Stepping Stones or Carbon Lock-In? Homeowner preferences for biofuels and heat pumps in residential heating decarbonisation

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Abstract

Decarbonising residential heating depends on millions of individual household decisions. While policy has largely focused on replacing fossil-fuel boilers with heat pumps, slow progress has prompted growing interested in alternatives. Lower-carbon “drop-in” fuels such as hydrotreated vegetable oil (HVO) and biomethane are one type of alternative that can be used within existing heating systems relatively straightforwardly. Whether promoting such biofuels accelerates decarbonisation by acting as a stepping stone towards heat-pump adoption or instead delays it by reinforcing incumbent technologies has received much debate, but little direct empirical attention. We generate evidence for this debate using a survey experiment with a nationally representative sample of Irish homeowners with gas or oil boilers (N > 1,000), in which all respondents evaluated both a biofuel option and a heat pump, with the order of exposure randomised. Awareness of biofuels was low, particularly for biomethane. Initial willingness to switch was high and driven primarily by the ease of switching, but fell sharply once respondents learned about higher fuel costs and sustainability concerns. Heat-pump evaluations became more negative as information was revealed, especially following disclosure of building-fabric retrofit requirements. Despite these declines, final willingness-to-switch remained substantially higher for biofuels than for heat pumps. Critically, exposure to biofuels did not reduce subsequent willingness to adopt a heat pump, with a point-estimate that was in-fact positive, providing no evidence for household-level carbon lock-in. The findings suggest that promoting lower-carbon fuel alternatives need not undermine support for electrification, though the attractiveness of both pathways remains strongly conditioned by their perceived financial and practical costs.

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1 Introduction

Decarbonising heating is one of the largest opportunities to reduce household emissions (IEA, 2024). However, across much of Northern Europe and North America, where per-capita greenhouse gas emissions remain among the largest globally, cold winters, fossil fuel dependence and ageing building stock are substantial obstacles (e.g., Eyre & Baruah, 2015). Progress depends on millions of individual household decisions about a durable good that is purchased infrequently, is not well understood by most consumers and only salient when an existing system fails. In Ireland, these problems are particularly acute. Oil and gas boilers continue to dominate the existing housing stock, and while generous subsidies have been introduced to accelerate heat pump adoption, progress has been constrained by the cost and disruption of building fabric upgrades often required before a dwelling qualifies for support (Lynch, Reaños & Farrell, 2026).

Given challenges to heating electrification via heat pumps, alternative pathways for residential heat decarbonisation have attracted increased policy attention. One such pathway is substituting fuels burned in existing boilers with lower-carbon “drop-in” alternatives, such as hydrotreated vegetable oil (HVO) for oil boilers or biomethane for gas-connected households (Guo, Song & Buhain, 2015; Jeswani, Chilvers & Azapagic, 2020). This pathway has lower entry barriers: no building fabric retrofit, no change in how the household experiences heat and continuity with existing infrastructure. These features may make biofuels attractive both economically and psychologically, as they minimise disruption and complexity relative to heat pump adoption. However, biofuels have received mixed policy reception. Proponents argue they represent a practical, near-term complement to electrification, capable of reducing emissions of “hard to reach” segments of the housing stock who are unable to install a heat pump in the short term, providing a stepping stone to decarbonisation until they can do so (Macedo de Araujo Azeredo, Moll Hüther, Barbosa Welang & Panizio, 2025; Scarlat, Dallemand & Fahl, 2018). Two distinct senses of ‘stepping stone’ are worth separating. In one sense, biofuels might simply reduce emissions during the period before a household can afford or is ready for a heat pump. In a second, biofuel adoption could itself make heat pump adoption more likely, for example by building momentum around decarbonisation, functioning as a bridge rather than just as a temporary substitute. Our design speaks most directly to testing this latter possibility.

Critics, however, point to variable environmental benefits of biofuels (Bouter, Duval-Dachary & Besseau, 2024; Ji & Long, 2016) and, more fundamentally, contend that fuel substitution risks extending the lifetime of fossil-fuel-compatible boiler infrastructure, thereby delaying rather than accelerating the necessary technology transition (Berti &

Levidow, 2014; Yovchev, 2026). This tension echoes a long-running debate over whether an incremental, lower-carbon alternative to an incumbent technology functions as a stepping stone toward deeper decarbonisation, or as a form of carbon lock-in that entrenches the very infrastructure a transition is meant to displace (Unruh, 2000).

Despite the policy significance of this debate, there is little evidence on how households themselves evaluate competing pathways for residential heat decarbonisation. Most discussions of lock-in have focused on energy systems, infrastructure networks and investment dynamics (Unruh, 2000). In those settings, lock-in typically arises through sunk costs and assets. Whether lock-in can emerge at the household level, for example through information, perceptions and preferences, has received considerably less attention. Existing research has largely examined determinants of heat pump adoption in isolation, focusing on factors such as cost and disruption (e.g., Chitchyan, 2025; Curtis, Grilli & Lynch, 2024; Timmons, Shier & Ó Ceallaigh, 2026). Less research has examined how households perceive fuel-switching alternatives, though existing reviews indicate public knowledge is limited (Løkke, Aramendia & Malskær, 2021). Even less research has examined whether exposure to information about one decarbonisation pathway shapes preferences for another. This is a consequential gap. If promoting biofuels dampens enthusiasm for heat pumps, consistent with a lock-in account, this has direct implications for how governments sequence and communicate complementary decarbonisation programmes. If it does not, the policy calculus around supporting both pathways in parallel changes.

This paper contributes to this debate using a survey experiment with a nationally representative sample of homeowners in Ireland with gas or oil boilers (*N* = 1,018). All respondents evaluated switching to a biofuel option (HVO or biomethane, matched to their existing boiler type) and a heat pump, but the order in which they encountered the two technologies was randomised. This design enables us to (i) identify homeowner awareness of, and willingness to switch to, biofuels; (ii) directly compare stated preferences for fuel-switching against heat pump adoption within the same sample; and (iii) exploit the randomised order manipulation as a test of whether exposure to one pathway shifts evaluation of the other, providing, to our knowledge, the first experimental test of the stepping-stone/lock-in question for residential heating preferences. Because the mechanism we test is attitudinal rather than financial, stated preferences and information exposure are the appropriate evidence base. Unlike system-level lock-in, which is typically evidenced through investment and infrastructure data, a household-level informational lock-in effect should be visible in how exposure to one pathway shifts evaluation of another, prior to any actual switching decision.

1.1 Literature Review

1.1.1 Residential Heat Decarbonisation Pathways

Heat pumps are a cornerstone of residential heat decarbonisation strategies in many countries (European Commission, 2022; IEA, 2022; Knobloch et al., 2020). When powered by increasingly low-carbon electricity systems, they can deliver substantial emissions reductions while offering high levels of energy efficiency relative to combustion-based heating. The scale of these reductions depends on the electricity generation sources, meaning the climate benefits of heat pumps depend on the extent to which the electricity supply is low-carbon. Under favourable electricity-to-fossil-fuel price ratios, they can also reduce running costs for homeowners, particularly when paired with solar PV systems. However, deployment has proven challenging (Eyre & Baruah, 2015; Lynch et al., 2026). Heat pump installation frequently requires significant upfront investment and, under Ireland's 'fabric adequacy' approach to grant entitlements, complementary upgrades to building fabric, radiators or other components of the heating system (Lingard, 2021). These requirements can make adoption costly and disruptive, particularly in older housing stocks with lower levels of energy efficiency.

Renewable fuels such as biofuels offer a way to reduce emissions while avoiding many of these barriers (Scarlat et al., 2018). HVO can be used in many existing oil boiler systems following relatively minor modifications, while biomethane can be supplied through existing gas networks with little or no change required on the consumer side (Guo et al., 2015). Because these fuels are compatible with incumbent heating technologies and infrastructure, they offer a less disruptive route to emissions reductions than complete technology replacement.

The environmental merits of biofuels under current policy regimes, however, remain contested (Bouter et al., 2024). Biofuels derived from wastes and residues generally offer the greatest emissions reductions, whereas those produced from dedicated food and feed crops can be associated with higher water use, biodiversity loss and, in some cases, emissions from direct or indirect land-use change that reduce or negate their climate advantages (Jeswani et al., 2020). Moreover, under current pricing policies, biofuels may lead to increased heating bills for many homes (Vollmer, Reaños & Lynch, 2025). More fundamentally, some scholars argue that replacing fossil fuels with low-carbon fuels in existing boilers may prolong the use of combustion-based heating systems and associated infrastructure, potentially slowing the transition to fully decarbonised heating technologies (Gross & Hanna, 2019).

Importantly, these debates are typically conducted at the level of energy systems, infrastructure and policy. Relatively little attention has been paid to how households themselves evaluate these competing pathways. Yet many of the main differences between heat pumps and renewable fuels are experienced most directly at the household level. Heat pumps generally promise better long-term emissions reductions – assuming electricity supply is decarbonised – but involve greater upfront cost, uncertainty and disruption. Biofuels offer a more incremental route to decarbonisation that preserve existing technologies and routines, though they presently have higher running costs, constrained supply and less certain environmental benefits. Understanding how households weigh these competing benefits and drawbacks is therefore critical to understanding the likely pace and direction of residential heat decarbonisation.

1.1.2 Household Heating System Preferences

Given the policy focus on heat pumps, research on residential heating transitions has focused primarily on understanding willingness to adopt them and suggests that households evaluate heating options across multiple dimensions, including financial costs, familiarity and the practical demands associated with adoption. Upfront installation costs and expected energy savings tend to dominate preferences for low-carbon heating technologies (e.g., Morland & Fylan, 2025; Rouvinen & Matero, 2013; Schleich et al., 2022). Because biofuels such as HVO and biomethane currently carry lower switching costs but higher running costs than the fossil fuels they replace, household enthusiasm for either option is difficult to predict.

Homeowners frequently report uncertainty about the suitability of new technologies for their dwelling and the practical implications of adoption. Although public awareness of heat pumps has increased in recent years, detailed understanding of how they operate, what installation entails and how they compare to traditional systems remains relatively limited (Chitchyan, 2025; Karytsas, 2018; Timmons, Ó Ceallaigh, Carthy & Rogan, 2026). Under such conditions, technologies that preserve existing routines and require fewer changes may be particularly attractive. However, surveys of householder familiarity with biofuels shows limited knowledge across multiple countries (Løkke et al., 2021).

A further consideration is disruption. The transition to a heat pump often involves more than replacing a boiler, particularly in older housing stocks where insulation upgrades or other building fabric improvements may be required (Lingard, 2021). These requirements impose “hassle costs” in the form of time, effort, uncertainty and disruption to everyday life (Gillingham & Palmer, 2014; Lades, Clinch & Kelly, 2021), in addition to substantial financial costs. Recent studies suggest that homeowners place substantial negative value on retrofit works once they realise the consequences for habitability and daily routines (Curtis et al., 2024) and become far less willing to adopt a heat pump once they learn of them (Timmons et al., 2026).

These considerations are particularly relevant when comparing technology-switching and fuel-switching pathways to heat decarbonisation. Whereas heat pump adoption typically requires replacing a heating technology and may necessitate complementary upgrades to the dwelling, biofuels such as HVO and biomethane can often be adopted while retaining the existing boiler and heating system. Relative to heat pumps, fuel-switching pathways are likely to be less costly, more familiar, and less disruptive, albeit for more limited emissions reductions and potentially higher running costs. While households may ultimately adopt both approaches, for example by switching to a biofuel in the short term before later installing a heat pump, the two pathways are often presented as alternative means of reducing emissions from home heating. Whether households perceive them as competing solutions to the same problem is currently uncertain.

1.1.3 Carbon Lock-In

The possibility that one decarbonisation pathway may influence support for another relates to a longstanding debate surrounding carbon lock-in. Carbon lock-in refers to the tendency for societies to remain committed to carbon-intensive technologies and infrastructures even after more efficient, lower-carbon alternatives become available, because existing systems benefit from accumulated investments, established practices, familiarity and preferences for the status quo (Unruh, 2000, 2002). A related literature concerns the role of “bridge” technologies, which reduce emissions relative to incumbent systems albeit to a lesser extent than the ultimate transition goal. It is often unclear whether bridge technologies accelerate the transition to low-carbon systems by providing an interim solution or instead delay it by reducing the urgency of more fundamental change (Levi, 2013; Seto et al., 2016).

These debates have typically been considered at the level of energy systems and infrastructure but they have an analogue in household decision-making. In the context of residential heating, biofuels such as HVO or biomethane are relatively easy to transition to from fossil-fuel heating systems, presenting an opportunity to substantially reduce emissions. However, fuel-switching could in theory weaken subsequent heat pump adoption and, as such, full heating electrification, if it satisfies the household’s desire to reduce emissions while allowing them to retain their existing heating system. They also leave open the possibility of households switching back to fossil fuels.

A complementary perspective comes from research in environmental psychology. 'Single action bias' refers to the tendency for individuals to reduce further action once they have undertaken an initial response to a problem (Weber, 2010). For example, one pro-environmental action can sometimes reduce motivation to pursue additional, potentially more effective actions (Choudhary & Dutt, 2024). Applied to residential heating, the availability of a lower-carbon fuel option could reduce the perceived need for a more transformative technology transition, representing a household-level analogue of the lock-in mechanism described above.

Despite their relevance to residential heating, these debates have rarely been examined at the level of individual consumer preferences. Existing studies typically investigate willingness to adopt a particular technology in isolation rather than how preferences change when multiple decarbonisation pathways are considered together. As a result, there is little direct evidence on whether fuel-switching options function primarily as interim solutions until, or substitutes for, heat pump adoption.

1.1.4 Information Integration and Order Effects

To understand how exposure to one decarbonisation pathway may shape evaluation of another, we draw on Information Integration Theory (Anderson, 1981). Information Integration Theory proposes that individuals form judgements by combining multiple pieces of information, each carrying a particular valence and weight. As new information is encountered, existing evaluations are updated rather than formed in isolation. The theory has been applied across a range of domains, including health, legal decision-making and political judgement (Kattan, 2009; Estrada-Reynolds, Gray & Nuñez, 2015; Chung et al., 2012) and recently to residential heat decarbonisation (Timmons et al., 2026).

In the present context, homeowners may evaluate one heating pathway in light of information about another, generating contrast effects. For example, a biofuel option that appears relatively simple and non-disruptive may alter how households evaluate the costs and requirements associated with heat pump adoption. Conversely, exposure to information about environmental benefits, energy security and running cost benefits of heat pumps may influence how households perceive the benefits and limitations of fuel-switching alternatives. Information Integration Theory therefore provides a mechanism through which both lock-in and stepping-stone effects might emerge.

Following Information Integration Theory and the method developed in Timmons et al. (2026), we conceptualise preferences for residential heat decarbonisation as evolving judgements that are updated as homeowners encounter new information. We measure evaluations at multiple stages of the decision-making process. Respondents first learn about the potential benefits associated with a pathway and subsequently receive information about its costs and limitations. This allows us to observe how preferences change as more complete information is incorporated into the judgements, following the order that homeowners are likely to encounter information in reality (i.e., first benefits, then drawbacks). By applying the same approach to biofuels and heat pumps, we can compare how evaluations evolve across the two pathways. By additionally randomising the order in which respondents encounter each technology, we can test whether exposure to one pathway influences evaluation of the other.

1.2 Research Questions

Given the above, our research questions were:

1. How familiar are homeowners with biofuel alternatives to conventional fossil-fuel heating?
2. How do homeowner evaluations of biofuel heating change as they learn about its (i) benefits and (ii) drawbacks?
3. How do homeowner evaluations of biofuel and heat-pump pathways compare as information about each technology is revealed?
4. Does learning about one decarbonisation pathway influence willingness to switch to the other?

We further report responses to two survey measures of technology perceptions, based on expected social norms and perceived effectiveness of each heating system.

2 Method

The study was implemented using Gorilla Experiment Builder and was compatible with laptop, tablet and mobile devices (Anwyl-Irvine et al., 2020). It was conducted in line with the ESRI's Research Ethics Committee policy.

2.1 Participants

Participants were recruited by a market research and polling agency[a] using stratified quota sampling to be representative of homeowners in Ireland by ownership status (with or without a mortgage), age and region in February 2026. Further inclusion criteria were to live in a house (rather than apartment or other dwelling), to have a gas or oil boiler and to have at least some responsibility over heating system decisions in their home.

A total of 1,175 participants met the inclusion criteria, though data were not stored for 93 who did not complete the study in full and a further 64 who failed one of two quality control questions (to select true statements about heat pumps from a list after being presented with a definition and a CAPTCHA). Characteristics of the final 1,018 analytic sample are presented in Table 1. The two information order treatments (described below) did not differ significantly on any characteristic in Table 1 (all *ps* > .212; see the Supplemental Material (SM)), consistent with successful randomisation.

Table 1. Sample Characteristics

Characteristic		%
Ownership	With mortgage	49.6
	Owns outright	50.4
Age	18-39 years	14.0
	40-59 years	51.1
	60+ years	35.0
Region	Dublin	28.7
	Rest of Leinster	27.9
	Munster	27.5
	Connacht-Ulster	15.9
House Type	Detached	45.0
	Semi-detached / End-of-Terrace	41.0
	Terrace	14.0

[a] https://www.ipsosknowledgepanel.com/en-ie/about-us

Building Energy Rating	AB	26.2
	CD	32.4
	EFG	3.1
	Exempt / Don't know	38.3
House Age	2010+	5.9
	2000-2010	29.7
	1978-2000	31.4
	1950-1977	21.3
	Pre-1950	11.7
Boiler Type	Gas	45.8
	Oil	54.2

2.2 Design and Measures

Following screening and quota questions, participants were informed that the study was about home energy use. They then completed a questionnaire about their home's type, heating system and building fabric characteristics.

Data were collected as part of a broader study on responses to residential heating decarbonisation (Timmons, 2026). The focus of this paper is a short module concerning biofuels, in which awareness was measured before presenting participants with their benefits and current drawbacks. In addition, we exploit similar questions contained in a module on heat pumps. Participants were randomly assigned with equal probability by the survey software to one of two treatments: (1) to first complete the module on biofuels followed by the module on heat pumps (n = 511), or (2) the heat pump module followed by the biofuel module; n = 507). Figure 1 illustrates the study design.

This design serves three purposes. First, the biofuels module allows us to examine awareness, willingness to switch to them and the perceived importance of different benefits and drawbacks. Second, because all respondents evaluated both biofuels and heat pumps, the design permits direct comparison between the two technologies within the same sample. Third, the randomised ordering of the two modules creates a mixed-within-between subject experiment in which all respondents evaluated both technologies but encountered them in different sequences, allowing us to assess whether exposure to one decarbonisation option influences subsequent evaluations of the other, thereby providing a test of competing stepping-stone and carbon lock-in hypotheses. Because each module presents benefit information before drawback information in a fixed sequence, this design isolates the effect of module order (which technology is encountered first) but cannot separately identify effects of benefit/drawback sequencing within a module from other within-module effects.

The biofuel module was tailored to the respondent's existing heating system. Homeowners with oil boilers read information about HVO, while those with gas boilers read information about biomethane. Preliminary analyses revealed no statistically significant differences between respondents evaluating HVO and those evaluating biomethane on the primary outcome measures, so we pool the two biofuel conditions throughout the analysis to simplify presentation and increase statistical power.

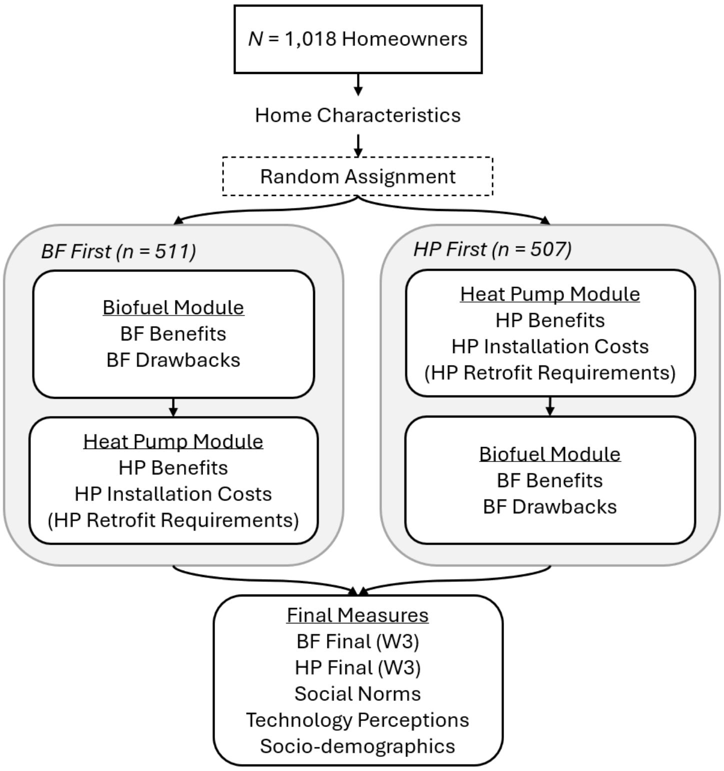

Figure 1. Experimental survey flow chart.

The complete survey instrument, information treatments, supplemental material and analysis code are available on the project's ResearchBox (https://researchbox.org/8968?PEER_REVIEW_passcode=ABNRBI). The measures used in this paper are presented in Table 2. Relevant Measures

2.2.1 Biofuel Module

Participants were first asked if they had heard of the biofuel under consideration (i.e., HVO or biomethane) and those who had were asked to briefly describe their understanding of it. Participants were then provided with a short definition to establish a common baseline level of familiarity and asked to identify which fuels they think the alternative can replace (e.g., diesel, petrol, kerosene).

The first information block covered the benefits of the fuel relative to conventional heating fuels, and these were matched between both fuels: lower carbon emissions, reduced local air pollution and ease of switching from an existing boiler system. Participants then rated their willingness to switch from a traditional boiler fuel to the respective biofuel, on a slider scale anchored at 0 (*would definitely choose another* boiler) and 100 (*would definitely choose the alternative*). Scales had endlabels but not numerical values to reduce anchoring on round numbers (e.g., Liu & Conrad, 2016). They also identified the benefit they considered most important.

Participants then received information on potential drawbacks, again matched between fuels: limited fuel availability in Ireland, sustainability concerns associated with feedstock production (deforestation in the case of HVO and purpose-grown energy crops in the case of biomethane), and higher operating costs relative to conventional fuels. Participants again reported their willingness to switch and identified the drawback they considered most important.

2.2.2 Heat Pump Module

After being presented with a definition of a heat pump, participants received information on its potential benefits relative to conventional heating systems, including lower heating costs, lower greenhouse gas emissions and potential increases in property value. They then reported their willingness to switch on the same 0-100 scale.

The next information block covered installation-related drawbacks, including financial costs and disruption associated with installation, with the willingness to switch measure repeated.

Participants subsequently received information about any building-fabric upgrades required for their home to qualify for a heat-pump installation grant. This information was tailored to each respondent based on the characteristics of their dwelling and contained embedded experiments on grant levels, which are reported on separately. As such, we conduct the primary analysis among the full sample and on a restricted sample of those assigned to see market-level grants, which reflects prevailing grant conditions during data collection. This restriction reduces statistical power relative to the full-sample models reported for biofuels. Detailed analysis of the grant-level experiment and upgrade requirements is reported separately. Importantly, the principal findings reported in this paper are substantively unchanged when all grant conditions are included in the analysis.

2.2.3 Final Measures

Following completion of both modules, participants provided a final willingness-to-switch rating from their existing boiler system to a biofuel and to a heat pump. Participants also indicated whether they believed households like theirs would be most likely over the next ten years to continue using a traditional boiler, switch to a biofuel or install a heat pump. They further rated the perceived heating effectiveness of traditional boilers, biofuels and heat pumps, from 1 "not at all effective" to 7 "very effective", before completing a standard socio-demographic questionnaire.

Table 2. Relevant Measures

Measure	Survey Item
Awareness of Biofuel	The next part of the study is about [HVO/biomethane]. Have you heard of [HVO/biomethane] before? • Yes • No (If Yes: Please briefly describe your understanding of [HVO/biomethane]). [HVO/biomethane] is a type of biofuel. This means it is made from renewable, natural materials – like plants or animal fats. Which of the following fuels do you think [HVO/biomethane] can replace? Select all that apply. ☐ Diesel (used in vehicles and machinery) ☐ Petrol (used in cars and small engines) ☐ Kerosene (used for home heating and jet fuel) ☐ LPG (liquid petroleum gas, used for heating and cooking) ☐ Natural gas (used for heating and cooking) ☐ I don't know
Willingness to Fuel Switch	*After benefits:* Based on what you now know about [HVO/biomethane], how likely would you be to switch your boiler to one that uses [HVO/biomethane]? 0 (Would definitely stick with traditional fuel) ---- 100 (Would definitely switch) Which of the following is most important to you? • Better for the environment – lower carbon emissions • Cleaner air – fewer pollutants • Easy switch – works with most existing [oil/gas] boilers • None *After drawbacks:* Based on what you now know about [HVO/biomethane], how likely would you be to switch your boiler to one that uses [HVO/biomethane]? 0 (Would definitely stick with traditional fuel) ---- 100 (Would definitely switch) Which of the following is most important to you? • Limited supply – [HVO/biomethane] must be imported.

	• Sustainability concerns – Possibly less sustainable than believed. • Price – Slightly more expensive than traditional [oil/gas]. • None *Final:* Based on what you now know about [HVO/biomethane] and getting a heat pump, how likely would you now be to switch your boiler to one that uses [HVO/biomethane]? 0 (Would definitely stick with traditional fuel) ---- 100 (Would definitely switch)
Willingness to Switch to a Heat Pump	*After benefits:* Based on what you now know about heat pumps, how likely would you be to switch to one? 0 (Would definitely choose a another boiler) ---- 100 (Would definitely switch to a heat pump) *After installation costs:* Based on what you now know about heat pumps, how likely would you be to switch to one? 0 (Would definitely choose a another boiler) ---- 100 (Would definitely switch to a heat pump) *Final:* Based on what you now know about [HVO/biomethane] and getting a heat pump, how likely would you now be to switch to a heat pump? 0 (Would definitely stick with traditional fuel) ---- 100 (Would definitely switch to a heat pump)
Additional Measures	Thinking about the upgrades needed for a home like yours to install a heat pump, what do you think other households like yours are likely to do over the next 10 years? • More likely to install a heat pump • More likely to switch their boiler to [HVO/biomethane] • More likely to stay using a [oil/gas] boiler How effective do you think each of the following would be at heating your home: • A heat pump • Switching your boiler to burn [HVO/biomethane] • Another boiler like your current one 1 (Not at all effective) – 7 (Very effective)

2.3 Analytic Approach

We employ four complementary analytical approaches. First, we examine awareness of HVO and biomethane descriptively using self-reported familiarity (RQ1). Second, we examine responses to biofuel benefits and drawbacks using descriptive statistics and OLS regression models (RQ2). We further use predicted means from these models to compare willingness to switch across the benefits and drawbacks that respondents identified as most important.

Third, we examine changes in willingness across the information sequence (i.e., from benefits to drawbacks and final willingness) by estimating OLS models with participant fixed effects, separately for biofuels and heat pumps under each information-order condition (RQ3). These models rely on within-person variation and therefore isolate changes in willingness associated with the introduction of each successive information block

Finally, central to our test of the stepping stone and carbon lock-in hypotheses, we compare final preferences for biofuels and heat pumps and test for order effects by constructing a respondent-level panel (RQ4). In this panel, each participants contributes two observations: one corresponding to their final biofuel rating and one corresponding to their final heat-pump rating. Mixed-effects regression models are estimated with observations nested within respondents. Models include alternative type, information order, their interaction, dwelling characteristics and socio-demographic controls, with standard errors clustered at the respondent level. The interaction between technology type and information order provides a test of whether exposure to biofuels influences subsequent willingness to adopt a heat pump.

3 Results

3.1 Awareness of Biofuels

Among oil boiler owners, 214 (38.8%) reported that they had heard of HVO before completing the study, though 25 of these failed to provide a definition that linked it to a fuel alternative, leaving a sample of 189 (34.2%) with awareness of HVO. Once explained that HVO is a type of biofuel made from renewable, natural materials, most (60.0%) guessed that it could replace diesel for use in vehicles and machinery and 39.0% guessed it could replace kerosene for home heating.

Fewer gas boiler owners reported hearing of biomethane (n = 124; 26.6%) and fewer still (n = 78; 16.7%) cited it as a fuel alternative or a derivative of waste organic matter. Once explained that biomethane is a biofuel, large minorities assumed it could act as an alternative to diesel (43.8%), natural gas (41.0%) and LPG (31.8%).

3.2 Evaluating Biofuels

Figure 2 shows the distribution of willingness to switch ratings after reading information on biofuel benefits and drawbacks. Most homeowners (69.7%) responded above the scale midpoint and were broadly willing to switch to both HVO (M = 61.5, SD = 25.9) and biomethane (M = 62.7, SD = 25.0) after reading about their benefits. For both fuels, the most commonly endorsed benefit was ease of switching (49.3% for HVO and 48.9% for biomethane), followed by emissions reductions (29.0% and 32.6%, respectively) and air quality (13.2% and 13.3%, respectively), with a small minority selecting 'none' (5.2% and 8.5%, respectively). Predicted means from an OLS model regressing ratings onto the most-important benefit selected showed that participants who selected emissions reductions were most willing to switch (M = 69.7, SE = 1.32), followed by air quality (M = 65.2, SE = 2.00) and ease-of-switch (M = 61.6, SE = 1.04), with those who selected no benefit as important the least willing to switch (M = 25.9, SE = 2.76) (see SM for full model output).

Willingness dropped sharply following information on drawbacks, for both HVO (M = 35.2, SD = 25.8) and biomethane (M = 39.5, SD = 25.4), with most participants (67.9%) now reporting below-midpoint willingness (Figure 2). The most important drawbacks were again consistent across fuels, with price selected by the majority (54.2% for HVO and 54.9% for biomethane), followed by sustainability concerns (21.5% and 21.2%, respectively) and supply limitations (19.9% and 20.2%), with few selecting 'none' (4.5% and 3.7%). Predicted mean switch ratings by selected drawbacks showed that those who chose sustainability concerns as most important remained most willing to switch

(M = 47.6, SE = 1.70) followed by supply concerns (M = 38.4, SE = 1.76) while the lowest ratings were reported by those who selected price and 'none' (M = 33.0, SE = 1.03 and M = 32.3, SE = 3.87, respectively). A further OLS model on the change in willingness (i.e., willingness after benefits subtracted from willingness after drawbacks) showed the largest declines among those who selected the price drawback (M = -27.6, SE = 1.06) followed by supply and environmental concerns (M = -23.8, SE = 1.75 and M = -22.9, SE = 1.70) with little change among the minority who selected none (M = -4.8, SE = 3.85).

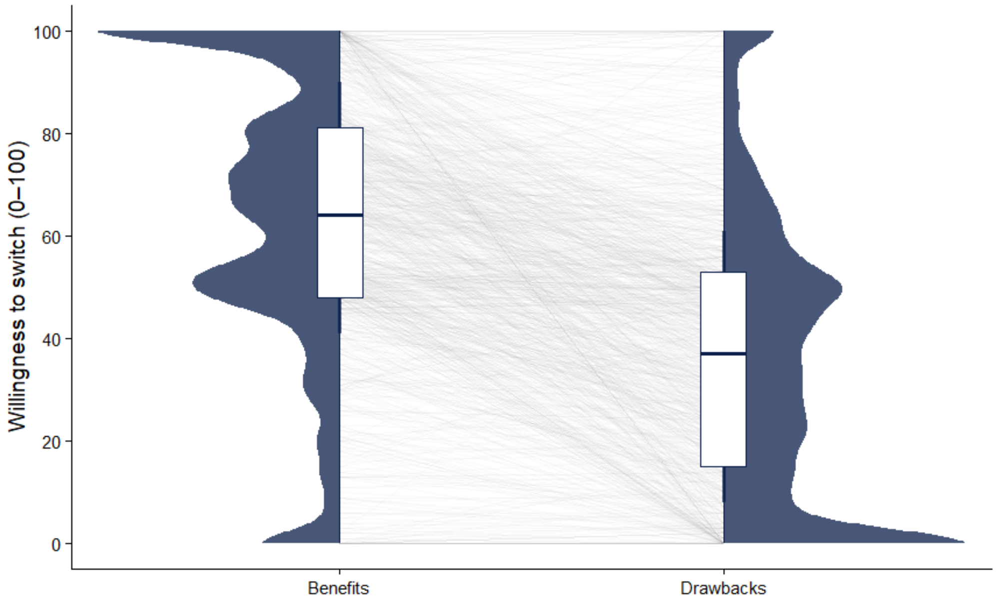

Figure 2. Raincloud plot showing willingness to switch to a biofuel after information on benefits and drawbacks.

Table 3 shows the joint distribution of benefit and drawback selections (χ^2 (9) = 175.90, p < .001). The largest group (31.3%) selected ease-of-switching as the most important benefit and higher running costs as the most important drawback, indicating a dominance of practical concerns over environmental ones. However, almost one-in-four (23.9%) were motivated by environmental benefits (emissions reductions or air quality improvements) but deterred by concerns about sustainability and supply. A further 19.0% were motivated by environmental benefits but identified higher running costs as the principal drawback. These three groups constitute three quarters (74.2%) of all homeowners.

Table 3. Combinations of most important benefits (columns) with most important drawbacks (rows).

Benefit: Drawback	Ease of Switch	Emissions Reductions	Air Quality	None	Total
Price	31.3	12.8	6.2	4.2	54.5
Sustainability Concerns	6.8	9.7	4.7	0.1	21.3
Limited Supply	9.8	7.4	2.1	0.8	20.1
None	1.2	0.8	0.3	1.9	4.2
Total	49.1	30.7	13.3	7.0	100.0

3.3 Comparing Biofuels and Heat Pumps

Table 4 presents participant fixed effects regressions on the effects of successive information blocks on willingness to switch to a biofuel (Models 1 and 2) and a heat pump (Models 3 and 4), separately for those who completed the biofuel module first (Models 1 and 3) and those who completed the heat pump module first (Models 2 and 4). The heat pump models include only those who saw market-level grants within that module. Predicted means are shown in Figure 3.

Figure 3 shows that, after exposure to the benefits of each technology, willingness to switch to a biofuel exceeds willingness to install a heat pump. Information on fuel costs, sustainability and supply limits substantially reduced biofuel willingness, bringing it marginally below heat pump willingness despite the costs and disruption associated with installation. By contrast, the largest decline in heat pump willingness occurred following information on retrofit requirements (received after information on installation costs but before the final rating), highlighting the importance of building fabric requirements in shaping preferences.

Figure 3 shows an order effect for biofuels. Respondents who encountered information on biofuels before information on heat pumps expressed significantly greater initial and final willingness to switch to them than those who learned about heat pumps first. In contrast, willingness to adopt a heat pump was initially increased by first learning about biofuels, consistent with a stepping stone effect, but this boost was not retained once retrofit requirement information was shown, suggesting that any stepping-stone effect on heat pumps is fragile in the face of concrete cost- and disruption-relevant information. Final willingness for biofuels remains almost 50% higher than heat pumps among those who first learned about biofuels.

Table 4. Fixed effects regressions on intentions-to-switch to a biofuel

	Model 1: BF BF First	Model 2: BF HP First	Model 3: HP BF First	Model 4: HP HP First
Information (Ref: Benefits)				
Drawbacks/	-25.26***	-24.52***	-7.84***	-6.54***
Installation Cost	(1.12)	(1.13)	(1.92)	(2.06)
Final	-23.08***	-24.20***	-22.90***	-19.09***
	(1.20)	(1.08)	(2.15)	(2.32)
Constant	65.39***	58.71***	51.57***	47.68***
	(0.67)	(0.69)	(1.18)	(1.28)
Obs.	1,533	1,521	382	320
N	511	507	129	108

Note. *$p < .05$; **$p < .01$; ***$p < .001$. Models 3 and 4 include only those who saw market-level grants. BF = Biofuel. HP = Heat pump.

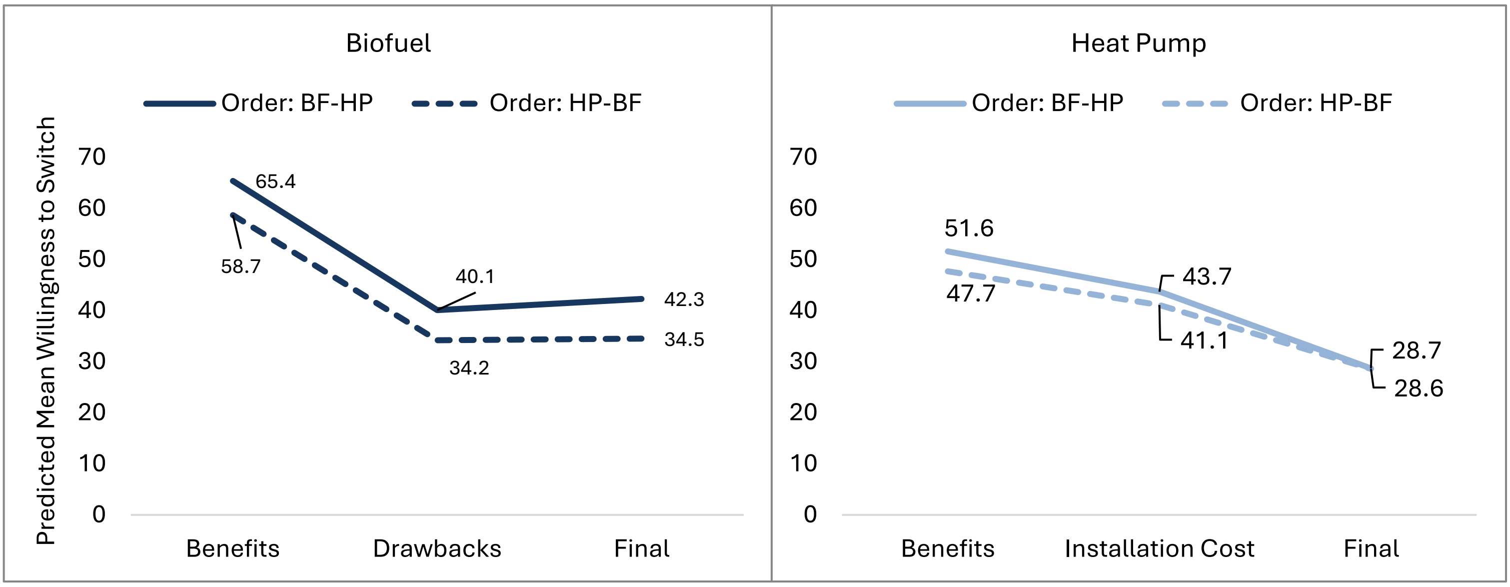

Figure 3. Predicted mean willingness to a biofuel (left) and heat pump (right) by order and information block.

3.4 Order Effects on Biofuels and Heat Pumps

Table 5 reports the mixed-effects models on final willingness ratings, including an interaction term between alternative type and information order, alongside building and participant characteristics. Model 1 presents results for the full sample, whereas Model 2 presents only those exposed to information on market-level heat pump and retrofit grants at the time of the study.

Order had a significant main effect on final biofuel willingness in both models: respondents who encountered biofuel information before heat-pump information reported stronger willing to switch to a biofuel than those who encountered heat-pump information first, both in the full sample (Model 1: *b* = 8.10, *SE* = 1.54, *p* < .001) and in the market-grant subsample (Model 2: *b* = 8.46, *SE* = 3.02, *p* = .005; Figure 4). The heat pump x order interaction was negative and significant in the full sample (Model 1: *b* = -6.31, *SE* = 1.97, *p* = .001), indicating that the order effect was substantially smaller for heat pumps than for biofuels. This interaction did not reach significance in the grant-restricted subsample (Model 2: *b* = -6.08, *SE* = 3.95, *p* = .123) but is of similar magnitude, consistent with reduced power in this smaller sample rather than necessarily reflecting a true absence of the effect.

Combining the order and interaction terms gives the net order effect on final heat-pump willingness: a small boost of 1.79 points in the full sample (8.10 - 6.31) and 2.38 points in the market-grant subsample (8.46 - 6.08) (Figure 4). Since the point estimate on heat pump willingness after first learning about biofuels is positive, this order effect is inconsistent with a carbon lock-in hypothesis.

The main effect of technology type (heat pump vs. biofuel, holding order and covariates constant) differed somewhat between models. In the full sample, baseline willingness to switch did not differ significantly between heat pumps and biofuels (Model 1: *b* = 0.16, *SE* = 1.34, *n.s.*). Under market-level grant conditions, however, heat pumps were somewhat less preferred than biofuels (Model 2: *b* = -5.39, *SE* = 2.91, *p* < .10).

Table 5. Mixed effects regression predicting intentions to switch from a traditional boiler.

	Model 1 Full Sample	Model 2 Market Grants
Heat Pump (Ref: Biofuel)	0.16	-5.39†
	(1.34)	(2.91)
Order: BF-HP (Ref: HP-BF)	8.10***	8.46**
	(1.54)	(3.02)
Heat Pump x Order: BF-HP	-6.31**	-6.08
	(1.97)	(3.95)
Oil Boiler (Ref: Gas)	1.96	5.39
	(1.74)	(3.43)
House Built (Ref: 2011+)		
2000-2010	-3.37	-10.64
	(3.20)	(7.29)
1978-2000	-3.00	-5.34
	(3.27)	(7.15)
1950-1977	-3.44	-10.44

	(3.38)	(7.62)
Pre-1950	-5.96	1.29
	(3.71)	(8.51)
House Type (Ref: Terrace)		
Semi-Detached	-5.03*	-0.54
	(2.22)	(4.23)
Detached	-5.76*	-4.39
	(2.53)	(4.85)
Owns Outright (Ref: With Mortgage)	-2.59	0.36
	(1.70)	(3.42)
Homeowner Age (Ref: 18-39 years)		
40-59 years	0.17	1.30
	(2.10)	(4.23)
60+ years	3.14	-5.08
	(2.77)	(5.35)
Man (Ref: Woman)	-1.42	1.35
	(1.43)	(2.60)
Region (Ref: Dublin)		
Rest of Leinster	-5.12*	-8.22*
	(1.43)	(3.80)
Munster	-0.91	3.25
	(2.14)	(4.32)
Connacht-Ulster	-3.43	-5.13
	(2.60)	(5.46)
Urban (Ref: Rural)	0.41	-0.68
	(1.96)	(4.05)
Degree or Above (Ref: Below Degree)	1.29	0.38
	(1.52)	(2.77)
Employment Status (Ref: Full-Time)		
Retired	-2.61	-0.85
	(2.39)	(4.58)
Other	-2.96†	-8.37
	(1.76)	(3.50)
Socio-Economic Grade (Ref: AB)		
C1	-3.58*	-4.71
	(1.61)	(3.16)
C2DEF	-1.05	-4.33
	(1.91)	(3.67)
Other Building Fabric and Survey Controls	Yes	Yes
Constant	49.39***	50.47***
	(5.20)	(11.96)
Obs.	2,036	474
N	1,018	237

Note. †$p < .10$; *$p < .05$; **$p < .01$; ***$p < .001$. BF = Biofuel. HP = Heat pump.

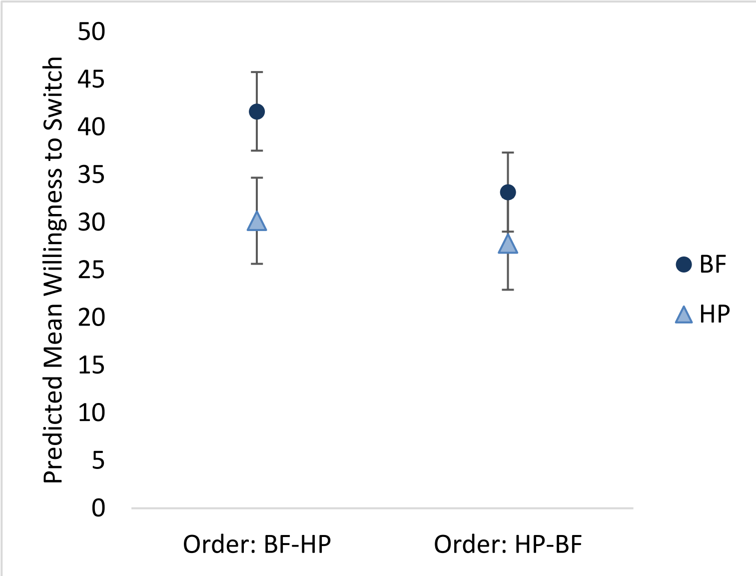

Figure 4. Predicted mean final willingness to switch, by alternative and order from Model 2 in *Table 5*. BF = biofuel; HP = heat pump.

Turning to the rest of the model, socio-demographic differences were modest, though those living outside of the Dublin (especially in the rest of Leinster), with detached or semi-detached homes, which are typically larger than terraced homes, and in lower socio-economic grades reported lower willingness-to-switch.

3.5 Other Perceptions

Most participants (56.7%) expected other homes like theirs to stick with a traditional boiler heating system over the next decade (Figure 5), while the next largest group (30.7%) expect others to switch to a heat pump system. Participants also perceived biofuels to be less effective at home heating ($M = 4.5$, $SD = 1.53$) compared to both heat pump ($M = 5.3$, $SD = 1.52$; $t(1{,}017) = 15.56$, $p < .001$) and traditional boilers ($M = 5.4$, $SD = 1.39$; $t(1{,}017) = 14.22$, $p < .001$), with no difference between these other two systems ($t(1{,}017) = 0.82$, $p = .411$).

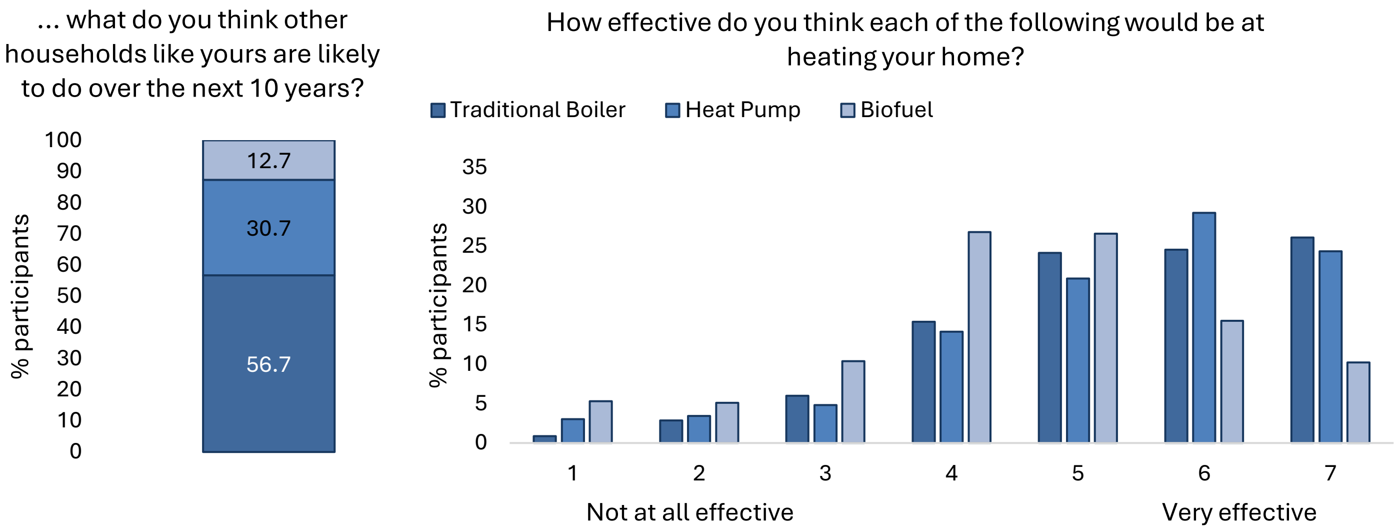

Figure 5. Perceived social norms (left) and heating effectiveness (right) for traditional boilers, heat pumps and biofuels.

Exploratory analyses revealed order effects on perceptions of heating effectiveness (Table 6). Predicted probabilities from ordinal logistic regression models showed a 20% (9.3%-point) increase in those who percevied biofuels as effective (i.e., above the scale midpoint) for those first exposed to biofuels compared to those first exposed to heat pumps (56.7% vs. 47.4%, respectively). Those first exposed to information on biofuels were also less likely to judge a traditional boiler as effective (72.8% vs. 77.8%, a 5%-point difference) and their perceptions of heat pump effectiveness was also higher, though not significantly so.

Table 6. Ordinal logistic regressions on perceived heating effectiveness

	Model 1 Biofuel	Model 2 Heat Pump	Model 3 Trad. Boiler
Biofuel First	0.39**	0.16	-0.24*
(Ref: Heat Pump First)	(0.11)	(0.11)	(0.11)
Other Survey and Characteristic Controls	Yes	Yes	Yes
N	1.018	1,018	1,018

Note. †$p < .10$; *$p < .05$; **$p < .01$; ***$p < .001$.

4 Discussion

Three findings stand out. First, homeowners were considerably open to biofuels when they learned of their potential benefits, though willingness fell by roughly 25 points on the 0-100 scale once drawback information, mostly about their higher running costs, was introduced. Second, despite higher running costs, biofuels hold a stated-preference advantage over heat pumps. "Fully-informed" willingness to switch to a biofuel remained about 50% higher than final willingness to install a heat pump among those who encountered biofuel information first, with the gap principally driven by the sharp decline in heat pump willingness following information on retrofit requirements. Third, and most directly relevant to the carbon lock-in question, we find no evidence that learning about biofuels reduces subsequent willingness to adopt a heat pump. If anything, the combined order and interaction effects point in the opposite direction.

4.1 Preferences for Biofuels

Awareness of biofuels is low and asymmetric, with twice as many oil-boiler owners having heard of HVO than gas-boiler owners who had heard of biomethane (34.2% vs. 16.7%) (RQ1). This gap is plausibly explained by the greater prevalence of HVO has an alternative to diesel for transport (e.g., Suarez-Bertoa, 2019). Importantly, our awareness question did not measure awareness of these biofuels as alternatives for heating, meaning we present upper-bounds on this functional familiarity. Awareness is substantially lower than for heat pumps, for which 45% of boiler-owners can indicate reasonable awareness (Timmons et al., 2026), meaning any campaign to promote biofuel switching will start from a lower base of consumer literacy. This unfamiliarity introduces scope for misinformation to take hold, but also for policy to inform consumers before misconceptions form (Lewandowsky et al., 2012).

Once informed of the potential benefits of biofuels, most homeowners were receptive, with over two-thirds (69.7%) rating their willingness to switch about the scale midpoint. Ease of switching, rather than environmental benefits, was the most commonly cited reason (almost half of respondents). This ordering of motivations is telling. Household enthusiasm for biofuels appears to be driven primarily by convenience rather than environmental commitment, a pattern reinforced by the joint distribution of benefits and drawbacks in Table 3. The single largest group of homeowners (31.3%) valued ease of switching most and cited price as their principal concern, a profile better described as pragmatic than environmentally motivated. This is consistent with the broader heating-preference literature on cost sensitivity (Rouvinen & Matero, 2013; Schleich et al., 2022). The scale of the decline in willingness after drawback information (from a mean in the low 60s to the mid-to-high 30s) confirms that price is doing most of that work: 55% of respondents identified price as their most important drawback, more than the share citing sustainability or supply concerns combined (RQ2).

4.2 Biofuels vs. Heat Pumps

Directly comparing the two pathways within the same respondents clarifies where their relative advantage lies. At the benefits stage, initial willingness to switch to a biofuel (broadly 59-65 depending on order condition) already exceeded initial willingness to switch to a heat pump (48-52). Cost and drawback information narrowed this gap, bringing willingness for biofuels down to a level marginally below heat pumps. However, retrofit requirements for heat pumps reopened the gap. In other words, heat pumps' disadvantage relative to biofuels is concentrated in building-fabric and retrofit requirements, not in installation cost or disruption of the system itself (RQ3). This is consistent with, and extends, existing evidence that homeowners place substantial negative weight on retrofit works (Curtis et al., 2024) and become markedly less willing to adopt a heat pump once retrofit requirements are made concrete (Timmons et al., 2026).

This asymmetry has a practical corollary: the two pathways' principal barriers differ in kind, not just degree. Biofuels' main deterrent – price - is a policy-tractable, largely fiscal barrier (e.g., through taxation, blending mandates, subsidy design). Heat pumps' main deterrent, retrofit requirements, is primarily structural, capital-intensive barrier tied to the physical condition of the housing stock, which cannot be resolved through pricing policy alone. We return to this distinction below.

4.3 Stepping Stone vs. Carbon Lock-In

We find no support for a carbon lock-in account for homeowner preferences (RQ4). The mixed-effects panel regressions show a significant main effect of order on final biofuel willingness that is not mirrored by a comparable negative effect on heat pump willingness. Combining the order and interaction terms, the net effect of encountering biofuels first on final heat pump willingness is modestly positive rather than negative.

This finding is complemented by the within-sequence fixed-effects decomposition. Heat pump willingness at the benefits stage was higher among respondents who had already encountered biofuel information (51.6) than among those encountering heat pumps first (47.7). This implies direct, if modest and short-lived, stepping-stone effect. Critically, however, this initial boost does not survive concrete retrofit-requirement information: final heat pump willingness converges to a near-identical level regardless of order (28.6 vs. 28.7). Any stepping-stone effect on heat pumps, in other words, is swamped by technology-specific costs and disruption.

Finally, the exploratory order effects on perceived heating effectiveness show a similarly bounded pattern. Respondents who encountered biofuels first rated biofuels as more effective and traditional boilers as less effective than those who encountered heat pumps first, but their perceptions of heat-pump effectiveness were statistically unchanged (although the point estimate was again positive). This suggests that order primarily influenced evaluations of the focal technology and the incumbent comparator rather than reducing confidence in an alternative decarbonisation option. Such a pattern is more consistent with an anchoring-and-integration account (Anderson, 1981), in which new information is incorporated into existing evaluations, than with a single-action-bias account. At the same time, the asymmetry of the effect is notable. Whereas encountering biofuels first did not reduce perceptions of heat pumps, exposure to heat pumps first was associated with less favourable evaluations of biofuels.

Taken together, these findings offer no consistent evidence that promoting biofuels crowds out enthusiasm for heat pumps in the way a carbon-lock-in account would predict. If anything, the balance of evidence is somewhat more consistent with a weak stepping-stone account, with exposure to biofuels modestly increasing initial willingness to adopt a heat pump. However, the effects are asymmetric. While biofuels do not appear to undermine support for heat pumps, making the costs and disruption associated with heat-pump adoption salient may reduce enthusiasm for alternative decarbonisation pathways. One possible explanation is that information about the practical challenges of heat decarbonisation generalises beyond the technology under consideration, though this interpretation is speculative. More generally, our findings speak most directly to the formation of preferences when homeowners are presented with competing decarbonisation pathways. Whether similar dynamics emerge once households face financial constraints, practical considerations and longer time horizons is an important question for future research.

4.4 Policy Implications

Three implications follow from the pattern of results above. First, because we find no evidence that biofuel promotion measurably undermines heat pump willingness at the level of stated household preference, government support for both pathways in parallel need not be seen as self-defeating from a consumer-preference standpoint. That said, this does not resolve separate concerns around biofuels, including feedstock and biomass supply constraints that limit how far biofuels can scale as a decarbonisation pathway regardless of household willingness (Bouter et al., 2024). Second, because the stepping-stone boost to heat pump willingness we observe is fragile and erodes once retrofit requirements are made concrete, policy cannot rely on generalised decarbonisation enthusiasm to carry households through to heat pump adoption; retrofit and fabric-readiness requirements need to be addressed directly, whether through expanded retrofit supports or a relaxation of the fabric-adequacy conditionality attached to current grant schemes, rather than assumed away by broader climate messaging. Third, because price is the dominant deterrent for biofuels specifically, and a comparatively tractable one, adjustments to how these fuels are taxed and priced relative to fossil equivalents, such as by taxing HVO as a heating rather than transport fuel, represent a direct lever for increasing biofuel uptake, should it become a policy goal. Factual awareness campaigns remain warranted given the low baseline familiarity we document, particularly for biomethane.

4.5 Limitations and Future Research

Several limitations qualify these conclusions and point to directions for future work. First, our design compares only two decarbonisation pathways. Policy faces a wider set of options, including district heating, solar thermal systems and electric boilers, that were outside the scope of this study. How exposure to a broader choice set affects the order-effect pattern we document here is an open question.

Second, our study examines evaluations at an early stage of decision-making (i.e., when homeowners learn about heating options) rather than observed adoption behaviour. This distinction is particularly important for home-heating systems, which are high-cost durable goods that many households replace only once or twice over a lifetime. The results therefore provide evidence on how homeowners process information about competing decarbonisation pathways, but not on how these preferences translate into eventual investment decisions when financing constraints, installer availability and household circumstances come into play.

Third, the information we presented reflects contemporary market conditions. Biofuel prices, heat pump grant levels and the fabric-adequacy eligibility criteria in place at the time of data collection are subject to policy change. Increasing biofuel supply, reducing biofuel running costs through altered fuel taxation, increasing retrofit supports for heat pumps, or relaxing the fabric-adequacy grant approach would each be expected to shift the relative balance of preferences reported here, and embedding these alternative policy scenarios directly into future survey experiments would allow a more direct test of their effect on the stepping-stone/lock-in balance.

Finally, though Ireland provides a particularly useful test case because of its oil- and gas-dominated housing stock and relatively low heat pump penetration, replication in other policy settings will be important.

4.6 Conclusion

This study provides to our knowledge, the first experimental test of the stepping-stone/carbon-lock-in question at the level of individual household decision-making in residential heating. Using a randomised, within-subject design in which a nationally representative sample of homeowners in Ireland evaluated both a biofuel and a heat pump pathway to decarbonisation, we find that exposure to biofuels does not reduce, and may modestly and temporarily increase, stated willingness to adopt a heat pump. The advantage biofuels hold over heat pumps in this sample is driven less by their environmental credentials than by their comparative ease and the absence of retrofit requirements. However, this advantage is substantially eroded once running costs are made salient. Conversely, heat pumps' principal disadvantage lies specifically in building-fabric requirements rather than installation cost or disruption more broadly. For policymakers, these findings suggest that promoting lower-carbon fuels alongside heat pump electrification need not be framed as a zero-sum trade-off at the level of household preference, provided that fuel-pricing policy and retrofit-support design are each addressed.

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