AN INSTITIÚID UM THAIGHDE EACNAMAÍOCHTA AGUS SÓISIALTA
ESRI ECONOMIC & SOCIAL RESEARCH INSTITUTE

ESRI SPECIAL ARTICLE

A REVIEW OF RESIDENTIAL HEAT DECARBONISATION IN IRELAND

MUIREANN LYNCH, MIGUEL TOVAR AND NIALL FARRELL

Available to download from www.esri.ie
https://doi.org/10.26504/QEC2026SPR_SA_Lynch

This Article has been accepted for publication by the Institute, which does not itself take institutional policy positions. Special Articles are subject to refereeing prior to publication. The authors are solely responsible for the content and the views expressed.

THE AUTHORS

Muireann Lynch is a Senior Research Office at the ESRI and an Adjunct Associate Professor at TCD. Miguel Tovar Reaños is a Research Officer at the ESRI and Adjunct Assistant Professor at TCD. Niall Farrell is an Associate Research Professor at the Economic and Social Research Institute (ESRI) and an Adjunct Professor at Trinity College Dublin (TCD).

ACKNOWLEDGEMENTS

The authors acknowledge funding from the Energy Policy Research Centre, as well as helpful comments and contributions from John Curtis, Fabio Bozzollo and Anita Vollmer. All remaining errors or omissions are our own.

A review of residential heat decarbonisation in Ireland

Muireann Lynch, Miguel Tovar and Niall Farrell

ABSTRACT

Ireland's Climate Action Plan targets rapid decarbonisation of residential heat, with 2030 targets for deep retrofits (500,000 homes to BER ≥B2), large-scale heat-pump deployment (400,000 in existing dwellings), and district heating (up to 2.7 TWh/yr). This article reviews progress to date and the empirical evidence on whether the current policy mix is likely to deliver the required emissions reductions. Using the latest administrative statistics, we show that delivery is materially off-track: by end-2024, deep retrofits reached 57,932 (11.5% of target) and heat-pump installations 14,194 (3.5% of target). Linear projections based on post-pandemic trends imply that even continued acceleration leaves substantial shortfalls by 2030, with district heating similarly unlikely to meet targets. We synthesise evidence on the barriers driving under-delivery—high household capital costs, disruption, administrative complexity, information constraints, and landlord–tenant split incentives—and highlight capacity trade-offs with housing supply via constrained construction labour and complementary electricity-network investment needs. We review the recent literature on retrofits to date, which shows that measured decarbonisation may be overstated because BER/EPC metrics can diverge substantially from actual energy use. Finally, we discuss supplementary policy pathways aimed at hard-to-reach households and system-wide efficiency: targeted fuel switching (including regulated renewable heat blends and sustainable liquid biofuels with robust traceability), more progressive targeting of supports toward low-income/high-impact homes, and enabling flexibility through smart controls and thermal energy storage. We conclude that meeting climate objectives will likely require both faster delivery of existing measures and additional, better-targeted interventions grounded in representative, data-driven evaluation.

1. INTRODUCTION

Ireland has set ambitious climate change targets, aiming to reduce emissions by 51% by 2030 relative to 2018 (Government of Ireland, 2021). The latest projections from the Environmental Protection Agency indicate that Ireland will fall short of this target, with an expected reduction of 23% by 2030, assuming full implementation of all policies and plans to date (Environmental Protection Agency, 2025).

The primary mechanism in place to limit emissions is carbon budgets, with the carbon budget from 2021-2025 set at 295Mt of CO_2 equivalent and the 2026-2030 carbon budget set at 200Mt of CO_2 equivalent. 63% of the 2021-2025 carbon budget had been exhausted by the end of 2023. A budget of 29 Mt CO2 equivalent has been set for the residential sector for 2021-2025, with 62% of it exhausted by the end of 2023. Emissions in the residential sector were 5.35 Mt CO_2 equivalent, or 9.7% of total emissions, in 2023. This represented a decline of 7.1% on the previous year, with fossil fuel usage declining by 22%, 13%, 0.3% and 14% for coal, peat, kerosene and natural gas, respectively.

Specific decarbonisation measures for each sector have been set as part of the Climate Action Plan (Government of Ireland 2025). The measures for decarbonisation of residential heat rely on significant investment from households and government, as well as behavioural change by households. This is in contrast to the electricity and transport sectors, which have a greater reliance on investments by the State as well private companies such as power generation companies and public transport providers. Furthermore, some *ex post* analyses of residential decarbonisation measures taken to date has been conducted, the findings of which can inform policy additions and adjustments going forward. A review of progress in the residential heating sector to date, and the research done on this specific sector, is therefore presented.

This special article will review the data and evidence relating to the progress in achieving residential heat decarbonisation targets and the effectiveness of measures employed to achieve decarbonisation objectives. We find that progress is lagging considerably behind that required to achieve the stated targets. Should these targets nonetheless be achieved, there is emerging evidence suggesting that the decarbonisation realised as a result will not be sufficient to achieve our climate objectives. Potential supplementary measures to aid Ireland in achieving our climate targets are discussed.

2. OUTLINE OF RESIDENTIAL HEATING POLICIES AND PROGRESS

Ireland's decarbonisation polices are outlined in the Government's Climate Action Plan (Government of Ireland 2025). While the Plan undergoes regular updates and revisions, the targets for residential heat decarbonisation have remained relatively stable since the 2019 Climate Action Plan (Government of Ireland, 2019). 2030 policy targets include:

- upgrading 500,000 homes to a Building Energy Rating (BER) of B2 or greater
- installing 400,000 heat pumps in existing dwellings and 200,000 heat pumps in new dwellings
- serving up to 2.7TWh/year, or 10% of heating demand, from district heating

Progress on these targets has been slow to date, however: while there have been over 186,000 home energy retrofits from 2019 to 2024, only 57,932 have been to a BER of B2 or higher (referred to as "deep retrofits") (SEAI, 2025). This amounts to 11.5% of the 2030 target for deep retrofits. Progress on heat pumps has been even slower, with just 3.5% of the targeted number installed by year end 2024. Table 1 shows the most recent figures for annual deep retrofits and heat pump installations.

TABLE 1: DEEP RETROFITS AND HEAT PUMP INSTALLATIONS TO DATE

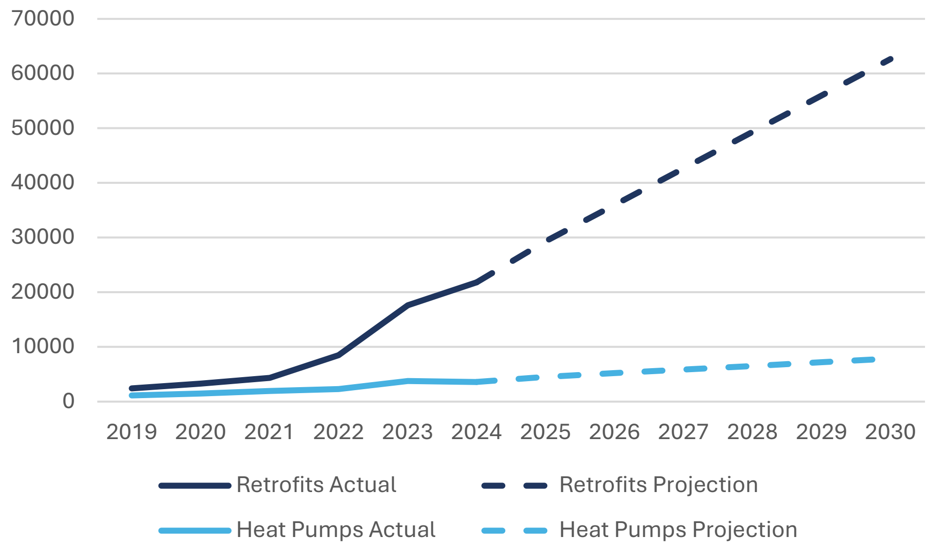
Year	Retrofits	Heat Pumps
2019	2423	1130
2020	3275	1454
2021	4340	1972
2022	8476	2271
2023	17601	3769
2024	21817	3600
Total	**57932**	**14194**

Source: SEAI (2025)

While there has been a significant acceleration in retrofits and heat pump installations alike, the current rate of progress suggests we will fall far short of the 2030 targets. Figure 1 fits a linear trendline to the data from 2022-2024 (previous years are excluded as Covid-19 restrictions meant construction activity in general was significantly curtailed) and projects annual progress towards both targets. Assuming this same acceleration is maintained every year until 2030, total deep retrofits by 2030 are projected to reach nearly 334,000, or 66.7% of the target, while total heat pump installations are projected to reach nearly 51,400, or 12.9% of the target. Deep retrofit and heat pump installations must therefore accelerate even faster than the rate seen to date to reach the 2030 targets. Indeed, SEAI

(2025) state that we need to deliver, on average, 75,000 retrofits per year to meet the 2030 target. This is over three times the 2024 rate of retrofit installation, and a linear continuation of the current rate of acceleration does not see annual retrofits passing 75,000 even by 2030.

FIGURE 1: ACTUAL AND PROJECTED DEEP RETROFITS AND HEATPUMP INSTALLATIONS PER YEAR



Progress on district heating is similarly delayed. Meeting the target of 2.5TWh of heat demand requires serving 187,000-314,000 homes with district heating by 2030. Current estimates suggest that 60,000 homes, at most, will be connected (Mac Uidhir and Rogan 2025), achieving between 20%-32% of the target.

There are multiple policies in place to support these targets, shown in Table 2. For the most part, the policies take the form of financial incentives to invest in retrofitting and/or low carbon energy technologies. The incentive takes the form of a direct grant or a VAT cut, with the decision to undertake the investment, and thus to avail of the financial incentive, generally made by the homeowner. The exception is the Warmer Homes Scheme, applicable to low-income households, and the Renewable Heat Obligation (Department of the Environment, Climate and Communications 2024). Under the Warmer Homes Scheme, low-income homeowners apply for retrofitting, the cost of which is entirely publicly funded, but the retrofit measures themselves are chosen by SEAI, while decisions to invest in local authority housing is undertaken by the local authority itself. While SEAI chooses the measures to be installed in the case of the Warmer Homes Scheme, the homeowner still must apply for the scheme on their own initiative.

The Renewable Heat Obligation Scheme, due to become operational in 2026, will require fossil fuel suppliers of fossil fuel for heat to demonstrate that a proportion of the energy they supply is from a renewable source. This proportion will initially be 1.5%, rising to 3%. This is the only policy that relates to the decarbonisation of residential heat where the full implementation is not dependant on decisions made by the homeowner. Thus, residential heat decarbonisation to date has primarily been in modular form, with homeowners deciding on an individual basis whether, and to what extent, to decarbonise their heating.

TABLE 2: OUTLINE OF POLICIES AND SUPPORTS FOR RESIDENTIAL HEAT DECARBONISATION

Policy	Description	Decision maker
Better Energy Homes Scheme	Grants for individual retrofit measures	Homeowner
One Stop Shop Scheme	Grants for deep retrofits	Homeowner
Warmer Home Scheme	Grants for retrofit measures for low income households	Homeowner (actual measures chosen by SEAI)
Home Energy Upgrade Loan	Low cost loans for financing retrofit measures	Homeowner
Energy Efficiency Retrofit Programme	Deep retrofitting local authority housing	Local authorities
VAT rate cut on solar panels	Removal of VAT on solar panels for residences and schools	Homeowner
VAT rate cut on heat pumps	Removal of VAT on heat pumps and associated heating systems	Homeowner
Renewable Heat Obligation	Requires 1.5% of fossil fuel to be met by renewable fuels (not yet operational)	Supplier

Investment in the networks for district heating can be undertaken by public or private entities. For example, the Tallaght District Heating Scheme operates under HeatWorks, a not-for-profit utility that is fully owned by South Dublin County Council. However, there are no direct grants or financial incentives to support district heating to date.

Policy support is therefore concentrated on efficiency and electrification, while policies regarding switching from fossil fuels to alternative/biofuels is via regulation rather than subsidisation.

There are several challenges to accelerating progress towards decarbonising the residential sector that have been identified in the literature. This paper will summarise these findings and discuss some potential paths forward.

3. CHALLENGES TO DECARBONISATION VIA RETROFITTING

A number of challenges to decarbonisation via retrofitting have been identified in the literature, encompassing financial, informational and behavioural barriers. In the case of heat pumps, (Zhu et al. 2023) demonstrates that failing to include these barriers in energy systems modelling will lead to a misidentification of the optimal policy. This section reviews the barriers as they apply to Ireland.

A. FINANCIAL BARRIERS

Capital costs are a significant barrier to retrofitting in particular, as well as to heat pump installation. Data from the One Stop Shop scheme administered by SEAI finds that that median cost of a deep energy retrofit ranges from €22,914 for an apartment to €66,503 for a detached house, with the portion of the cost covered by the homeowner ranging from €16,378 to €42,900 (SEAI 2025c). If the full cost to the householder is borrowed over five years at a rate of 3%, which is available under the Government-backed retrofit loans scheme, this equates to a monthly loan repayment of €294.05 for apartment dwellers and €770.06 for detached house dwellers. These repayments are equivalent to 19.6% and 70.0% of median rental payments, respectively[1], or 35.1% and 97.6% of average mortgage repayments, respectively (calculated from (Central Statistics Office 2023)). The retrofit costs are offset by an energy expenditure saving of just under €700 per annum for an apartment and just under €900 per annum for a detached house, assuming a pre-retrofit BER of D[2]. The financial burden of the retrofit costs that accrue to households therefore represents a significant increase in expenditure on accommodation, even when the entirety of these costs is financed at a low rate.

In the rental market, (Kren et al. 2025) finds that the costs of deep retrofitting a rental property from a C rating costs €30,000, while a deep retrofit from a G rating is €43,000. The rental market also suffers from the "split incentives" problem: a resident homeowner benefits from reduced bills and an increase in property value from an energy retrofit. A tenant benefits only from the former. In most circumstances, the landlord benefits only from the latter, but may benefit from the former if markets are sufficiently competitive that energy costs are capitalised into rents. This is unlikely to be the case in a market characterised by excess demand, like the Irish rental market (Gillingham et al. 2012; International Energy Agency 2007; Petrov and Ryan 2021). This further reduces the incentive to retrofit rental properties relative to owner-occupied dwellings. Other factors also place barriers to landlord investment in retrofitting, including the pause in tenancy and rental income foregone, although the possibility of increasing rent by more than the rent pressure zone cap can ameliorate these disincentives somewhat. Nevertheless, the total expenditure required to update the private rental stock is estimated by (Kren

[1] Median rental costs per property type sourced from the RTB.
[2] Calculated from archetype data provided as part of the SEAI heat study

et al. 2025) at between €7 and €8bn, with the majority of landlords unable to afford a retrofit of €25,000 or more.

B. BEHAVIOURAL AND INFORMATIONAL BARRIERS

In addition to financial barriers, behavioural and informational barriers to retrofitting and electrification have been identified in the literature. Recent research has found that there is a considerable cohort of the population who may not wish to install a retrofit. (Curtis et al. 2024) found that 21% of homeowners consider themselves to have completed any renovations they would undertake, including energy saving measures, but these measures may encompass small or negligible energy efficiency measures – the total proportion of the building stock to have undergone a deep energy retrofit to date is less than 5%, while the proportion of households to have undertaken any retrofitting measures at all is less than 10%. A further 23% of homeowners agreed with the statement "We're content with our home as it is. We wouldn't dream of making any major changes to its layout or physical properties". This suggests that over 40% of homeowners are highly unlikely to undertake a deep retrofit or to switch to a heat pump heating system. Any attempt to reduce emissions from this cohort of homeowners must utilise alternative pathways.

For those homeowners that may consider renovations or upgrades to their home, one non-monetary barrier to doing so is the disruption that building improvement works can cause for households. This potentially includes the vacation of part or all of the premises for the duration of the work. (Curtis et al. 2024) estimates the median monetary value of this disruption to range from €9,000 for minor disruption to €24,000 for major disruption. In other words, this is the sum of money a household would need to be paid to compensate them for the inconvenience of the disruption. This is a monetary estimate of the cost of disruption and cannot be amortised like capital

costs and so represents an upfront barrier.

The literature also shows that low-income households may abandon applications even when retrofit measures are offered for free, indicating that significant barriers persist for these households, despite the absence of financial constraints (Pillai et al., 2021). This study draws on administrative records detailing application and processing data from the Better Energy Warmer Homes Scheme. The authors report that 9% of eligible households abandon their retrofit application, attributing this to communication issues. A smaller number of planned retrofit measures was linked to a higher likelihood of abandonment—suggesting that households perceive fewer measures as offering limited benefits. The authors argue that families can struggle to assess the long-term financial and environmental benefits of retrofits accurately. They recommend strengthening advisory and consultation services—particularly at the initial stages—to better communicate these benefits and reduce abandonment rates.

However, abandonment may represent only one side of the challenge. Some households never apply for government assistance because they view the process as overly complex. (Tovar Reaños et al. 2024) conducted a telephone survey of Irish homeowners to investigate which household types opt not to take advantage of retrofit support. They found that older households are more likely to cite administrative complexity as a barrier, while high-income households are less likely to avoid assistance.

A lack of practical information also emerges as a significant barrier to retrofitting. Tovar et al. (2023) found that, after high costs, insufficient information was among the most common obstacles preventing households from engaging in retrofits. Their study shows that households that have previously undertaken unrelated energy efficiency improvements are more likely to retrofit. Similarly, knowing someone who has completed a retrofit increases the likelihood of exploring it—indicating that familiarity and access to information play a critical role in decision-making.

C. TECHNICAL AND PERFORMANCE BARRIERS

In Ireland, the Building Energy Rating (BER) system is the common benchmark for measuring household energy consumption and therefore progress towards achieving residential decarbonisation. Research suggests however that BER-predicted energy consumption deviates from actual consumption, and therefore the energy saving benefits of retrofit installations, as determined by a dwelling meeting a given BER (specifically, B2 or higher) may be overestimated. This has important policy implications: even if we reach our retrofit target, we may not achieve sufficient decarbonisation to meet our climate target.

This section will review Ireland's BER and the literature relating to the ability of this metric to accurately measure energy performance. It will give insight into the magnitude of any potential deviation between predicted and actual energy consumption and discuss the implications for reaching our climate targets.

Background on Ireland's Building Energy Rating (BER) system

Energy Performance Certificate (EPC) systems are used throughout Europe to provide a benchmark calculation of building energy consumption. These are governed by the EU Energy Performance of Buildings Directive (EPBD) (EU, 2010). Ireland's Energy Performance Certificate (EPC) is known as the Building Energy Rating (BER).

EPCs, including Ireland's BER, predict what a building's energy consumption is likely to be. This is calculated conditional on the observed dwelling characteristics and assumed behaviour, as opposed to a calculation based on observed patterns of actual energy consumption. In Ireland, the BER is calculated by an SEAI-registered assessor using standardised software known as DEAP (Dwelling Energy Assessment Procedure). To predict a benchmark usage profile, DEAP models the building fabric, heating systems, ventilation, lighting, renewables and standardised assumptions relating to factors such as occupancy and weather.

As the BER predicts rather than observes energy consumption, there is the possibility that the prediction will be different to actual consumption. This hypothesis has been extensively tested in the literature; with the findings that BER-predicted consumption has potential to deviate considerably from actual consumption.

Irish and international research have found that EPC/BER-predicted energy consumption can deviate considerably from actual observed energy consumption. In an Irish context, (Coyne and Denny 2021) find that theoretical energy use is, on average, 17% below actual energy use, and this difference varies by the BER rating of the dwelling. These findings correspond to those of (Meles et al. 2023; 2024), where BER is shown to have a lesser than expected predictive power on energy consumption and heat loss.

According to (Coyne and Denny 2021), the energy consumed by more efficient homes is closer to that predicted by the BER, whereas those less efficient have a greater discrepancy. For the most efficient homes, Coyne and Denny (2021) find that actual energy use exceeds the BER prediction by 39.6% on average for A or B-rated homes. For the least efficient homes, actual energy use is below the BER prediction. This difference is 24% for D-rated homes, 39% for E-rated homes and 56% for F or G-rated homes. This finding is consistent with the international literature. Similar patterns have been observed in other studies, such as that of (Few et al. 2023; Cozza, Chambers, and Patel 2020; Cozza, Chambers, Deb, et al. 2020) and the meta analysis of (Zheng et al. 2024).

A striking observation from the Irish studies of Coyne and Denny (2021) and Meles et al. (2025) is the lack of variation in average actual energy use between dwellings in different BER categories: average energy consumption is similar for an A-rated house and a G-rated house. Dwellings in the Coyne and Denny (2021) sample show that households consume around 10,869kWh/year, and this does not vary considerably by BER rating. A-rated dwellings consume an average of 10,569kWh/yr , whilst F and G-rated households consume an average of 10,964kWh/yr. Indeed, this may not be an Ireland-specific observation, with a UK study of office buildings by the Better Buildings Partnership (2019) finding a similar pattern of consumption.

The mechanism driving this observation in the data is not clear, but there are many plausible hypotheses put forward in the literature. First, there may be what is known as the "rebound effect": householders in poorly-insulated dwellings may underheat to save money. When the insulative performance is improved, a reduction in heat consumption is not observed, as householders choose to avoid underheating rather than continue to underheat at a lower cost. Irish research backs this up: (Coyne et al. 2018) find that socially vulnerable occupants often under-heat their homes and use more energy and alternative heating fuels following a retrofit. Similar findings are observed in other contexts. In Germany, (Sunnika-Blank and Galvin 2012) find that occupants consume roughly 30% less heating energy than indicated by their EPC. They also find evidence that low-energy dwellings tend to engage in this 'rebound' after retrofit installation by consuming more energy than predicted by their Energy Performance Certificate.

Secondly, the DEAP approach involves the use of standardised values for many parameters, including household behaviour, ventilation, etc. Differences between assumed and actual values can lead to some of the deviations observed in the data, an issue raised by studies such as (Majcen et al. 2013) and (Cozza, Chambers, Deb, et al. 2020; Cozza, Chambers, and Patel 2020). Finally, Collins et al. (2018) find evidence of systematic bunching in ratings around certain cut offs: evidence is found of bunching in the post-works distribution but not the pre-works distribution of BER categorisations. The authors find no evidence of perverse actions by BER assessors, suggesting it is likely that homeowners plan their renovations to just surpass a grade threshold.

The observation by (Coyne and Denny 2021)that average energy consumption is consistent across BER values suggests that household energy demand may not be as responsive to dwelling energy efficiency as expected ex ante. No conclusive evidence exists to understand the mechanism driving this observation. There are many plausible explanations: for instance, it may be the case that comfort is more flexible than energy expenditure. A certain amount of energy consumption may be affordable or deemed acceptable by householders, beyond which underheating becomes more common. This is consistent with the 'rebound effect' and the observation that low efficiency dwellings tend to consistently consume much less energy than predicted by BER/EPC systems. Further research may be required to investigate this hypothesis fully.

It is clear from the literature that the standardised approach associated with BER and EPC systems is likely responsible for much of the deviations between predicted and actual energy consumption, with deviations between assumed and actual consumption patterns also contributing. This brings the obvious consideration: should energy performance calculations incorporate observed data? Much research is emerging to develop data-driven methods to both validate and calculate BERs/EPCs to overcome many of these deficiencies (for examples in an Irish context, please see (Ahern et al., 2026;Eslamirad et al. 2025; Raushan et al. 2024).

4. TRADE-OFFS WITH HOUSING POLICY

As shown in the previous section, there is a well-developed literature on the barriers and challenges to decarbonisation via retrofitting and electrification. Less well developed is the literature on the spillover effects of residential heat decarbonisation on other sectors. In particular, deep retrofitting requires labour and materials from the construction sector, which is currently at full capacity. While the supply of labour and materials for a given economic sector is flexible in the long run – new employees and additional materials can be sourced, given sufficient time – this supply is fixed in the short run. Some of the labour and capital required for new builds versus retrofits is not substitutable between the two construction activities, but to the extent that at least some substitution is possible there is a trade-off between new builds versus retrofits.

This means that, all else equal, a policy that increases construction sector activity in one area will reduce construction sector activity in other areas, in the short run. In the context of an acute housing shortage, and with delivery of new housing units falling short of recent targets, there is an immediate trade-off between upgrading existing homes to meet retrofit goals and building new homes to meet housing demand (National Competitiveness and Productivity Council 2025).

The exact trade-off between the polices has not been quantified, but (Barrett and Curtis 2023) provide some estimation of the construction sector labour required for retrofitting. An assumption of 50,000 retrofits per year translates to a requirement of 15,000 workers per annum to carry out the required works. This number is similar to the requirement identified by Government of Ireland (2022a, 2022b) of a construction sector expansion of 18,180, and recruitment of 22,779, to meet this challenge. 15,000 workers per annum equates to 8.5% of the construction sector employment in Q4 2024, or 20.8% of those employed who

"Mainly do not work on new housing developments/renovations" (Central Statistics Office 2025). As noted above, one cannot assume perfect substitution between labour for new builds versus retrofits, and so the labour supply numbers here should be interpreted as an upper bound on the potential labour diverted from new builds to retrofitting.

In addition, there will be a labour supply requirement for electricity system investment. This includes distribution grid upgrades and the construction of power system generation and transmission required to meet the increased power demand from heat pumps. These extra requirements would increase the construction sector requirement beyond that required for retrofitting alone, which may further crowd out housing investment.

5. ALTERNATIVE POLICY PATHWAYS

Given the challenges in meeting existing retrofit and heat pump installation targets, as well as the deficiencies in using BERs as a proxy for emissions reductions, it is likely that emissions from residential heating will not meet anticipated levels of decarbonisation under the current policy mix. Additional measures are therefore likely to be required to achieve levels of decarbonisation consistent with our climate objectives. This section explores and discusses potential additional (as opposed to alternative) policies.

A. FUEL SWITCHING

As the preceding sections have highlighted, there is much evidence to suggest that considerable logistical, behavioural and financial barriers exist to impede the retrofitting of many homes. If Ireland is to meet the current decarbonisation targets, additional measures to decarbonise heat may be required.

The first potential additional policy measure is to switch fossil fuels, particularly oil and solid fuel boilers, to a lower carbon fuel. This policy need not replace electrification but rather provides a pathway for households that will not undertake a retrofit and/or a switch to a heat pump to reduce their emissions from heating. Lower emissions alternatives include gas, via the gas network or LPG, while zero emissions fuels include Hydrogenated Vegetable Oil (HVO) or biodiesel. A number of options exist and each measure has both positive and negative aspects.

The first fuel switching option is to switch oil or solid fuel heating for natural gas or methane. The emissions from natural gas, or methane, are roughly one quarter lower per unit energy than kerosene, at 203gCO_2/kWh vs 264g CO_2/kWh (SEAI

2025a). (Curtis and Grilli 2021) find that there are 110,000 homes located within 30km of a gas pipeline that are not connected to the gas network, of which roughly 75% currently use oil fired central heating, 10% use electricity and 8% use coal. (Curtis et al. 2020) find that up to 13% of such households are likely to connect to the gas grid if there were no connection charge, yielding a 3.9% reduction in emissions and a 1.5% reduction in fuel expenditure, weighted towards the least affluent households. The value of the savings in emissions offsets the connection cost of this policy. If the emissions intensity of natural gas decreases, due to policies such as the Renewable Heat Obligation (Department of the Environment, Climate and Communications 2024), the net saving from switching from kerosene to gas would likely increase over time.

Many homes are not sufficiently close to the gas network to render connection feasible. A lower emissions replacement for kerosene that does not require connection to the gas grid is Liquid Petroleum Gas, or LPG, which has associated emissions factor of 229.3gCO_2/kWh. LPG can be used in a dwelling that currently burns kerosene, requiring a new boiler and tank but without requiring any changes to the building fabric or heating infrastructure (i.e. radiators, etc). The cost per unit energy is significantly more expensive, however, at 11.11c/kWh vs 16.29c/kWh (SEAI 2025b), which does not include a standing charge. Most LPG suppliers will install a new tank with no upfront cost to the householder, but will recoup the cost of the tank through the customer's bills.

Other options for fuel switching include renewable liquid fuels, such as Hydrotreated Vegetable Oil (HVO) or biofuels. These alternatives potentially have far greater emissions savings than switching to gas or LPG, but are less readily available. Biofuels in particular, such as renewable dimethyl ether (rDME) or biopropane (bioLPG) are available in nascent form at present. BioLPG can be produced as a byproduct of the refining process for HVO and sustainable aviation fuel (SAF), while rDME can be produced directly from various household and agricultural waste products (Gray et al. 2021). HVO is known as a "second generation" biofuel, in that it is manufactured from waste oil that would otherwise go to landfill, such as cooking oil. These fuels can be blended with kerosene with no modifications required, or can be fully substituted for kerosene in domestic oil tanks and boilers with some replacement seals and valves required.

While renewable liquid fuels may represent a theoretical zero carbon heat source, the emission reduction potential assumes that the feedstocks are from genuine waste products, and are sustainably sourced. The evidence suggests that this may not always hold in reality. Over 70 countries supplied feedstocks for Ireland's biofuels in 2024 (NORA 2025), with China the largest source of used cooking oil, all certified under voluntary schemes such as ISCC. However, the IrBEA contends that around one-third of these fuels derive from high-fraud-risk supply chains, particularly non-EU imports of UCO and HVO from Asia (Cogan 2025). In an attempt to address these concerns, the European Commission has established an Expert Group on Renewable and Low Carbon Fuels which is tasked, amongst other things, with creating a database to monitor and trace the feedstocks for biofuel and low carbon fuel production (European Commission 2025).

A number of factors must be considered when evaluating whether switching of carbon intensive fossil fuels for less carbon intensive fossil fuels is worthwhile. A major advantage of switching fuels rather than electrifying is the greatly reduced financial and behavioural barriers, with little to no capital cost involved, depending on whether the switch is to a form of biodiesel such as HVO or to a fuel such as LPG. In this context, fossil fuel switching may have a positive effect if adopted by householders who would otherwise not decarbonise through electrification because of financial and/or behavioural barriers. However, this may have a negative effect if it replaces heat pump installation. If fossil fuel switching were to be considered alongside the current set of policies, much care is required to target towards those who are least likely to install a heat pump.

There are additional hurdles that must be overcome for successful implementation. For certain fossil fuel switching options, a capital cost may be incurred that could lead households towards utilising a fossil fuel for longer than they otherwise would, by postponing or discouraging electrification. The extent with which this is likely must be understood. For such dwellings, the immediate carbon saving associated with a lower intensity fossil fuel must be weighed against any zero carbon years foregone. In addition, while financial barriers to heat pump installation can be quantified, the behavioural barrier is still understudied. Further potential behavioural downsides to fuel switching, such as additional aspects of fossil fuel lock-in, are also understudied. Future research should address these concerns.

B. TARGETING LOW-INCOME AND HIGH-IMPACT HOMES

The analysis of the data from the application of the Better Energy Warmer Homes Scheme, which offers free retrofits for eligible households, reveals that grant-funded retrofits lead to improvements in energy efficiency. However, the extent of these gains depends on the initial energy efficiency of the dwelling and the types of measures implemented. The highest return on investment occurs in homes with the poorest pre-retrofit energy performance. Furthermore, upgrades such as heating system improvements deliver some of the most significant efficiency gains (Pillai et al. 2021).

(Estévez and Tovar Reaños 2024) show that potential gains regarding improvements in households' ability to maintain adequate warmth from energy efficiency are more likely to be realised among homes at the lower end of both the energy efficiency and income distributions.

Low-income families who do not qualify for the free retrofit scheme often face prohibitive upfront costs. While general grants are available to the broader population, they require households to make the full investment before being reimbursed. For tenants, the decision to retrofit lies with landlords, creating another barrier. To address these challenges, the Energy Poverty Action Plan introduces low-cost loans and a mechanism that allows homeowners to pay only the portion of retrofit costs remaining after the grant has been applied. Tax incentives are also available for small-scale landlords to encourage participation.

Despite these efforts, the rise in energy arrears (CRU, 2025) indicates that there is still significant scope to enhance the design of energy efficiency policies through a more inclusive approach. The literature advocates for a coordinated strategy that integrates energy efficiency measures with employment policies and social support programs (Karpinska and Smiech 2021).

C. DEMAND FLEXIBILITY AND SMART CONTROLS

The Irish electricity sector has ambitious targets for decarbonisation, primarily via variable renewable generation sources such as wind and solar power. One feature of these generation sources is that they can be curtailed when there is excess supply of generation. EirGrid and SONI estimate that excess supply from renewable generation could exceed 20% by 2030 in the absence of measures to combat this (EirGrid and SONI 2023). One such measure is increasing the flexibility of demand, by shifting electricity demand to hours when renewable generation would otherwise be curtailed. To support this, the Climate Action Plan includes a target of 20-30% of demand flexibility by 2030, with the CRU publishing a National Energy Demand Strategy to achieve this target (Commission for the Regulation of Utilities 2024).

Electrified heating can potentially contribute to flexible demand via two channels. The first is that heat pumps can be operated with some degree of flexibility without compromising on thermal comfort levels, especially by smart controls that operate the heat pump according to signals from the power grid. The second is by the installation and utilisation of heat storage, or thermal energy storage (TES). A TES system can allow a heat pump to run when electricity supply is greater than demand, and store the heat for later use. Heat storage is an emerging technology but has been shown to reduce total electricity and heating costs when the electricity and heat systems are considered in aggregate (Gaur et al. 2022).

In practice, however, accessing these sources of flexibility from electrified heating is not straightforward. At present in Ireland, flexible demand requires the user to actively manage their demand, as no supplier is currently offering a tariff that controls heating demand remotely. Smart meters have been made available for all electricity users as part of a nationwide rollout, but uptake of smart tariffs is currently less than 20%. This, however, is in line with the international literature, which finds that opt-in to smart tariffs is as low as 1%, and goes no higher than 43% even with intentional policies to encourage uptake (Nicolson et al. 2018). Only when smart tariffs are on an opt-out basis does the figure increase. This limitation can be bypassed by allowing demand response to be automated, if heat pumps are "smart enabled" – in other words, if the heat pump has smart controls and connectivity and can be operated by signals from the grid rather than by the consumer themselves. The additional cost to smart controls is relatively low and so there may be a net benefit from smart-enabled heat pumps (with or without TES). In this case, subsidising and/or mandating smart-enabled heat may prove socially optimal as an additional decarbonsation policy.

As regards TES, many of the cost reductions from TES accrue as saving in electricity grid investment. This means that a homeowner may not capture the full monetary savings available from TES, as grid investment costs are socialised across all electricity users. Any potential reduction in grid investment enabled as a result of TES investment can be considered a positive externality, and all else equal justifies a subsidy in order to raise TES investment to the socially optimal level. However, any potential subsidy should be well-designed to ensure that it is set at the right level and accrues to the right agent. Further research is required to determine these parameters and ensure that the optimal level of TES investment at least cost takes place.

6. DISCUSSION

The evidence reviewed in this article, sourced from the literature and the rate of retrofit and heat pump installation observed to date, suggests that Ireland will not meet residential heat decarbonisation targets. Failure is likely on two counts. First, the rate of retrofit, heat pump and district heating rollout is likely to fall short of the proposed targets. The rate of installation of retrofits, for instance has been c. 21k in 2024, much lower than the 75,000 retrofits required per annum (SEAI, 2025).

Second, target-consistent retrofit installation is likely to under-deliver the required rate of decarbonisation. Evidence suggests that there is a considerable gap between predicted and actual energy usage across the building stock, leading to an under-estimation of the potential energy savings associated with energy efficiency upgrades (Coyne and Denny, 2021). Finally, even in the event of current targets being met, a large proportion of the housing stock will remain without retrofitting or electrification post-2030. Thus, any additional policies that target households that would otherwise continue on a business as usual trajectory will improve the total decarbonisation rate, regardless of whether existing policy targets are met. Policy makers must decide whether the benefits of additional policies for residential heat decarbonisation and/or policies to decrease emissions beyond current targets in other sectors outweigh the costs of failing to meet decarbonisation targets in this sector. The implications of policy targets that are likely to be missed by a substantial margin may prompt reevaluation of the carbon reduction targets for the residential sector as well as other sectors, and should also be considered in the context of carbon budgets and cross-sectoral spillovers. The current and potential additional policies considered in this paper are summarised in Table 3.

TABLE 3: SUMMARY OF EXISTING AND POTENTIAL ADDITIONAL POLICIES

Policy	CAPEX to household	Decision maker	Behavioural barriers	Lock in potential?
Retrofit existing stock	> € 25,000	Homeowner	Significant	No
Heatpumps	€10,000 > €25,000	Homeowner	Significant if tied to retrofit	No
Thermal energy storage	< €10,000	Homeowner, local authority or developer	Significant if tied to retrofit	No
Increase gas grid connections	< €10,000	Homeowner	Moderate	Yes
Renewable Heat Obligation	n/a	Suppliers/Government	None	Unlikely
Switch to LPG	Low	Homeowner	None	Yes
Switch to Biofuels	Low or negligible	Homeowner	None	Unlikely
Mandate smart controls	Negligible	Government	Low	No
Smart contract opt-out	None	Government/CRU/Suppliers	Moderate	No

While the literature shows that BERs in general are not a good indicator of total energy use, there is still a case for prioritising retrofitting and electrifying towards the least efficient dwellings. The fact that gas usage in the residential heating sector has declined by 13% since 2019 compared to a 0.3% decline in oil usage is noteworthy in this regard. Policies that attempt to target dwellings that are less efficient, or use higher carbon fuels at present, may therefore prove preferable to the current approach, under which grants and incentives apply homogeneously across the population. Any attempt to better target dwellings that are likely to see a greater reduction in emissions should be informed by research to ensure that the polices are effective.

As well as improved targeting of retrofitting and electrification, potential additional policies include switching fuels for households that are least likely to undertake retrofit or energy efficiency investment. This allows additional decarbonisation while avoiding much of the behavioural barriers and the large upfront cost associated with energy efficiency investment, but at a higher marginal cost. There may therefore be an optimal level of fuel switching: while retrofits and electrification rates are low, it may be optimal for a large proportion of households to use alternative, lower carbon fuels. Again, targeting is key: any additional policy to shift from high carbon to low carbon fuels should be well-designed to ensure that dwellings that undergo fuel switching are drawn from the stock that is least likely to retrofit or electrify. Such a policy design should aim to ensure that retrofitting remains at the maximum feasible rate given constraints in the construction sector, while reducing carbon emissions from other dwellings in the meantime. Targeting households that are least likely to retrofit or electrify their heating minimises the likelihood of delayed electrification among a subset of households. However, it should be noted that this risk is not removed completely, and policy must consider if and to what extent this is likely, and weigh the expected value of any potential delayed electrification behaviour against the value of lower carbon emissions through fuel switching.

Any inclusion of additional, more targeted policies should be informed by research which (a) identifies the incentive required and (b) differentiates between households that are more or less likely to electrify. This will minimise any potential for “fossil fuel lock-in”. Recall that many lower-carbon liquid fuels often require relatively small system adjustments. In this context, if substitution for lower-carbon liquid fuel is associated with a low level of fixed investment, as opposed to full system installation, the potential for fossil fuel lock-in is minimised; any barrier to electrifying or retrofitting that holds in a household burning a low-carbon fuel most likely also holds when a household is burning a higher-carbon fuel. However, policy must ensure that alternative fuels are genuinely low-carbon and sustainable, with robust tracing and anti-fraud mechanisms in place. The European Union Database under the Renewable Energy Directive (RED III) is a timely development in this regard.

Finally, there may be a role for increased demand flexibility in reducing emissions from the electrified portion of residential heating. However, the literature suggests that there is a limit to the degree of engagement that can be expected from consumers via smart tariffs and meters, as long as consumers must opt in to these tariffs. Furthermore, network tariffs levied on supply companies can incentivise these companies to encourage demand flexibility amongst their customers, but it is important that tariffs remain cost-reflective.

Given the potential for TES and flexible heat pump operation to reduce total system costs, further research should be undertaken to determine the extent of these cost savings and to whom those saving accrue. This research can then inform whether there is a case for mandating and/or subsidising investment in TES and smart heating controls. This is a complex area with potential for cost and emissions increases as well as decreases, and so any policy intervention in this area should be well-designed *ex ante* and should be evaluated and adjusted *ex post* if necessary.

In general, residential heating decarbonisation has suffered from a lack of evidence and data from real households in advance of any investments or technology adaptations, and has instead relied to a large degree on investment costs and emissions savings predicted by mathematical and engineering modelling conducted *ex ante*. Furthermore, *ex post* analysis has largely been conducted using administrative data, which is drawn from the proportion of homeowners and landlords that have already completed or engaged with the retrofit systems, and so suffers from selection bias. There is little *ex post* analysis conducted on the basis of quasi-experimental or randomised controlled trials. This has led to large sums of public money being invested in the residential sector to date for potentially very little gain in terms of emission reduction, while potentially diverting labour and capital away from new building. Policy can be better informed, leading to faster, more cost- and carbon-effective policy decisions, by basing policies on data collected from nationally representative households chosen by robust statistical methodologies.

Using smart/connected devices to track energy usage, by different appliances, along with detail on the characteristics of the dwellings and occupants, would provide an invaluable dataset that can improve policy design, and would also allow for trialling and testing policy interventions for effectiveness and unintended consequences before national roll-out. The development of such a trial and database should be strongly considered by policy-makers.

7. CONCLUSION AND RECOMMENDATIONS

This paper analysed progress to date towards policy goals in the residential heating sector. We find that policy targets for increased energy efficiency and electrification in this sector are unlikely to be achieved. Furthermore, the literature suggests that energy efficiency measures do not deliver the carbon savings predicted by *ex ante* modelling. Finally, a large proportion of Irish households have no intention of undertaking retrofitting or renovations, and so efficiency and electrification is not a feasible route to decarbonisation for those dwellings in the short to medium term.

Upgrading insulative capacity can aid the energy performance of a building. Both domestic and international research has shown that the benefits to the climate are consistently mis-specified by Building Energy Rating (BER) metrics. Should we quantify performance with error, progress will be measured with error. This leads to two calls for action. First, if we wish to meet our climate targets, more climate action is required. Second, good policy requires good measurement. If we wish to make good policy decisions, such as identifying a cost-effective suite of decarbonisation policies, we must measure impacts correctly. Data-driven metrics, which account for many of the outlined deficiencies, exist and are being developed by Irish and international researchers (see for instance, Ahern et al., 2026; Eslamirad et al. 2025; Raushan, et. al. 2025). Policy should incorporate such methods in decision-making with priority given to *ex post* analysis of the outcomes of policy and investment to date. Otherwise, underperformance is embedded by design.

Policy-makers may choose to underperform in residential heating decarbonisation relative to Climate Action Plan targets, or may wish to adopt additional policies and targets in addition to the electrification and retrofitting policies to date. Options for additional policies include switching from fossil fuel heating to lower carbon fossil fuel options, such as natural gas or LPG, or to newer alternative fuels such as HVO, BioLPG or rDME. Policies should be well designed to ensure that the households that are least likely to undertake retrofitting or electrification are targeted for any such additional policies, and supply chains and sources of alternative fuels should be regulated to ensure that these fuels come from genuinely sustainable sources.

There is also potential to incentivise or regulate thermal energy storage and smart devices and controls for home heating to boost flexible demand and decarbonisation. Research should be undertaken to quantify the net costs and benefits of such policy decisions, and policy instruments should be appropriately designed. Further research is also recommended to ensure any additional policy recommendations are designed and tested *ex ante*, based on data gathered from a representative sample of real households. Behavioural interventions should also be tested and piloted for efficiency and cost-effectiveness before being implemented at national scale.

REFERENCES

Ahern, C., Enright, B., Griffin, A., & Norton, B., 2026."A method for determining a true national statistical distribution of building element U-values and its application to a dataset underpinning a building stock energy model." *Building Services Engineering Research and Technology*, 47(1), 31-50. https://doi.org/10.1177/01436244251364542, https://doi.org/10.1177/01436244251364542

Barrett, Alan, and John Curtis. 2023. "THE NATIONAL DEVELOPMENT PLAN IN 2023: PRIORITIES AND CAPACITY." ESRI. https://www.esri.ie/system/files/publications/SUSTAT123_3.pdf#page=112.

Central Statistics Office. 2025. "QLF52 - Construction Employment." https://data.gov.ie/dataset/qlf52-construction-employment.

Cogan, James. 2025. "Full report – Irish Bioenergy Associa on (IrBEA) Analysis on NORA biofuel consump on figures 2024." IrBEA.

Commission for the Regulation of Utilities. 2024. "National Energy Demand Strategy Decision Paper." https://www.cru.ie/publications/28200/.

Coyne, Bryan, and Eleanor Denny. 2021. "Mind the Energy Performance Gap: Testing the Accuracy of Building Energy Performance Certificates in Ireland." *Energy Efficiency* 14 (6): 57. https://doi.org/10.1007/s12053-021-09960-1.

Coyne, Bryan, Daire McCoy, and Sean Lyons. 2018. "The Effects of Home Energy Efficiency Upgrades on Social Housing Tenants: Evidence from Ireland." *Energy Efficiency*, ahead of print. https://doi.org/10.1007/s12053-018-9688-7.

Cozza, Stefano, Jonathan Chambers, Chirag Deb, Jean-Louis Scartezzini, Arno Schluter, and Martin K. Patel. 2020. "Do Energy Performance Certificates Allow Reliable Predictions of Actual Energy Consumption and Savings? Learning from the Swiss National Database." *Energy and Buildings*, ahead of print. https://doi.org/10.1016/j.enbuild.2020.110235.

Cozza, Stefano, Jonathan Chambers, and Martin K. Patel. 2020. "Measuring the Thermal Energy Performance Gap of Labelled Residential Buildings in Switzerland." *Energy Policy* 137: 111085. https://doi.org/10.1016/j.enpol.2019.111085.

Curtis, John, and Gianluca Grilli. 2021. "Does Moving Home Affect Residential Heating Decisions? Exploring Heating Fuel Switching in Ireland." *Energy and Buildings*, ahead of print. https://doi.org/10.1016/j.enbuild.2021.110918.

Curtis, John, Gianluca Grilli, and Muireann Lynch. 2024. "Residential Renovations: Understanding Cost-Disruption Trade-Offs." *Energy Policy*, ahead of print. https://doi.org/10.1016/j.enpol.2024.114207.

Curtis, John, Miguel Tovar Reaños, and Gianluca Grilli. 2020. "Access to and Consumption of Natural Gas: Spatial and Socio-Demographic Drivers." *Energy Policy*, ahead of print. https://doi.org/10.1016/j.enpol.2020.111614.

Department of the Environment, Climate and Communications. 2024. “Renewable Heat Obligation.” Department of the Environment, Climate and Communications. https://www.gov.ie/en/publication/renewable-heat-obligation/.

EirGrid and SONI. 2023. “Shaping Our Electricity Future: Technical Roadmap Report.” https://cms.eirgrid.ie/sites/default/files/publications/Shaping-Our-Electricity-Future-Roadmap_Version-1.1_07.23.pdf.

Eslamirad, Nasim, Mehdi Gholam Nia, Payam Sajadi, and Francesco Pilla. 2025. “Leveraging Machine Learning for Data-Driven Building Energy Performance Prediction (with BER) in Urban Environments.” *Energy and AI* 20: 100370.

Estévez, Andrés, and Miguel Tovar Reaños. 2024. “Empowering Homes? Unravelling the Connection Between Energy Efficiency and Well-Being.” ESRI Working Paper series. https://www.esri.ie/system/files/publications/WP784.pdf.

Few, Jessica, Despoina Manouseli, Eoghan McKenna, et al. 2023. “The Over-Prediction of Energy Use by EPCs in Great Britain: A Comparison of EPC-Modelled and Metered Primary Energy Use Intensity.” *Energy and Buildings* 288: 113024. https://doi.org/10.1016/j.enbuild.2023.113024.

Gaur, Ankita, Desta Fitiwi, Genaro Longoria, and Muireann Lynch. 2022. “Implications of Heating Sector Electrification on the Irish Power System in View of the Climate Action Plan.” *Energy Policy*, ahead of print. https://doi.org/10.1016/j.enpol.2022.113136.

Gillingham, Kenneth, Matthew Harding, and David Rapson. 2012. “Split Incentives in Residential Energy Consumption.” *The Energy Journal* 33 (2): 37–62. https://doi.org/10.5547/01956574.33.2.3.

Government of Ireland. 2025. “Climate Action Plan 2025.” https://www.gov.ie/en/department-of-climate-energy-and-the-environment/publications/climate-action-plan-2025/.

Gray, Nathan, Shane McDonagh, Richard O’Shea, Beatrice Smyth, and Jerry D. Murphy. 2021. “Decarbonising Ships, Planes and Trucks: An Analysis of Suitable Low-Carbon Fuels for the Maritime, Aviation and Haulage Sectors.” *Advances in Applied Energy*, ahead of print. https://doi.org/10.1016/j.adapen.2021.100008.

International Energy Agency. 2007. “Mind the Gap: Quantifying Principal–Agent Problems in Energy Efficiency.” IEA. https://www.iea.org/reports/mind-the-gap.

Karpinska, L, and S Smiech. 2021. “Breaking the Cycle of Energy Poverty. Will Poland Make It?” *Energy Economics*, ahead of print. https://doi.org/doi:10.1016/j.eneco.2020.105063.

Kren, Janez, Eoin Kenny, Conor O’Toole, Eva Shiel, and Rachel Slaymaker. 2025. “Exploring Investment Requirements for Energy Efficiency Upgrades in the Private Rental Sector.” https://www.esri.ie/system/files/publications/RS205.pdf.

Mac Uidhir, Tomás, and Fionn Rogan. 2025. “Can Ireland Still Meet Its District Heating Targets by 2030?” MaREI. https://www.ucc.ie/en/media/research/energypolicyandmodellinggroup/CanIrelandStillMeetItsDistrictHeatingTargetsby2030.pdf.

Majcen, Daniël, Laure C. M. Itard, and Henk J. Visscher. 2013. “Theoretical vs. Actual Energy Consumption of Labelled Dwellings in the Netherlands: Discrepancies and Policy Implications.” *Energy Policy* 54: 125–36. https://doi.org/10.1016/j.enpol.2012.11.008.

Meles, Tensay, Niall Farrell, and John Curtis. 2023. “How Well Do Building Energy Performance Certificates Predict Heat Loss?” *Energy Efficiency* 16: 74. https://doi.org/10.1007/s12053-023-10146-0.

Meles, Tensay, Niall Farrell, and John Curtis. 2024. “Are Energy Performance Certificates a Strong Predictor of Actual Energy Use? Evidence from High-Frequency Thermostat Panel Data.” *Economics of Energy and Environmental Policy* 13 (1). https://doi.org/10.5547/2160-5890.13.1.tmel.

National Competitiveness and Productivity Council. 2025. “Ireland’s Competitiveness Challenge 2025.” National Competitiveness and Productivity Council. https://www.competitiveness.ie/media/3y4kcpus/irelands-competitiveness-challenge-2025.pdf.

Nicolson, Moira, Michael Fell, and Gesche Huebner. 2018. “Consumer Demand for Time of Use Electricity Tariffs: A Systematized Review of the Empirical Evidence.” *Renewable and Sustainable Energy Reviews*, ahead of print. https://doi.org/10.1016/j.rser.2018.08.040.

NORA. 2025. “NTFO Annual Reports.” https://www.nora.ie/annual-reports.

Petrov, Ivan, and Lisa B. Ryan. 2021. “The Landlord-Tenant Problem and Energy Efficiency in the Residential Rental Market.” *Energy Policy* 157: 112458. https://doi.org/10.1016/j.enpol.2021.112458.

Pillai, Arya, Miguel Tovar Reaños, and John Curtis. 2021. “An Examination of Energy Efficiency Retrofit Scheme Applications by Low-Income Households in Ireland.” *Heliyon*, ahead of print. https://doi.org/10.1016/j.heliyon.2021.e08205.

Raushan, Kumar, Tomás Mac Uidhir, Manuel Llorens Salvador, Brian Norton, and Ciara Ahern. 2024. “A Data-Driven Standardised Generalisable Methodology to Validate a Large Energy Performance Certification Dataset: A Case of the Application in Ireland.” *Energy and Buildings* 323: 114774.

SEAI. 2025a. “Conversion Factors.” Www.seai.ie. https://www.seai.ie/data-and-insights/seai-statistics/conversion-factors.

SEAI. 2025b. “Domestic Fuel Cost Comparison.” https://www.seai.ie/sites/default/files/publications/Domestic-Fuel-Cost-Comparison.pdf.

SEAI. 2025c. “National Retrofit Plan - Full Year Report 2024.” SEAI. https://www.seai.ie/sites/default/files/publications/SEAI-Retrofit-Full-Year-Report-2024.pdf.

Sunnika-Blank, Minna, and Ray Galvin. 2012. “Introducing the Prebound Effect: The Gap between Performance and Actual Energy Consumption.” *Building Research and Information*, ahead of print. https://doi.org/10.1080/09613218.2012.690952.

Tovar Reaños, Miguel Angel, John Curtis, David Meier, and Aria Pillai. "Looking beyond Energy Efficiency and the Role of Financial Literacy in Experiencing Fuel Poverty: Evidence from Irish Homeowners." *Energy Research and Social Science*.

Zheng, Zitian, Jing Zhou, Jing Zhu, Yifan Yang, Feng Xu, and Hong Liu. 2024. "Review of the Building Energy Performance Gap from Simulation and Building Lifecycle Perspectives: Magnitude, Causes and Solutions." *Developments in the Built Environment* 17: 100345. https://doi.org/10.1016/j.dibe.2024.100345.

Zhu, Tong, John Curtis, and Matthew Clancy. 2023. "Modelling Barriers to Low-Carbon Technologies in Energy System Analysis: The Example of Renewable Heat in Ireland." *Applied Energy*, ahead of print. https://doi.org/10.1016/j.apenergy.2022.120314.