally important outcome is to improve wellbeing and comfort for occupants - especially among groups that disproportionately experience fuel poverty and health inequity. Evidence from New Zealand noted lower hospital admissions post-retrofit, especially for occupants experiencing respiratory issues (Fyfe et al. 2020). As such, there is a case for policies that target these groups to be co-financed by health departments. Ireland has a strong track record of supporting health-related energy policy, with the *Warmth and Wellbeing Scheme* in place to support occupants in fuel poverty with respiratory illness (SEAI 2018).

Earlier initiatives such as the *Better Energy Warmer Homes* scheme helped to support 124,345 homeowners from 2009 and 2019 that experienced fuel poverty that were also in receipt of certain social welfare transfers. Such initiatives require cross-departmental collaboration from SEAI as grant provider and the Department of Employment Affairs and Social Protection to verify the occupant's circumstances. Deeper collaboration between agencies could lead to more proactive targeting of occupants in most need that could achieve energy savings. Chapter 5 noted that the *Better Energy Warmer Homes* scheme could be extended to support tenants (or their landlords) in instances where occupants experience fuel poverty.

The unique nature of retrofit and the difficulty in prioritising groups to receive supports is a challenge. Considering the important health-related benefits as part of cost-benefit analyses could help prioritise dwellings that need support. In an environment where labour and material resources are stretched, prioritising projects with the greatest energy and health benefit could be useful. This is especially true if such dwellings can provide an equal level of energy or carbon savings - helping policymakers to simultaneously address two needs.

The flip side of multiple benefits of low carbon heating technology is rebound effects. There is likely to be a trade-off between improved comfort and well-being in fuel-poor dwellings post-retrofit and the energy savings realised. The sample of dwellings studied by Coyne and Denny (2021b) show clearly that households living in the worst BER-rated homes are not spending the amount judged sufficient to heat a home with that level of energy performance. The factors underlying deviations in energy use often reflect factors such as income poverty and the type of heating system, as well as energy performance of the building. It can be expected that after an upgrade to a more efficient home with low-carbon heating, the household may use a similar amount of energy as before but with a much greater level of comfort.

It is important that policy makers recognise both the multiple benefits and rebound effects associated with a transition to low carbon heating systems. Identification of the multiple benefits of efficient, low-carbon heating systems will help with policy design that motivates people to invest in these technologies by understanding what matters most to them. It can also help with sourcing funding for low carbon heating from a range of sources such as the health department, social welfare department, as well as private investment and the department of environment. Recognition of the rebound effects is crucial to be able to realistically estimate the likely energy and carbon emissions savings from a low carbon heating programme of investment.

6.5 Resource constraints

There is increasing awareness that significant financial and labour constraints are likely to impede delivery of ambitious heating decarbonisation targets (CCAC, 2021). A number of issues could help to unlock the potential and achieve national targets. In particular we focus on the supply of skilled labour to achieve change, the national B2 retrofit target, the tailored nature of retrofit, and timing of action as issues for consideration.

The importance of having sufficient factors of production to achieve the required residential decarbonisation change cannot be overstated. The need for suitable labour has been identified by the Expert Group on Future Skills Needs (EGFSN) - an independent advisory body to the Irish government (EGFSN 2020). They have highlighted the significant demands that will be placed on human capital to meet national projects such as the Climate Action Plan (Government of Ireland 2019). In addition to limited labour supply in the short term, the report also emphasises the needs for upskilling and retraining for the current labour force to accommodate new standards that require Building Information Modelling (BIM) and expertise with Nearly-Zero-Energy Buildings.

Under the latest Housing for All plan, an average of 33,000 new homes should be built each year across the country to 2030 (Government of Ireland 2021c). Some analyses suggest that this falls short of a need of 50,000 homes per year to reflect demographic changes (Lyons, 2021). A key pillar of Irish residential climate action policy is based on the goal to upgrade 500,000 dwellings to B2 BER standard by 2030 (Government of Ireland 2019). These two policy ambitions could stand in conflict, especially if both policies increase competition for construction materials and skilled labour. The Housing for All plan identifies that 27,500 more skilled workers are required to deliver change, while the national retrofit target seeks an additional 20,000 workers.[65] With substantial goals to decarbonise the built environment, there is a need to ensure that labour supply has the capacity to meet the challenge. National policies should be designed to provide skilled labour to meet both targets - otherwise a conflict will emerge.

Analysis of the skills deficits facing the Irish labour market for the low carbon economy highlights that there is sufficient labour in some areas (e.g. engineers, planning and legal), but there is a need for upskilling in the space of low-carbon technologies - both at third level and in continued professional development (EGFSN 2021). This report signals a clear labour and skills shortage within craft and retrofit occupations which could hinder national retrofit targets. One issue highlighted is the need to reach workers in a sector with a high rate of self-employment among skilled tradespeople who might have limited capacity to avail of professional development support (EGFSN 2020).

There has been recognition by policymakers as part of the Action Plan for Apprenticeship 2021-2025 to boost work-based learning that meets current and emerging skills needs through a single system with a clear governance framework (DFHERIS 2021). It is intended that there will be 10,000 new apprentice registrations per annum by 2025 (DFHERIS 2021). One key aspect of the plan includes additional support targeted to small and medium enterprise in areas such as apprentice supervision and recruitment. This could help encourage employers in the built environment sector to take on apprentices and also offer apprenticeships that appeal to a wider pool of potential applicants. Delivery of this plan is crucial to mitigate the competition for skilled workers in the decarbonisation strategy and avoid cost increases.

In a situation with labour market constraints, it may be necessary for policymakers to consider whether to prioritise new housing construction or the retrofit of existing buildings. The SEAI Deep Retrofit Pilot Programme demonstrated that deep retrofit is possible but costly, with the average total capital cost from the participating 508 homes to upgrade a home from the

[65] See https://www.irishtimes.com/business/economy/delivery-the-only-true-measure-of-success-for-new-housing-plan-1.4669616

average F rating (416 kWh/m2/year) to A3 (52 kWh/m2/year) at €60,229, particularly for the poorest quality homes.[66] New houses on the other hand are all built to minimum A3 standard and currently are in severe shortage. A realistic assessment of the construction sector is required to understand the optimal use of limited construction resources in the near and longer term and make strategic choices that will deliver societal and climate goals over the next decade.

A related issue is the scale and depth of the planned retrofit of the building stock by 2030. Good quality data is needed to understand the implications of targets and the scale of transformation required. Although all residential buildings in Ireland have not had an assessment of the energy performance, recent efforts have been made by the Central Statistics Office to scale up the existing BER database to the national dwelling stock using information on the dwelling location, the period the dwelling was built, and the dwelling type (Central Statistics Office 2021). Table 6.2 presents the BER distribution scaled to national level and split by dwelling type. From this we observe that the distribution of dwelling energy performance is concentrated in the middle of the distribution, with over half of households being either C- or D-rated. The second observation is that there is a substantial share of low rated dwellings, with roughly a quarter of the dwelling stock being E-rated or worse.[67] In total, 89 per cent of the dwelling stock (1.38 million homes) require upgrade to reach at least a B2 standard, as is envisioned in the Climate Action Plan (Government of Ireland 2019). Although many dwellings may require a smaller improvement, others require substantial work.

[66] See https://www.seai.ie/grants/home-energy-grants/deep-retrofit-grant/key-findings/

[67] This region of the distribution is likely to understate the true number of less efficient dwellings, as the measure of the national dwelling stock considered omits roughly 8 per cent of dwellings with no comparable dwelling with a BER nearby.

Table 6.2 BERs extended to national level (2009-2021)

	Energy Rating (% of row)													Total
	A	B1	B2	B3	C1	C2	C3	D1	D2	E1	E2	F	G	
Apartment	8	2	6	9	11	11	10	11	10	6	5	4	7	166,491
Detached house	5	1	3	7	10	12	12	12	11	6	5	6	11	685,906
Semi-detached	7	1	2	5	10	13	13	14	12	7	5	5	5	442,018
Terraced house	6	1	2	6	10	11	11	12	11	8	7	7	9	259,949
Total	**6**	**1**	**3**	**7**	**10**	**12**	**12**	**12**	**11**	**6**	**5**	**6**	**8**	**1,554,364**

Source: Central Statistics Office (Central Statistics Office 2021). Note: Total dwellings reflects the 2016 Census occupied dwelling stock value with a roughly 8% deduction for properties with no comparable BER-rated dwelling nearby.

Dwellings with lower initial energy performance will incur higher costs of retrofit to achieve B2 level. At the same time, they are more likely to feature occupants experiencing fuel poverty and under-heating (relative to their BER). In this sense, retrofit could deliver multiple benefits for households in the least energy efficient dwellings but at higher cost. Research by the Contract Research Unit in IT Sligo has flagged potential unintended consequences as a result of the national target of 500,000 retrofits to B2 level (Gavin 2020). They suggest that the B2 requirement for any substantial retrofit (e.g. internal dry lining or any other measure affecting a quarter of the building envelope) might cause retrofit service providers to only improve homes that can reach B2 standard more easily or at lower cost (Gavin 2020). This could marginalise older, less efficient homes or occupants that cannot afford to upgrade to B2. Therefore, a requirement to retrofit all homes to B2 level might not support change among the least energy efficient dwellings. Clearly, affordability and access to suitable finance help determine the likelihood of a retrofit occurring. Conventionally, support is weighted towards projects that provide the greatest net present value. However, retrofit delivers important non-monetary benefits - especially for homes experiencing fuel poverty and in low-efficiency dwellings - and should be encouraged if there are social benefits.

More flexible eligibility requirements for grants to upgrade poorer quality homes could be considered. Figure 6.2 illustrates how the retrofit of a national average D1 dwelling to B2 would reduce energy demand by 125 kWh/m2/year. However, a retrofit from G to E1 would provide a higher expected energy saving of 150 kWh/m2/year. Based on this, there is clear merit for improvements in energy performance within the lower bands of the BER scale as a first step that can possibly deliver greater energy and emissions savings at lower cost.

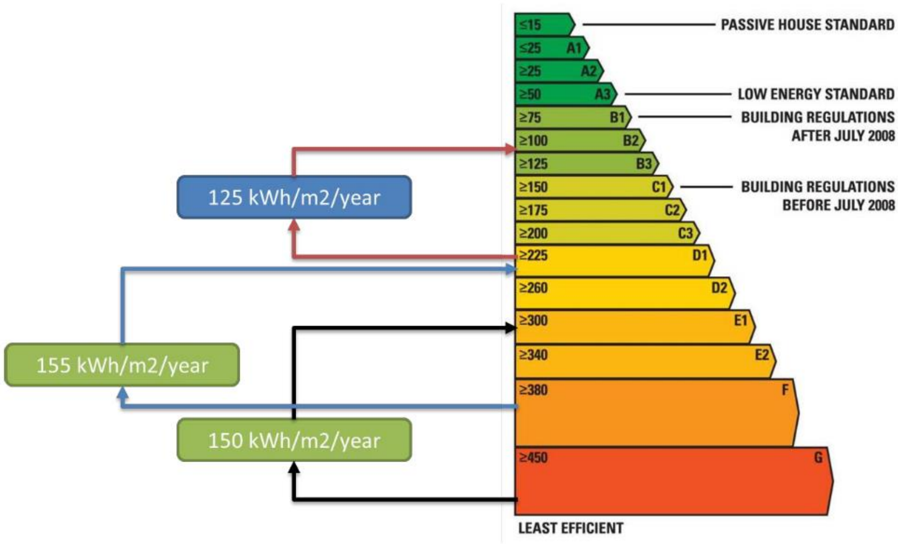

Figure 6.2 Expected energy savings from retrofit (Source: Gavin 2020)

National policy should seek to be inclusive of low-efficiency dwellings - especially when considering the multiple benefits of retrofit for occupants. It may make more sense in some cases for a hybrid policy that supports an improvement in energy demand to a lower than B2 level and to decarbonise the remaining energy demand, rather than waiting until sufficient funds are available to upgrade all the way to B2 level. Particularly in urban areas where the renewable choices include biogas and district heating which do not require high energy performance of the building, this could be a good option for poor quality homes. Grant supports could target an equivalent BER improvement in kilowatt-hour terms, limited to account for larger homes (Gavin 2020). This alternative criterion would support change for low-efficiency dwellings, could potentially achieve greater energy savings and realise the important social and health-related benefits of supporting occupants that disproportionally experience fuel poverty.

Lastly, the timing of action in delivering emissions reduction from residential heating is an important consideration. This report has considered the technologies required to reduce emissions from heating in the residential sector, some of which are more readily available in the immediate term than others. National climate policy has set renewable heat and energy demand targets for the residential sector for 2030. A strategic roadmap is required to deliver a pathway to achieve these targets. It should outline whether more emissions savings can be achieved with greater societal benefit by concentrating initial efforts on upgrading the largest number of homes possible with energy efficiency and renewable heating measures to less than B2 level (shallow) or a lower number of homes to higher performance (deep retrofit).

In all cases, strong action needs to be taken in the early decade to 2030 in decarbonising the heat sector in Ireland. National carbon budgets are consistent with the 2050 net-zero greenhouse gas target featured in Article 4 of the Paris Agreement and as part of the European Green Deal. However, the agreement to limit global temperature rise to 1.5°C above pre-industrial levels (Article 2 of the Paris Agreement) places an urgent burden on achieving change sooner rather than later. Mc Guire et al. (2020) outline how later action on decarbonisation can lead to substantially higher global temperature rise.

Ireland has enshrined the net zero emissions target in law (Government of Ireland 2021a) and has developed carbon budgets that span five-year periods with the goal of reaching the emissions target (CCAC 2021). The first carbon budget to 2025 requires a lower annual reduction (4.8%) than the second 5 year period (8.3%). For the residential heating sector, this should not be interpreted as less action in the first half of the decade. Changing heating systems in homes is a slow process, as it requires significant, potentially once-in-a-lifetime, capital investment and is only carried out infrequently. Therefore, to achieve the scale of decarbonisation required by 2030, sustained effort is needed throughout the decade. Households identified as more open to upgrading will need to begin the process in the immediate future, as slower-to-adopt households will likely only replace their heating systems later. There will be a lag between any policy measures introduced in the heating sector, the resulting implementation of new heating technologies, and the gains from the emissions savings. Therefore, to achieve the step change in reducing emissions from the heating sector in the second half of the decade, strong action is required immediately.

6.6 Concluding remarks

This report collates analysis on future decarbonisation targets, the technologies which will be required to achieve change in the sector, Ireland's building stock characteristics, private household energy behaviour, and the multiple benefits of energy efficiency that may help drive policy design and technology uptake. This concluding chapter draws together the analysis in the preceding chapters and highlights five specific considerations which have emerged from that analysis to increase the effectiveness of residential heating policies:

1. **A multi-fuel future** – residential decarbonisation will require a myriad of technologies to reflect the heterogeneity in the sector
2. **Technologies will need to be matched with users** – ensuring efficient and equitable allocation of supports and matching optimal heating technology based on dwelling type, location and household circumstances
3. **Behaviours and barriers** – a mindset change is required and barriers such as upfront costs need to be removed in order to increase residential decarbonisation
4. **Multiple benefits** – there are other benefits to decarbonisation such as health, comfort, energy security, reduction of fuel poverty which need to receive more attention in the promotion and evaluation of policy impacts
5. **Resource constraints** – the prioritisation and allocation of scarce resources, such as skilled labour supply, requires careful consideration to ensure that resources are targeted at those dwellings and locations which yield the greatest decarbonisation impact.

This report has considered the latest policies and technologies that seek to reduce emissions and energy use in the Irish residential sector. It covers the latest policies, legacy and future heating technologies and factors influencing adoption of low-carbon technologies. It details the substantial opportunity to use low-carbon district heating in urban Irish settings and details academic evidence into the multiple benefits associated with improving energy efficiency. By highlighting international leadership and academic evidence across these areas, it should serve as a valuable and timely resource for decision makers.

In this chapter we have expanded on some selected insights from the report, which identify areas for further policy attention. We have highlighted some of the constraints facing policymakers that warrant further consideration and some opportunities for substantial growth. This report seeks to provide additional proposals and refinements to current policy to realise change. Although the focus of the report is on the residential sector, similar issues may feature in other settings.

The 2030 policy targets for the residential heating sector chart a course towards a low-carbon economy in 2050. Market constraints and stage of readiness of different heating technologies and consumer awareness mean that some trade-offs and additional policy decisions may be needed to achieve the 2030 CO2 emissions targets for the residential sector. In particular, the relationship between energy efficiency and heating decarbonisation targets in the residential sector may need to be considered. These targets are related but different and more understanding of their complementarity or substitutability is needed. Optimising the efficiency of energy resources and therefore energy demand reductions should always be a priority of energy policy. However, if the ultimate goal is to reduce carbon emissions, then the energy efficiency improvement required could be flexible and dependent on the existing energy performance and decarbonisation heating technology suitable for the individual home. For example, while heat pumps can decarbonise heating they are only suitable in homes that have low energy demand so energy performance targets are required; biogas and district heating can be slotted into buildings already on the grid, regardless of energy performance. Trade-offs in terms of prioritisation of new buildings and retrofit of existing buildings may also need to be considered in the initial part of the decade if construction skills shortages prevail.

Heating policy should be designed to account for differences in socioeconomic, locational, technological, and building characteristics. Careful targeting and matching of technologies with appropriate buildings, regions and consumers will yield more effective results. Without consideration of the heterogeneity of population and building characteristics across urban and rural areas, policy supports could be rendered ineffective due to mismatch. By converting the criteria for the B2 retrofit target into a kilowatt-hour improvement, supporting the rollout of low-carbon district heating, matching low-carbon heating technologies for appropriate settings, and targeting consumer supports to individuals who stand to gain the most from the multiple benefits of energy efficiency, policy measures can achieve more impact. Increased supports to improve the supply of skilled workers across the built environment sector are also a necessary prerequisite for change to occur.

Climate change is the issue of our time, with excellent work being performed across the public and private sector to reach a low-carbon future. With many low-carbon technologies in existence, resources should be dedicated to learning more about energy use and consumer preferences to help understand the barriers towards adoption. Only by learning about the barriers and their scale can they be overcome as part of a just transition that allows everyone - regardless of socioeconomic status - to make the low-carbon future a reality.

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8 Appendix

The research team hosted a series of workshops with expert stakeholders from industry and policy to gain a deeper understanding of the current landscape in Ireland and abroad. Workshops featured a lively diversity of opinion in discussing challenges facing the implementation of policies. This dialog resulted in several key considerations:

- Certainty of supports

It was noted that further clarity on budgetary commitments over longer term, multi-annual horizons may provide sufficient certainty to allow industry to achieve the targets for improving residential energy efficiency. In particular, there is increased emphasis on education and training resources to provide qualified workers that can turn policy into reality. The need for pre-emptive workforce development has been identified to foster the significant restructure of local economies to transition to a low-carbon economy (NESC 2020).

- New data - new opportunities

The emergence of ground-breaking data sets that can help to provide greater understanding of our energy demand. Such information can help to devise targeted policies that are achievable and realistic. A prime example of this is recent evidence that the majority of high heat density areas in Ireland are compatible with district heating networks to help achieve 40% renewable heat in Ireland by 2030 (Renewable Energy Ireland 2021).

- Sustainable financing

A common theme during the discussion was the disconnect between substantial upfront investment in energy efficiency compared to the long-run benefits it provides. It was noted that low-cost financing from the European Union Recovery and Resilience Facility[68] could offer a solution. This Facility, launched in February 2021, features €312.5 billion in grants and €360 billion in loans to support reforms and investments to mitigate the economic impact of the COVID-19 pandemic and support member states during the green transition.

[68] https://ec.europa.eu/info/business-economy-euro/recovery-coronavirus/recovery-and-resilience-facility_en