

# Insights Paper

Replacing oil boilers with heat pumps: household economics and system-wide impacts



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## Executive summary

Around 700,000 homes in Ireland use oil as their primary space and water-heating fuel. Oil is a relatively expensive and carbon intensive fuel. A move away from oil heating in homes can reduce carbon emissions, the reliance on imported fuels, and household energy bills. Two primary means are available to homeowners to achieve these aims: 1) improving the building's insulation, heating controls and thermal performance and/or; 2) switching from oil to an alternative heating source.

SEAI advocates an energy-efficiency-first approach to all energy decisions based on evidence that these are the most cost effective measures and come with a wide range of additional benefits. SEAI's 'Unlocking the Energy Efficiency Opportunity' report outlines this evidence and describes the potential costs and benefits of energy efficiency in detail.<sup>1</sup>

This paper focusses on the second option and provides some insights into the household economics and system-wide impacts, of a possible long term transition to heat pumps as an alternative energy source to oil. In order to provide insights in a straightforward way, the paper bases its analysis on the current thermal performance of the housing stock with some comment on how a realisation of the energy efficiency potential may affect the findings. Potential scenarios for the impact of other feasible actions, specifically the costs and benefits of energy efficiency retrofits, are not quantified here but are critical to the formation of any policy that seeks to move away from oil as a heat source in the residential sector.

Correctly installed and sized heat pumps are proven to be an efficient source of heat and offer an available alternative for homes currently using oil, especially those homes in rural areas without easy access to the gas grid. This report analyses the economic feasibility of air source heat pumps as an alternative source of heat energy to oil boilers from the homeowner's perspective. A simple payback is estimated based on the operational expenditure and installation cost differences between a heat pump and a new oil boiler in a number of house types. A range of system-wide impacts from a complete conversion of the oil-heated homes to heat pumps are examined in the context of potential future 2030, and 2050, climate and energy targets. These include the impacts on total primary fuel requirements, CO<sub>2</sub> emissions, renewable heat output and the electricity demand profile in the hypothetical (long term) scenario where all homes currently using oil switch to a heat pump alternative.

The quantity of primary energy a dwelling requires to maintain a comfortable internal temperature is an important factor in determining the economics of a heat pump replacement. The methodology categorises dwellings by their building type (apartment, terrace, semi-detached or detached) and their energy

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<sup>1</sup> SEAI (2015), 'Unlocking the Energy Efficiency Opportunity' available at: [http://www.seai.ie/Publications/Energy\\_Policy\\_Publications/Energy\\_Modelling\\_Group\\_Publications/Unlocking-the-Energy-Efficiency-Opportunity-Main-Report-.75081.shortcut.pdf](http://www.seai.ie/Publications/Energy_Policy_Publications/Energy_Modelling_Group_Publications/Unlocking-the-Energy-Efficiency-Opportunity-Main-Report-.75081.shortcut.pdf)

efficiency rating into nine representative archetypes. Annual space heating and hot water requirements are estimated for each archetype.

The performance and efficiency of heat pumps can be affected by the prevailing weather conditions, how they are operated by households, and by how much hot water they are required to deliver. In order to capture these effects, the methodology uses operational performance assumptions for heat pumps based on published field trial data and consultation with industry groups. Heat pumps can be configured to work with auxiliary heat sources to meet high temperature peaks outside of the optimal temperature range for a standard heat pump. The operational performance changes for different hybrid system configurations are analysed to investigate the pros and cons of using an auxiliary oil or gas boiler<sup>2</sup> at such times. As a large scale switch to electricity-driven heat pumps could have significant implications for the electricity system demand profile, the final step in the methodology is a preliminary assessment of the effect on the electricity system demand profile and a comment on how this may affect system operation.

The analysis shows that, choosing a heat pump instead of an oil boiler, could result in reduced fossil fuel usage and CO<sub>2</sub> emissions, increased renewable heat generation, lower on-going operational expenditure, and greater security of fuel supply. The magnitude of the savings depends on the type of dwelling, how energy efficient it is and if the dwelling has access to night rate electricity. These benefits are considered from the consumer and system-wide perspectives.

### Consumer level impacts

- Annual savings on fuel bills are estimated to be in the range of €200 – €400 for smaller, more efficient homes that switch to heat pumps, and €600 – €1,300 for larger, less efficient homes.
- The installation cost difference between a new oil boiler and an air source heat pump ranges from €5,500 in smaller homes to €7,700 for larger homes.
- Based on the relative installed cost difference of heat pumps and oil boilers for each archetype, around 460,000 dwellings in Ireland have a simple payback of 11 years or less.

### System-wide impacts

For the hypothetical scenario of a full conversion of all 700,000 dwellings in Ireland to heat pumps over the long term, the analysis suggests the following annual results:

- Oil usage in the residential sector could be reduced, with savings estimated at €411 – €494 million to consumers after additional electricity costs associated with heat pump use are accounted for. The overall primary energy usage in Ireland is reduced by 1.9 – 2.5%.

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<sup>2</sup> Supplied by portable refillable gas tanks.

- Between 2.2 – 2.9 million tonnes of CO<sub>2</sub> (MtCO<sub>2</sub>) is transferred from the non-ETS to ETS sector.<sup>3</sup> When the additional emissions associated with increased electricity generation are accounted for, overall CO<sub>2</sub> emissions reductions are in the range of 1 – 1.3 MtCO<sub>2</sub>.
- The renewable heat contribution (from heat pumps alone) is estimated at between 14 – 15% of total projected 2020 heat demand.<sup>4</sup>

### Key considerations for policy makers and households

Whilst the estimated impacts of a large scale shift to heat pumps from oil heating in the residential sector represent potentially significant contributions to emissions reductions, energy savings and renewable heating, a number of considerations must be made at policy level to facilitate this paradigm shift.

Fabric upgrades such as insulation, triple glazing and draught proofing should be considered first as a lower cost way to reduce energy bills. Such upgrades should happen before fitting a new heat pump to ensure the pump is correctly sized. Given the limited budget of households (and Government) to invest in energy efficiency, and/or supply-side efficiency, improvements such as a switch to heat pumps, or trade-offs between energy efficiency upgrades and heat pump investments, require further examination.

Given that savings realised by consumers are sensitive to changes in the operational performance of the heat pump, the importance of correct sizing and installation of heat pumps in homes is essential to maximise their efficiency. The need for codes and standards to ensure expert system commissioning was demonstrated in the Energy Savings Trust field trials in the UK which highlighted these as significant factors in the underperformance of heat pumps in actual operation. Results also indicate the use of night rate electricity is an important factor for householders when calculating the operating costs and payback of installing a heat pump.

Finally, a preliminary analysis of the impact of additional electricity demand from heat pumps on the electricity system has been undertaken for this report. Large scale electrification could place additional stress on the electricity system at peak times due to the correlation between peak heat and peak electricity demands in homes. With the use of smart grid technology this effect may be mitigated and with heat pump demand used to support system stability, optimising the use of renewable electricity output. These elements relating to a large scale move to heat pumps require further analysis.

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<sup>3</sup> This represents 10 – 13% of the non-ETS energy related emissions target for 2020.

<sup>4</sup> Demand forecast for 2020 is sourced from [37].

## The Sustainable Energy Authority of Ireland

The Sustainable Energy Authority of Ireland (SEAI) was established as Ireland's national energy authority under the Sustainable Energy Act 2002. SEAI's mission is to play a leading role in the transformation of Ireland to a society based on sustainable energy structures, technologies and practices. To fulfil this mission, SEAI aims at providing well-timed and informed advice to Government and delivering a range of programmes efficiently and effectively, while engaging and motivating a wide range of stakeholders and showing continuing flexibility and innovation in all activities. SEAI's actions will help advance Ireland to the vanguard of the global clean technology movement, so that Ireland is recognised as a pioneer in the move to decarbonised energy systems.

SEAI's key strategic objectives are:

- Energy efficiency first – implementing strong energy efficiency actions that radically reduce energy intensity and usage;
- Low carbon energy sources – accelerating the development and adoption of technologies to exploit renewable energy sources;
- Innovation and integration – supporting evidence-based responses that engage all actors, supporting innovation and enterprise for our low carbon future.

SEAI is part financed by Ireland's EU Structural Funds Programme, and co-funded by the Irish Government and the European Union.

The *Insights* paper series aims at providing new information and insights to policy makers and the modelling community. *Insights* papers focus on individual questions relating to the energy policy, and the impacts, of sustainable energy technologies. Policy makers can consider the findings from the *Insight* series as part of the larger body of evidence and the modelling community can build on and refine the analysis in future iterations.

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Any oversights or omissions are the authors alone.

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## 1. Introduction

Heat pumps are regarded as highly efficient thermal energy producing devices. Based on a thermodynamic refrigeration cycle, they have the potential to produce up to six times the thermal output for each unit of electrical input [1]. In Ireland, with our high levels of renewable electricity generation and fuel import dependence (89% in 2013 [2]), heat pumps can provide an alternative to the existing heat sources used to meet the nation's thermal energy needs. The potential benefits include lowering national reliance on imported fossil fuels, reducing CO<sub>2</sub> emissions, displacing non-ETS<sup>5</sup> CO<sub>2</sub> emissions, and delivering renewable heat.<sup>6</sup> Heat pumps are also capable of operating in conjunction with smart grid technology to maximise the benefits from renewable electricity generation [3] [4] [5] [6].

### 1.1. Ireland's residential sector

Ireland's residential sector is the second largest energy using sector after transport, accounting for 27% (3,553 ktoe) of primary energy use in 2013. The sector is also one of the largest sources of CO<sub>2</sub> emissions, producing 27% (~10 MtCO<sub>2</sub>) of Ireland's total energy related CO<sub>2</sub> emissions in 2013 and 46% of the energy related emissions subject to Ireland's binding non-ETS CO<sub>2</sub> emissions reductions targets [2]. Space heating and hot water provision account for the majority of fuel use in the residential sector.

Ireland's residential sector is notable for the large amount of oil used to generate heat. According to SEAI's most recent 'Energy in the Residential Sector report', oil fired central heating (OFCH) systems are used in 700,000 or 44% of Ireland's dwellings [7]. Many of these are in rural locations away from the national gas grid, limiting the options for switching to the lower cost, and less carbon intensive, natural gas. Figure 1 illustrates the primary energy use in the residential sector for heating purposes.<sup>7</sup> The figure shows there was more oil used in 2013 than gas – this is in contrast to the EU-27 average where gas utilisation is approximately 2.7 times higher than oil [8].

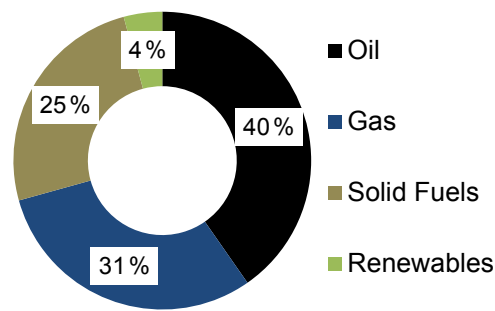
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<sup>5</sup> Non-ETS represents CO<sub>2</sub> emissions not covered under the emissions trading scheme (ETS). The ETS is the cornerstone of the European Union's policy to combat climate change along with reducing greenhouse gas emissions[34].

<sup>6</sup> Heat pumps are considered a renewable source of heat under EU Renewable Energy Directive 2009/28/EC[10].

<sup>7</sup> Figure 1 takes account of primary energy consumed to generate the electricity used for heating purposes.

Figure 1: Total primary energy used for heating purposes in the residential sector, 2013 [7]



## 1.2. National renewable and energy efficiency 2020 targets

Under the Energy Efficiency Directive 2012/27/EC [9] and the Renewable Energy Directive 2009/28/EC [10] EU Member States are encouraged to lower energy consumption and are legally bound to increase the deployment of renewable energy technologies. Ireland must increase renewable energy use to 16% of gross final energy consumption by 2020 and have committed to reducing the national energy demand by 20% (33% in the public sector) compared to the average 2001 – 2005 level through energy efficiency measures by 2020 [11]. The EU Effort Sharing Decision 2009/406/EC [12] stipulates that the EU as a whole must reduce the emissions that fall outside of the emissions trading scheme (ETS) by 10% relative to 2005 levels [13]. Ireland's target to reduce non-ETS emissions by 20% (along with Luxembourg and Denmark) is the most challenging of all EU Member States. Since the residential sector accounts for 46% of Ireland's energy related non-ETS emissions so reducing oil use would make a significant contribution to reaching this target. Achievement of these goals comes with the added benefits of reduced reliance on imported fossil fuels, improved security of supply, and reduced exposure to fossil fuel price volatility.

Energy efficiency policies have been successful in reducing household demand for thermal energy, while building regulations for household dwellings implemented in 2008 have led to an increased amount of renewable energy being used for heat [14]. In spite of these developments, fossil fuels continue to dominate heat production in the residential sector – an issue that was recognised by Government in the recently published 'Green Paper on Energy Policy in Ireland' as an area energy policy can improve [15]. Nevertheless significant barriers remain to facilitating a shift away from carbon intensive oil systems to more sustainable options. The higher capital costs of renewable technologies, access to the natural gas grid, and a lack of market experience in the use of renewable options have all added to the list of barriers restricting the uptake of alternatives [8] [16] [17] [18]. The electrification of heat production via heat pumps is an option that can contribute towards renewable energy targets while also helping to achieve national emissions targets.

### 1.3. Report purpose

This report has two aims:

- 1) to investigate the economic feasibility of converting Irish dwellings currently using oil fired central heating systems to air source heat pumps and;
- 2) to analyse the impacts of a large scale conversion to air source heat pumps on fossil fuel usage, CO<sub>2</sub> emissions, the contribution to renewable energy targets, and to consider the possible effects of this conversion on the electricity system demand profile.<sup>8</sup>

### 1.4. Methodology overview

The methodology allocates thermal demand across nine building archetypes that represent the various hot water and space-heating requirements of the most common dwelling types in the segment of the Irish building stock heated by oil. Consideration is given to the efficiency of a heat pump in terms of how their performance changes as ambient temperatures vary, and how a consumer's daily heat requirements for hot water and short term boosts in internal temperatures influence heat pump efficiency. Since heat pumps work most efficiently when the temperature gap between the output of the device and the heat source is low, spikes in space or hot water heating demand can reduce the efficiency of heat pumps. Scenarios are developed to examine various configurations of heat pumps, including those with auxiliary systems, to meet these high temperature demand peaks through additional electrical input (i.e. electric immersion heater) or using auxiliary gas or oil boilers.

Large scale conversion to heat pumps may influence the electricity demand profile with consequential impacts for electricity system operation. This potential impact is incorporated into the methodology and examined using high resolution heat demand profiles for different dwelling types based on data from the national smart meter trials.<sup>9</sup>

### 1.5. Report structure

This report is structured as follows. Section 2 contains an overview of heat pump technology and the factors that influence operational efficiency. Section 3 explains the methodology employed to evaluate heat pump performance and Section 4 discusses the findings. The concluding section discusses some of the policy implications of the results and identifies where future work is required.

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<sup>8</sup> The decision to investigate air source heat pumps (ASHP) over the other types of heat pumps is based on previous analysis that found ASHPs are the least disruptive and most inexpensive replacement option (in terms of heat pumps) for existing boilers in most circumstances[5][16][22].

<sup>9</sup> The national smart meter trials were carried out between 2009 – 2010 across Ireland to assess the performance of smart meters, their impact on customers' energy consumption, and the economic case for a wider national rollout[30].

## 2. Heat pump technology and operation

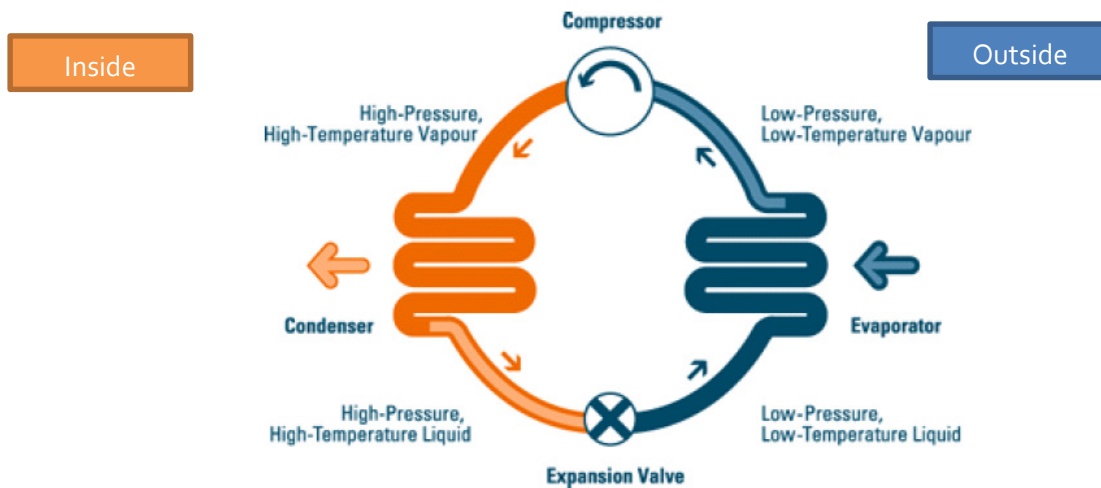
Heat pumps transfer thermal energy from a heat source (usually outdoor) into internal spaces through a process of evaporation and condensation known as a vapour-compression cycle. Heat pumps are categorised based on the outdoor heat source used – most commonly air, water or ground source heat pumps, and the indoor heating medium – air or water. The installation costs and operational efficiencies differ somewhat across these sources. Ground and water source heat pumps require more civil works and as a result are more expensive to install, however they provide a more consistent operational efficiency compared to that of air source heat pumps (ASHP), which are affected more by changing ambient temperatures [1] [19] [20].

Auxiliary heat sources are also taken into account during the analysis to provide thermal energy outside the optimal performance range for a heat pump. Through either an electric immersion heater, oil or gas boiler, this additional heat source is present in all scenarios throughout the analysis. A situation where both a heat pump and boiler are present is known as a *hybrid system*. A hybrid heat pump system can deliver heat at more optimal performance levels as the auxiliary heat source is designed to provide water and peak space heating requirements that generally require output temperatures outside the optimal performance range of heat pumps. Manufacturers have developed hybrids that choose the most economical heat source at a particular moment of time. The decision is based on ambient temperatures, energy prices and internal heat load [21].

### 2.1. Basic principles

A heat pump uses electricity (or some other high-grade energy source) to power a pump that compresses a working fluid. The working fluid, generally a refrigerant, evaporates at low temperatures, absorbing heat from the outside heat source as it changes state from liquid to gas. The compressor, usually powered by electricity, increases the temperature and pressure of the refrigerant causing the working refrigerant to release the previously absorbed heat as it condenses. The condenser transfers this heat into the building through underfloor coils, water, radiators, or air [20]. Figure 2 illustrates the four stages that occur in the thermodynamic cycle: 1) Compression, 2) Condensation, 3) Expansion, and 4) Evaporation.

Figure 2: Schematic of the thermodynamic cycle that occurs in a heat pump [20]



The primary advantage of a heat pump lies in its ability to provide thermal energy at high efficiencies by drawing energy from low temperature sources. Potentially a heat pump can provide up to six times the electrical input in the form of thermal energy output [1]. This performance is measured using a parameter called the coefficient of performance (COP), as shown in Equation 1.  $Q_h$  represents heat output and  $W_{in}$  is electrical input.

$$COP = Q_h / W_{in} \quad [1]$$

## 2.2. Operational efficiency – what influences COP?

Heat pumps operate at higher COPs when the temperature difference between the outdoor heat source and the internal space is small. Their performance is also influenced by how they are operated and if they are correctly sized and properly installed.

Heat pumps are not designed to provide heat in the same way a boiler would. The latter is demand responsive, meaning it operates in a responsive manner to the changing thermal load. However, a performance-optimised heat pump would operate over a prolonged period, providing lower, more constant levels of heat input to the dwelling, which could have positive knock-on effects on the electricity system.<sup>10</sup>

Cold weather conditions act to reduce the heat source temperature and can increase the heat output required from a heat pump. The increased temperature difference leads to a reduction in the heat pump's COP, as the pump must work harder to deliver the same heat output. In addition, extremely cold weather conditions can cause the heat pump to freeze and ice can build up on external coils adding a layer of insulation, making the transfer of heat more difficult. Many heat pumps use a de-icing feature that provides heat to the outdoor coils to prevent ice build-up and liquid freezing, but this comes at the expense of COP.

<sup>10</sup> This assumes that the house is well insulated enough to hold the heat inside the home and that the radiator system can deliver heat into the internal space.

Similarly, if the delivery temperature of heat demand varies widely over short periods, then a heat pump is less likely to maintain its high operational efficiency as more electricity is needed to deliver the required high temperature heat output. To ensure the thermal demand is met in these types of difficult conditions, an auxiliary heat source is often included in the system set-up to provide instantaneous heat during the periods when the heat pump may not be able to meet the thermal demand in normal operation.<sup>11</sup> This has the effect of improving the heat pump's overall seasonal coefficient of performance, known as seasonal performance factor (SPF).

Field trials carried out by the Energy Savings Trust in the United Kingdom found that the performance of a heat pump can be affected by other factors, such as the appropriate sizing and correct installation of the device. The trials were carried out in two phases: the first installed, measured and analysed the heat pump operation; then the second improved certain aspects of the installations, such as system sizing, buffer tanks, controls, low temperature radiators, etc. The upgrades increased system performance significantly for both air source and ground source heat pumps, highlighting the effects of incorrectly applied sizing and installation [17].

### 2.3. Renewable heat contribution of a heat pump

Due to their potential for high efficiencies, heat pumps are considered a renewable source of heat under EU Renewable Energy Directive 2009/28/EC [10]. The proportion of the device's output considered renewable is dependent on the average COP of the heat pump over a heating season (known as the seasonal performance factor [SPF]) compared to the efficiency of the electricity supply. However before determining the SPF, the heat pump system boundary used for the calculation must be defined. To comply with the EU Directive, the system boundary must be limited to the thermal output of the heat pump divided by the electrical input to the device. No energy input or output from the auxiliary heat source is accounted for in the calculation [10] [23].

Equation 2 shows the formula outlined in Annex VII of the Renewable Energy Directive to calculate the renewable energy contribution from a heat pump ( $E_{RES}$ ) based on the total usage heat delivered from the device ( $Q_{usable}$ ) and the SPF.<sup>12</sup>

$$E_{RES} = Q_{usable} * (1 - 1/SPF) \quad [2]$$

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<sup>11</sup> Inclusion of an auxiliary heat source is also used for disease prevention, eradicating the potential for bacteria to multiply in the system. For more details see [33].

<sup>12</sup> Only heat pumps with an  $SPF > 1.15 * 1/\eta$  are taken into account.  $\eta$  represents the ratio between total gross production of electricity and the primary energy consumption for electricity production and shall be calculated on an EU average based on Eurostat data[10].

#### **2.4. Fossil fuel and CO<sub>2</sub> emissions savings from a heat pump**

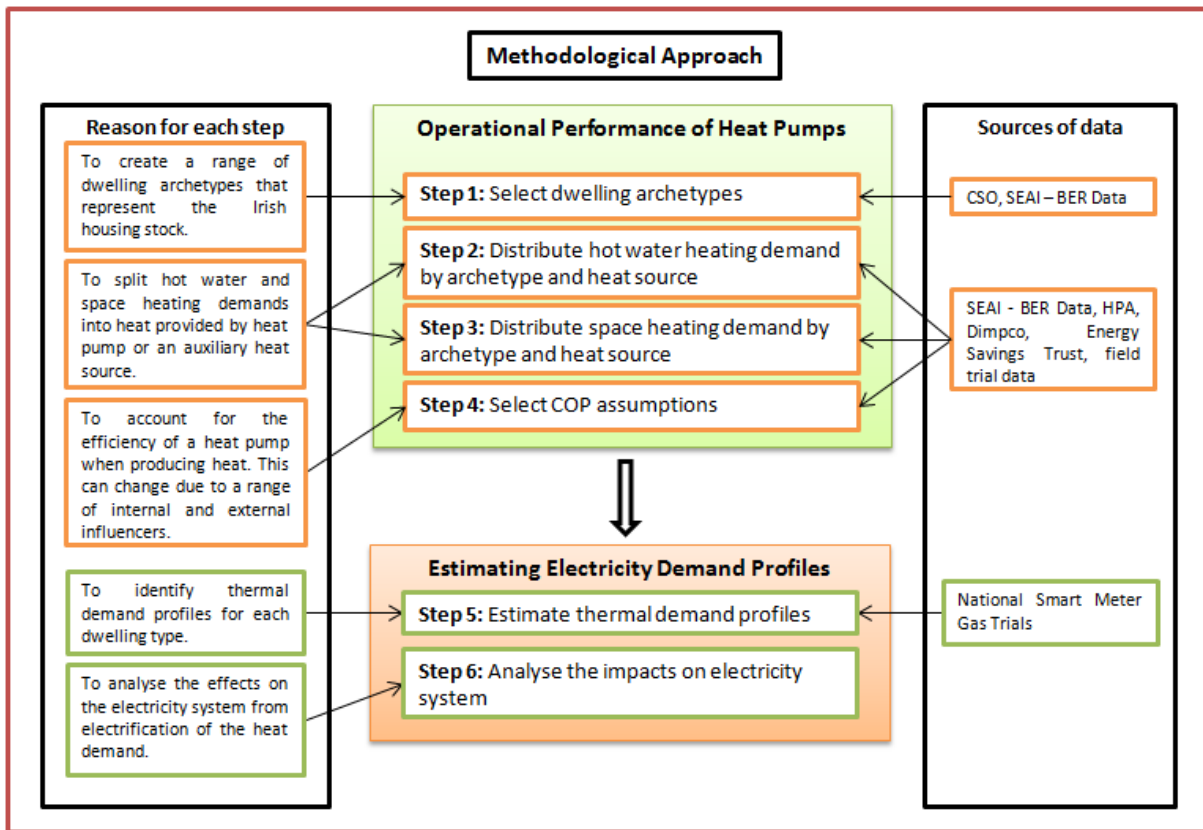
Electrification of a heating system consists of increasing electricity demand while decreasing fossil fuels used for heating purposes. Through heat pumps this can become a more efficient method of producing heat due to their high performance levels, even when taking into account the electricity system efficiency. Coupled with an electricity system containing high levels of renewable generation, the benefits can be even larger and could affect more aspects of national targets.

Considering all these, electrification could: 1) decrease fossil fuel usage in the residential sector, lowering non-ETS emissions as a result; 2) contribute to national renewable targets and; 3) increase the flexibility of electricity demand.

### **3. Methodology**

The methodology is used to estimate the electricity use of heat pumps in a range of archetypes that represent the building stock in Ireland currently heated by oil. The value of savings due to the oil displacement is compared to the installation cost difference between a heat pump and an oil boiler to estimate a simple payback for a heat pump in each dwelling archetype. The methodology also estimates the overall fossil fuel and CO<sub>2</sub> savings, the potential for renewable heat production, and the impact of a large scale conversion to heat pumps on the daily electricity demand profile. The methodological framework (as shown in Figure 3) uses a step-by-step approach that first establishes the heat use characteristics across dwelling archetypes and then suggests the potential savings based on estimates of the heat pump performance in meeting the heat demand of these dwellings. A separate stage estimates the potential impact of a large scale conversion of oil dwellings to heat pumps on electricity demand, based on how dwellings currently use heat energy.

Figure 3: Schematic of the methodological framework applied in the analysis



### 3.1. Operational performance of heat pumps

A four-step calculation is used to determine the energy demand requirements of heat pumps. Firstly, as the type of building a heat pump is installed in is a primary influencer of both the total annual heat demand and the proportion of heat demand that is hot water, the building stock is categorised into archetypes based on Building Energy Rating (BER) and Central Statistics Office (CSO) data. The second step highlights how space and hot water demands differ depending on the building type. BER data is used to estimate overall demand and the proportion of hot water in each dwelling archetype. The third step captures the impact of consumer behaviour on the operation of a heat pump, while the fourth step establishes an average heat pump performance across the year.

#### 3.1.1. Select building archetypes

The residential dwelling stock is categorised into archetypes to assess the feasibility of heat pumps to act as a replacement for oil fired central heating (OFCH) systems in different residential buildings. Archetypes are created based on the building type and their BER. The BER ratings are divided into three bands that represent the efficiency of the building: high (A or B), medium (C or D), and low (E, F or G). Building types are divided into three broad categories, flat/apartment (small), terrace (medium), and semi-detached/detached (large). These provide the basis for the nine archetypes shown in Table 1. The table

outlines the name given to each archetype, along with the number of buildings, the estimated average annual thermal demand and the estimated share of hot water demand in each archetype.

Table 1: Dwellings with oil fired central heating systems in Ireland categorised by dwelling type and BER<sup>13</sup>

Archetype	BER	Dwelling type	Number of buildings	Thermal demand per building (MWh/year)	Thermal demand (GWh/year)	Hot water share (%)
AB-Small	A, B	Flat/Apartment	10,721	3.5	38	32%
AB-Medium	A, B	Terrace	16,485	4.6	76	39%
AB-Large	A, B	Semi-det., Detached	67,649	7.1	480	27%
CD-Small	C, D	Flat/Apartment	48,705	7.3	356	30%
CD-Medium	C, D	Terrace	74,891	9.7	726	31%
CD-Large	C, D	Semi-det., Detached	307,328	14.5	4,456	24%
EFG-Small	E, F, G	Flat/Apartment	19,618	12.3	241	19%
EFG-Medium	E, F, G	Terrace	30,165	18.8	567	20%
EFG-Large	E, F, G	Semi-det., Detached	123,788	26.3	3,256	17%
<b>Total</b>			699,350		10,196	

### 3.1.2. Hot water heating demand

Hot water requirements vary less across the building archetypes than space heating requirements. Larger, less efficient dwellings require more energy for space heating than smaller, more efficient dwellings. As a result hot water requirements make up a greater proportion of total thermal energy demand in a highly energy efficient dwelling as compared to one at the bottom, or less efficient end, of the BER scale. Information on hot water heat demand is collected as part of the BER assessments and used to estimate the proportion of hot water heating in each dwelling archetype. The final column in Table 1 shows the percentage of total thermal demand that is attributed to hot water requirements in each of the archetypes.

With a standard central heating system, the primary heat source provides for space heating demand while also increasing the water temperature in the storage tank. This contributes to the energy used for delivering hot water requirements and is taken into account using an assumption discussed with the industry representatives that helped compile data for this analysis.<sup>14</sup> It is assumed heat pumps can produce 75% of hot water requirements for each archetype at the same efficiency as space heating demand is produced.<sup>15</sup> The remaining heat is provided by an auxiliary heat source, i.e. electric immersion heater, oil boiler or gas boiler (supplied by portable/refillable gas tanks) depending on the scenario.

- **Hot water demand = 75% ASHP + 25% auxiliary heat source**

### 3.1.3. Space heating demand

How a consumer uses a heat pump to deliver their heating requirements can influence heat pump efficiency. Heat consumers with oil or gas fired systems are used to being able to boost the internal temperature of a dwelling with bursts of high temperature output from their boilers. For a heat pump to

<sup>13</sup> Information shown in Table 1 is sourced from 2011 census data from the Central Statistics Office[35] and SEAI's BER database[36].

<sup>14</sup> SEAI consulted with the Heat Pump Association of Ireland and Dimpco.

<sup>15</sup> Sensitivity analysis of ±10% is included in the analysis to measure the impact of this assumption.

provide high temperature boosts in a similar way would negatively influence its COP. The energy efficiency of a dwelling is an important factor to consider. For example: as well as requiring less overall energy input, an efficient dwelling will also require less of this boost activity, as internal temperatures are likely to be maintained over longer periods with the need for gradual top ups only. This contrasts with a less efficient dwelling, where a heat boost may bring the temperatures of internal spaces back up to comfortable levels in a short period, but maintaining internal temperatures for long periods requires significant ongoing energy input.

A number of comprehensive field trials have been published that record how consumers use heat pumps to service heat demands in a range of climate conditions, house types, and with different types of heat emitters [17] [18] [24] [25] [26]. One particular field trial carried out on a gas hybrid heat pump system in an English terraced house found the heat pump providing 80% of space heating while the remaining 20% was met using an auxiliary heat source capable of providing large increases in output temperatures over short periods of time [24]. The field trial is considered a 'worst case scenario' as it is based in a 110-year-old, 140-metre-squared terraced house that is fitted with a traditional high flow temperature heating system and an annual thermal demand of 18.5 MWh. The field trial has many similarities with OFCH systems in Ireland, such as a significant thermal load, as can be seen in Table 1, large floor area and an aged structure. heat production split (80% – ASHP, 20% – auxiliary) for space heating is used for all analysis carried out on hybrid ASHP system configurations. In general, most ASHPs currently installed in Ireland do not include a boiler in the system configuration and therefore it can be assumed that the ASHP is capable of providing 100% of the space heating demand. Figure 4 shows the share of hot water and space heating thermal demand in each archetype for both hybrid and ASHP system configurations using the assumptions previously outlined.

Figure 4: Share of thermal demand in each archetype produced by heat source for both ASHP (left) and hybrid ASHP (right) scenarios

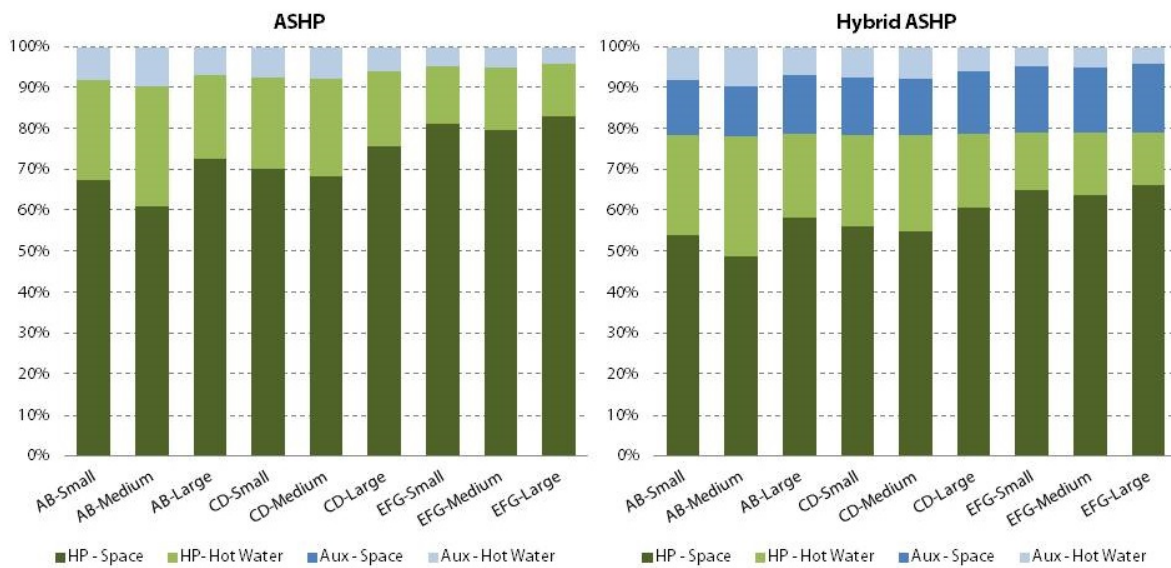


Figure 4 shows how heat pumps produce a higher proportion of space in archetypes with low energy efficiency compared to more energy efficient dwellings. When comparing both figures, it is apparent that heat pumps produce more thermal energy if there is no hybrid system configuration. However this comes at the cost of operational performance. A hybrid system can lead to more efficient use of the heat pump by activating the auxiliary heat source when the heat pump is not operating at its optimal performance efficiency – therefore the auxiliary acts to increase the average performance of the heat pump.

- **Space heating demand (ASHP system) = 100 % ASHP + 0 % auxiliary heat source**
- **Space heating demand (hybrid ASHP system) = 80 % ASHP + 20 % auxiliary heat source**

### 3.1.4. Coefficient of performance assumptions

The main advantage of using a heat pump over a conventional oil or gas boiler is efficiency. A heat pump in ideal laboratory test conditions can produce high levels of thermal output compared to the electrical input. However, this efficiency, or coefficient of performance (COP) as it is more commonly referred to, is reduced in operation due to sub-optimal ambient environmental conditions, and a range of other influencing factors.

SEAI's Home-heating Appliance Register of Performance (HARP) database lists the average COP of an ASHP in Ireland to be approximately 3.5 [27]. This is based on appliances tested under certain fixed standardised test temperatures using European standards, for example, measuring the performance of the heat pump at an air temperature of 7°C and delivery water at 45°C in laboratory test conditions. When compared with data from field trials a significant difference in performance levels is found. Numerous field trials conducted in the UK found that ASHPs providing space heating alone can have a COP anywhere

between 2.5 and 3.0 [17] [18] [19] [25] [28] [29]. The most comprehensive of these was the Energy Savings Trust trials which identified a COP of 2.73 for 15 ASHPs [17]. The two COP values (based on test and field trial conditions) are used in otherwise identical scenarios in the analysis to identify the difference in savings between the two.

Field trials on a gas hybrid heat pump system have found the COP to be anywhere in the range of 3.1 – 3.8<sup>16</sup> [24] [26]. For the purpose of this analysis it is assumed the COP of all hybrid scenarios is 3.45, i.e. the average result from field trials.

- *COP – test (ASHP system) = 3.50*
- *COP – field trials (ASHP system) = 2.73*
- *COP – field trials (hybrid ASHP system) = 3.45*

### 3.2. Estimating electricity demand profiles

A large scale conversion of oil fired homes to heat pumps has the potential to cause significant disruption to the electricity system. Peaks in heat demand are highly correlated with peaks in electricity demand and the transference of the heat demand into electricity has the potential to introduce steep short term increases in the electricity system load. This may have implications for the security, efficiency and generation-cost of an electricity system.

In order to create a high resolution daily demand profile for the electricity used to power heat pumps, data from the national smart meter trial for gas-using homes was used as a proxy. High resolution 30-minute gas demand data is available from the trials for a statistically representative sample of Irish households [30]. An electricity demand profile for a large scale conversion of oil fired homes to heat pumps is estimated from the recorded consumer heating behaviour observed in the trial, adjusted for heat pump electrical requirements.

#### 3.2.1. Thermal demand profiles

From the national smart meter gas trial data, individual thermal demand profiles are created for each of the three dwelling type categories from the trial. This classification is necessarily more aggregated than the nine archetypes used in the operational performance calculation due to the data availability. The three houses types are flat/apartment (small), terrace (medium), and semi-detached/detached (large).

The gas profiles recorded the actual gas demand of each house type in 2009, the majority of which was used for heating purposes. The gas demand profiles are used to estimate electricity demand profiles as accurate high resolution demand profiles are required to show the effects on the electricity system. The gas profiles

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<sup>16</sup> This COP was calculated from [24] using the UK electricity system efficiency of 36.6%.

are aggregated up to the annual thermal demand for the specific house type, which is the volume weighted combination of the three archetypes that represent each house type. It is recognised that there are some differences in the heat demand profile between oil and gas; the gas data is the best available source for this estimation.

It is worthwhile noting that certain consumer behavioural aspects are embedded in the gas demand data; for example, booster activity, hot water storage, weather and occupancy patterns are all accounted for. Similarly gas used for non-heating purposes such as cooking is also embedded in the data; however this usage represents only a small proportion of overall gas demand and it can be assumed that changes in gas demand across time are primarily driven by gas use for heating.

### **3.2.2. Impact of additional electricity demand**

As shown earlier in Figure 4 (share of thermal demand), not all thermal demand is provided by heat pumps, some is produced by an auxiliary heat source. Identifying the periods when demand is met by either a highly efficient heat pump or auxiliary mode is critical, as it has a large effect on the electricity demand at certain periods of the day and has the potential to either increase or decrease the technical strain on an electricity system.

The high resolution information required to identify when the thermal demand is met from one heat source over another is not recorded in any heat pump field trials available. To overcome this information gap, it is assumed the thermal demand in every period is met simultaneously using both heat sources, with the production share based on the total thermal demand delivered by both sources. This method of estimating the additional electricity demand profile provides a conservative indication of the effects on the electricity system, since, in a more realistic situation, auxiliary heat would be expected to deliver a higher percentage of thermal demand during periods of high demand compared to periods of low demand, as was found in field trials [24]. This would affect the distribution profile of the additional electricity required to operate the auxiliary heat source.

### **3.3. Examining caveats and assumptions**

The following points seek to strengthen the assumptions used in the analysis and expand on any caveats found through the explanation, clarification and, finally, justification of each.

- During the analysis it is assumed heat pumps can provide 75% of hot water demand while retaining their high performance levels. This assumption is based on feedback from industry and a  $\pm 10\%$  sensitivity analysis on this estimate is presented in the results section.
- Assumptions surrounding space heating demand and operational performance levels of heat pumps are taken from the best available data and are vetted by industry representatives for their accuracy and robustness.

- The analysis assumes heat pumps are capable of meeting the heat requirements of all the archetypes developed. This may overestimate the ability of heat pumps to provide adequate heat to poorly insulated homes with sub-optimal radiator area etc.
- Converting the electricity demand from each scenario in high resolution profiles is an area that requires more analysis. Due to a lack of detailed, high resolution information on how auxiliary heat sources would operate in conjunction with a heat pump, this report assumes the additional electricity demand is from both heat sources simultaneously, based on the annual production split.
- This report assumes heat pumps are a direct replacement for the existing oil boiler with no retrofitting being carried out. It is common for heat pumps to be installed with equipment such as buffer tanks, low temperature radiators or underfloor heating, however this report does not account for these or the impact these measures have on COP and on installation costs. For example if a buffer tank was installed it would allow stored energy used to it when it is needed and thus decouple the electricity demand of the heat pump for the customers heat demand. Experience gained from industry consultation highlights that, for an optimised operational performance of a heat pump, it is recommended that the technology operates continuously when there is a heat load. This has the effect of lowering the cost of electricity by using night rate electricity prices in some periods. However, in reality, this type of operational strategy could increase the overall thermal demand per dwelling especially if thermal energy is allowed to leak into the external environment, i.e. in a home with low energy efficiency standards.
- The analysis carried out does not take into account the implementation of further energy efficiency measures to upgrade a dwelling's energy performance levels. This was excluded as this report is an insight study comparing one technology to another, all else being equal.

### 3.4. Scenario selection

The following scenarios are created to examine the potential impacts of replacing an oil boiler with a heat pump or a hybrid heat pump system configuration. All scenarios are heat-pump-based systems, except with different energy sources providing auxiliary heat, and are compared to a new oil boiler. The first and second scenarios are identical heat pump systems, both with an electrically driven auxiliary device, i.e. immersion. The difference between the scenarios is the first uses manufacturers' performance data (HP-Elec<sub>test</sub>) while the second uses data collected from field trials (HP-Elec<sub>field</sub>).

To examine a broader spectrum of options, hybrid heat pump systems are also analysed and represented in the third and fourth scenarios. The third scenario integrates a heat pump with the existing oil fired central heating system, with the latter providing auxiliary heat (HP-Oil). This scenario is examined in order to represent a transitional phase between the two technologies, where the homeowner uses the existing oil boiler as the auxiliary heat source for delivering hot water at peak demand, while the heat pump provides

the majority of the thermal demand. The final scenario is a gas fired hybrid heat pump configuration with natural gas providing the auxiliary heat through refillable canisters (HP-Gas). The list of scenarios is as follows:

- 1) Air source heat pump with electric immersion (HP-Elec<sub>test</sub>);
- 2) Air source heat pump with electric immersion (HP-Elec<sub>field</sub>);
- 3) Air source heat pump with oil boiler hybrid configuration (HP-Oil);
- 4) Air source heat pump with gas boiler hybrid configuration (HP-Gas).

Options 3 and 4 are not common in the market but are included here based on the existence of hybrid systems.

### 3.5. Summary of inputs assumptions to analysis

The following tables summarise the assumptions and inputs used throughout the analysis. Table 2 outlines the individual scenario-specific input assumptions, which were explained in the methodology section.

Table 3 and Table 4 introduce general assumptions used during analysis, with a detailed explanation following each table.

Table 2: Scenario-specific input assumptions used during the analysis

	ASHP with immersion(HP-Elec <sub>test</sub> )	ASHP with immersion (HP-Elec <sub>field</sub> )	ASHP & oil boiler hybrid (HP-Oil)	ASHP & gas boiler hybrid (HP-Gas)
<b>COP</b>	3.50	2.73	3.45	3.45
<b>HW - heat pump delivered</b>	75%	75%	75%	75%
<b>HW - auxiliary delivered</b>	25%	25%	25%	25%
<b>Space - heat pump delivered</b>	100%	100%	80%	80%
<b>Space - auxiliary delivered</b>	0%	0%	20%	20%

Table 3: General input assumptions during the analysis

<b>Emissions Factors</b>	<b>Gas</b>	204.7	gCO <sub>2</sub> /kWh
	<b>Oil</b>	257	gCO <sub>2</sub> /kWh
	<b>Electricity</b>	468.9	gCO <sub>2</sub> /kWh
<b>Efficiency</b>	<b>Electricity system</b>	48.3	%
	<b>Oil boiler (new)</b>	90	%
	<b>Oil boiler (existing)</b>	79	%
	<b>Gas boiler (new)</b>	90	%
<b>Residential Fuels Costs</b>	<b>Electricity (night rate)</b>	0.097	€/kWh
	<b>Electricity (day rate)</b>	0.208	€/kWh
	<b>Electricity (dual rate)</b>	0.166	€/kWh
	<b>Oil</b>	0.097	€/kWh
	<b>Gas</b>	0.079	€/kWh

Table 3 shows the emissions factors and electricity system efficiency for 2013. The figures are taken from SEAI's 'Energy in Ireland' publication [2]. Efficiency assumptions for both existing and new boilers are

typical values expected in Dwelling Energy Assessment Procedure (DEAP)<sup>17</sup> and the (HARP) database [31, 27]. Residential fuels costs are the average price for 2014, sourced from SEAI's 'Domestic Fuel Comparison of Energy Costs' [32]. The dual rate electricity price is calculated based on advice from industry representatives who recommend that a heat pump is operational 24 hours a day for the optimal performance. Therefore the dual rate electricity price is based on nine hours at night rate, and fifteen hours at day rate, electricity prices.

**Table 4: System sizing and the associated capital costs for each system type**

Archetype		AB-Small	AB-Medium	AB-Large	CD-Small	CD-Medium	CD-Large	EFG-Small	EFG-Medium	EFG-Large
<b>Annual Thermal Demand (MWh)</b>		3.5	4.6	7.1	7.3	9.7	14.5	12.3	18.8	26.3
<b>System Sizing (kW)</b>	Oil Boiler	12	12	12	12	12	16	16	22	30
	Heat Pump	8	8	8	8	8	12	12	16	16
<b>Installation Costs (€)</b>	Oil Boiler	2,000	2,000	2,000	2,000	2,000	2,150	2,150	2,150	2,300
	Heat Pump	7,500	7,500	7,500	7,500	7,500	8,500	8,500	10,000	10,000

The system sizing and installation costs shown in Table 4 were calculated for each archetype based on their annual thermal demand following consultation with industry.<sup>18</sup> The oil boilers are sized to meet the maximum demand, whereas heat pumps are sized based on the assumption of a longer operating/running period, eliminating the need for the device to meet the maximum thermal demand; rather it produces heat at a slower, steadier rate. Heat pumps and oil boilers generally come in standard sizes and in some case have the ability to modulate below 50% of their maximum thermal output. Industry experience recommended that heat pump systems do not change size in any scenario, whether hybrid or not. This is due to their ability to modulate and because the device should be sized to meet all thermal demand. The only time the auxiliary heat source should be used is when the performance of the heat pump drops below its optimal efficiency.

#### 4. Results and discussion

In order to present insights in a straightforward way, this analysis is necessarily based on the current thermal performance of the housing stock with some comment on how a realisation of the energy efficiency potential may affect the findings. Potential scenarios for the impact of other feasible actions, specifically the costs and benefits of energy efficiency retrofits, are not quantified here but are critical to the formation of any policy seeking to move away from oil as a heat source in the residential sector. Fabric upgrades such as insulation, triple glazing and draught proofing should be considered first as a lower cost

<sup>17</sup> The average efficiency of a new oil boiler from DEAP is 94%. However, this report assumes an operational performance efficiency of 90% to allow for the difference between optimised and field conditions. The efficiency of an existing oil boiler is based on the installations effected since 1998.

<sup>18</sup> Installation costs for gas hybrid heat pump systems could not be obtained.

way to reduce energy bills. Such upgrades should happen before fitting a new heat pump to ensure the pump is correctly sized.

The results provide some insights into the household economics and system-wide impacts of a possible long term conversion of all 700,000 dwellings in Ireland from oil fired heating systems to heat pumps. While this is unlikely over the short term, looking further, towards the 2030 and 2050 climate policy milestones, heat pumps could play a large part in meeting our future EU obligations.

The analysis indicates that savings associated with replacing oil boilers with heat pumps are sensitive to the dwelling where they are installed and the potential for heat pumps to use off-peak electricity. In general, larger dwellings at the less efficient end of the BER scale using hybrid systems see the greatest savings. When the efficiency of the electricity system is accounted for, the overall annual primary energy savings from a full conversion of all oil heated homes to a heat-pump-based system is estimated to be in the range of 244 – 330 ktoe, representing a 1.9 – 2.5 % reduction in primary energy.<sup>19</sup> Concentrating on oil displaced in the residential sector only, the savings are in the range of 740 – 974 ktoe, representing 76 – 100 % of all residential oil use.<sup>20</sup> Accounting for the price of displaced oil with the cost of additional electricity, the annual savings are estimated between €411 – €494 million to the consumer. The analysis suggests that between 2.2 – 2.9 MtCO<sub>2</sub> is transferred from the non-ETS to the ETS sector, as a result of shifting heat demand from oil to electricity. This represents 10 – 13 % of the non-ETS energy related emissions targets for 2020. The overall CO<sub>2</sub> emissions savings are in the range of 1 – 1.3 MtCO<sub>2</sub>. An additional 6,096 GWh are also added to the renewable heat contribution, equivalent to a 14.7 % RES-H share or approximately 4.5 % of the overall RES target set for 2020. This section also highlights the results of targeting entire archetypes, where all dwellings in a particular archetype are converted to heat pumps.

Operational cost savings are greatest in those dwellings with the highest annual thermal demand. These buildings are larger and less efficient so require more heat input to maintain a comfortable internal temperature. The use of night rate electricity improves the operational savings further. Based on the relative installation cost difference of heat pumps and oil boilers for each archetype the simple payback ranges from 7 – 37 years.

Dwellings at the lower end of the BER scale are not well insulated and in most cases struggle to maintain internal temperatures without constant heat input. Night time operation of heat pumps may not be feasible in these settings as the building is unlikely to hold heat for long enough to provide consumers with heat

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<sup>19</sup> The following results are taken from scenarios, HP-Elec<sub>field</sub>, HP-Oil, and HP-Gas. Scenario HP-Elec<sub>test</sub> is not included.

<sup>20</sup> This analysis takes a bottom-up approach, estimating the average thermal demand for each archetype from BER data based on their building type and energy efficiency. Therefore residential oil displacement in this report can be larger than oil usage in any one particular year. Residential oil consumption ranged from 918 ktoe in 2013 to 1,263 in 2010.

when they require it the most, i.e. late afternoon and evening time. Policies aimed at improving the building fabric of dwellings can help consumers to reduce heat demand and to shift the demand to lower cost periods – however the resultant reduction in demand will reduce the theoretical savings from heat pumps.

The impact on the daily electricity demand profile is significant and could potentially present difficulties and opportunities for the operation of the electricity system. The operation of heat pumps at off-peak times, as well as lowering operating costs, would reduce the stress on the electricity system. Further analysis is required to establish the potential impact on the electricity system and the relative cost effectiveness of choosing whether to incentivise the uptake of heat pumps and/or further encourage the improvement of the efficiency of the building stock.

#### **4.1. Residential oil and primary energy savings**

Energy savings are analysed using two different perspectives to highlight the benefits to: 1) the residential sector in terms of oil savings and; 2) the overall system primary energy savings. In this section, the primary energy savings from HP-Elec<sub>test</sub> and HP-Elec<sub>field</sub> scenarios are compared to highlight the difference between the two scenarios. Next, a comparison of scenarios, all of which use field trial assumptions, is carried out to highlight differences in residential oil and primary energy savings.

##### **4.1.1. Comparing primary energy savings of scenarios HP-Elec<sub>test</sub> and HP-Elec<sub>field</sub>**

Using two identical scenarios with different efficiency (COP) assumptions, the matter of test results versus field trial results is addressed. The primary energy savings take account of the oil displaced and energy used to generate the additional electricity required for heat pumps compared to the oil usage of an oil boiler. Figure 5 shows the results of the comparison.

Figure 5: Primary energy savings per dwelling for scenarios HP-Elec<sub>test</sub> and HP-Elec<sub>field</sub>

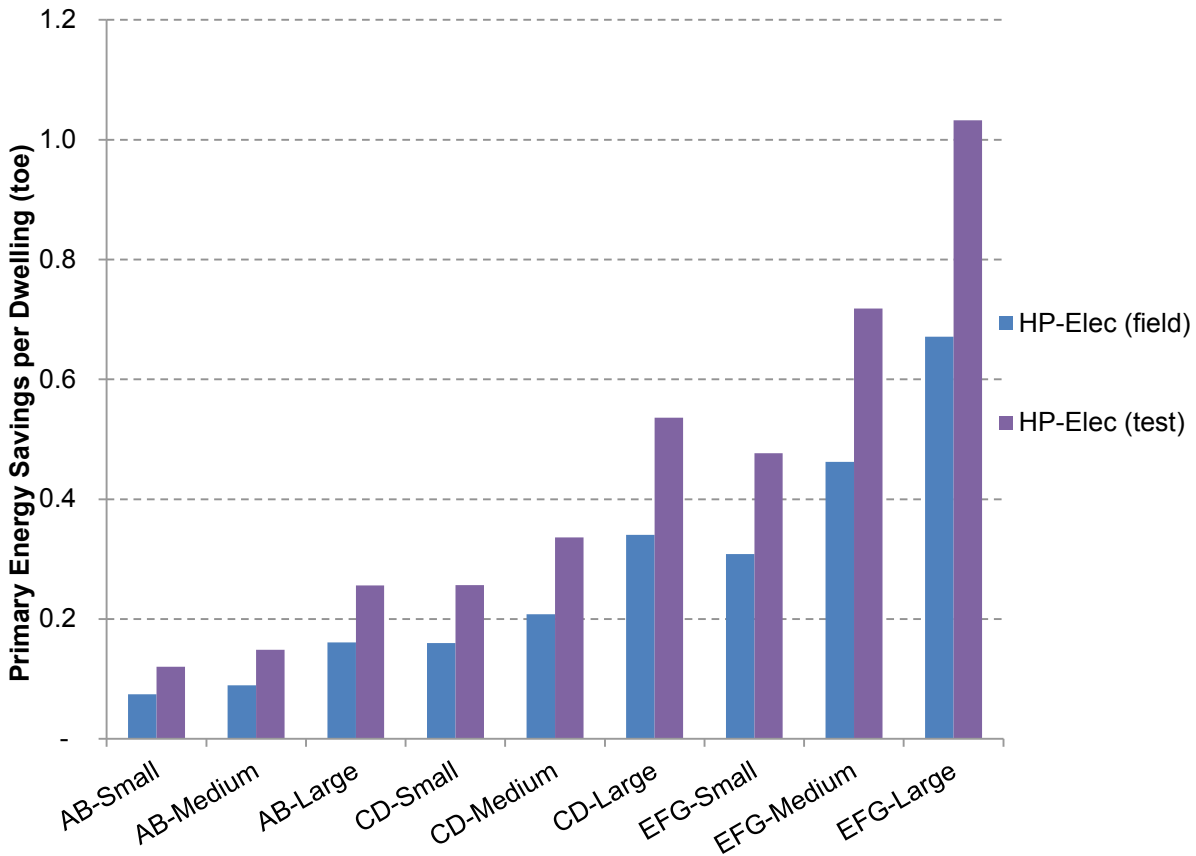


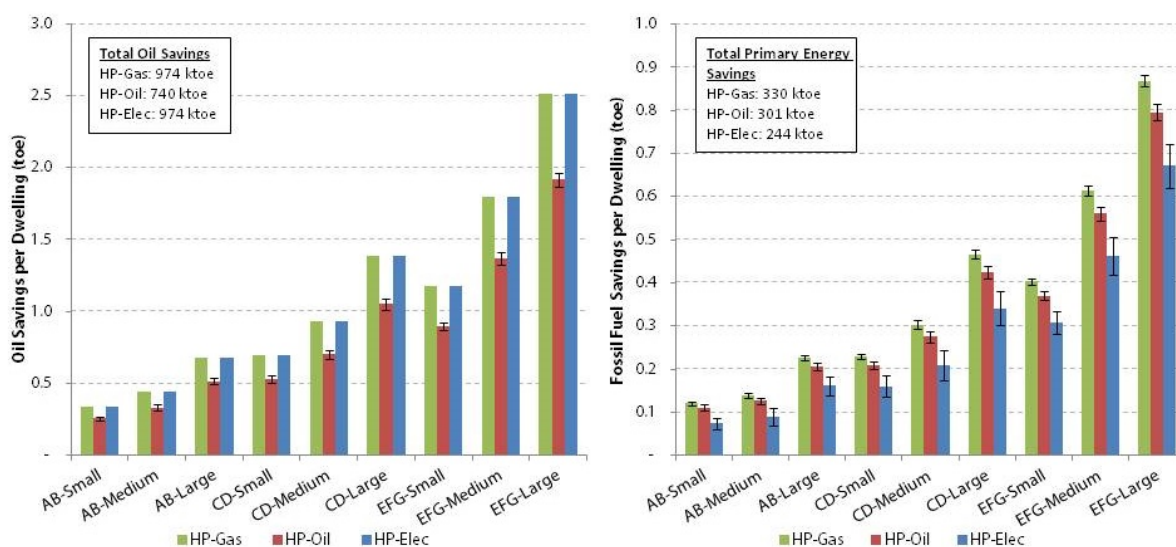
Figure 5 shows a significant difference in primary energy savings between laboratory and field trial conditions. Field trials may be site/region/country specific and typically result in lower efficiencies than recorded under laboratory conditions. The benefit of field trials is that they capture performance under non-optimised everyday conditions. For this reason the test condition scenario is no longer compared to the other scenarios, which all use COPs based on field trial data, instead the complete set of results from HP-Elec<sub>test</sub> is visible in Table 9. From this point onwards three scenarios, HP-Elec<sub>field</sub> (hereafter HP-Elec), HP-Oil, and HP-Gas are compared against an oil boiler.

#### 4.1.2. Comparing residential oil and primary energy savings of different scenarios

Scenarios HP-Elec, HP-Oil, and HP-Gas are compared to show the different levels of oil displacement at the household level per annum, and the primary energy savings after electricity supply efficiency is accounted for, as shown in Figure 6. The figure shows both parameters side by side so the difference between the two can be fully appreciated. The total savings for each scenario is also shown in Figure 6.<sup>21</sup>

<sup>21</sup> Error bars presented in subsequent charts represent  $\pm 10\%$  sensitivity on the share of thermal energy produced from the heat pump versus an auxiliary heat source.

Figure 6: Residential oil and primary energy savings per dwelling for each archetype and scenario



It is apparent from Figure 6 that the largest amount of savings occur in archetypes with lower energy efficiency. In terms of oil displaced, scenarios HP-Elec and HP-Gas both achieve the maximum amount of displacement (974 ktoe) compared to HP-Oil (740 ktoe), which uses oil to provide auxiliary heat. In the oil savings bar chart, error bars only appear in scenario HP-Oil because the amount of oil displaced in the other scenarios does not change.

Viewing from a macro-system perspective and taking account of electricity system generation efficiency along with gas and oil boiler efficiencies, the HP-Gas scenario experiences the largest primary energy displacement (330 ktoe), followed by HP-Oil (301 ktoe) and HP-Elec (244 ktoe). This is a result of the HP-Gas scenario providing auxiliary heat through a high-efficiency condensing boiler (90%), whereas the HP-Oil scenario uses an existing oil boiler with an efficiency of 79% and HP-Elec uses electricity at 48.3% system efficiency.

Table 5 shows the potential savings in terms of residential oil and primary energy if all dwellings in each archetype were converted to heat pumps – allowing an insight into a possible *archetype target approach* to solving the issue of over-utilisation of oil boilers in the residential section.

Table 5: Total primary energy and residential oil savings when all dwellings in each archetype are converted<sup>22</sup>

	Scenario	AB-Small	AB-Medium	AB-Large	CD-Small	CD-Medium	CD-Large	EFG-Small	EFG-Medium	EFG-Large
Residential Oil Savings (ktoe)	HP-Elec	3.6	7.2	46	34	69	426	23	54	311
	HP-Oil	2.7	5.4	35	26	52	323	18	41	237
	HP-Gas	2.7	5.4	35	26	52	323	18	41	237
Fossil Fuel System Savings (ktoe)	HP-Elec	0.8	1.5	11	8	16	105	6	14	83
	HP-Oil	1.2	2.1	14	10	21	131	7	17	99
	HP-Gas	1.3	2.3	15	11	23	143	8	19	108

<sup>22</sup> The table is colour coded to highlight the largest fuel savings (green) and smallest fuel savings (red) of each scenario.

## 4.2. CO<sub>2</sub> emissions savings

Figure 7 shows the overall CO<sub>2</sub> emissions savings per dwelling, per year for each scenario from the emissions transfers from non-ETS to ETS. The savings are possible through using a combination of: 1) electricity with high levels of carbon-neutral generation and; 2) heat pumps. The emissions savings shown are directly related to the total primary energy displacement seen in Figure 6. Table 6 highlights the potential CO<sub>2</sub> emissions savings if all dwellings in each archetype convert to heat pumps.

Figure 7: Total CO<sub>2</sub> emissions savings per dwelling for each archetype and scenario

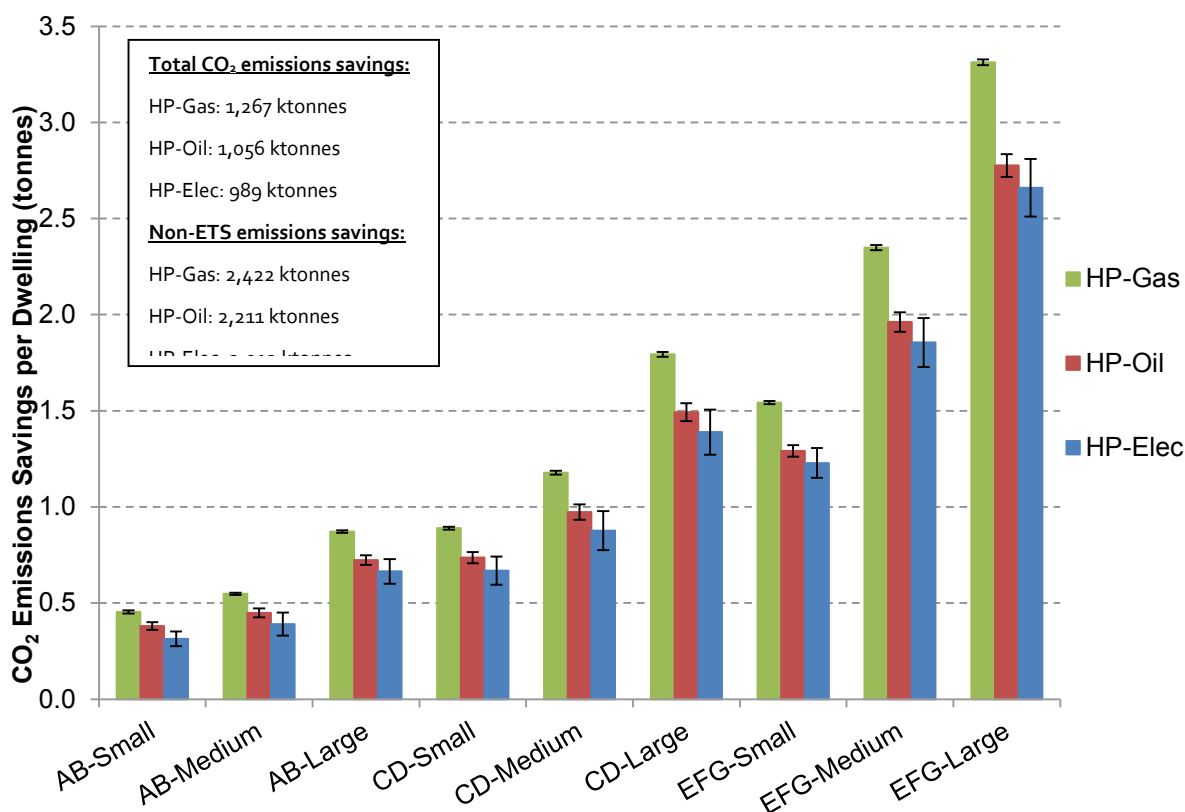


Table 6: Total CO<sub>2</sub> emissions savings per archetype if all dwellings were converted to heat pumps

	Scenario	AB-Small	AB-Medium	AB-Large	CD-Small	CD-Medium	CD-Large	EFG-Small	EFG-Medium	EFG-Large
Non-ETS CO <sub>2</sub> Emissions Savings (ktonnes)	HP-Elec	10.7	21.7	137	102	207	1273	69	162	930
	HP-Oil	8.1	16.2	104	77	156	965	52	123	709
	HP-Gas	8.9	17.9	114	84	172	1058	57	135	775
CO <sub>2</sub> Emissions Savings (ktonnes)	HP-Elec	3.4	6.4	45	33	66	427	24	56	329
	HP-Oil	4.1	7.4	49	36	73	459	25	59	344
	HP-Gas	4.9	9.0	59	43	88	551	30	71	410

Figure 7 shows CO<sub>2</sub> emissions savings are possible in all archetypes and scenarios. HP-Gas results in the largest CO<sub>2</sub> emissions savings of the three scenarios are due to: 1) the emissions factors of natural gas compared to oil or electricity generation and; 2) the amount of fossil fuel displaced in each scenario. The figure also identifies the total CO<sub>2</sub> emissions savings for each scenario along with the non-ETS emissions transferred. The non-ETS emissions value is larger as it does not take account of the fuels used to generate

the electricity or its system efficiency. This touches on the next pertinent question surrounding the efficiency of converting OFCH systems to heat pumps.

### 4.3. Heating system efficiency

The overall heating system efficiency is the parameter used to compare each scenario as it encapsulates all primary energy inputs and thermal energy outputs of the entire central heating system, unlike the COP which only accounts for the inputs and outputs of the heat pump. The average system efficiency for the three scenarios is shown in Table 7.

Table 7: Heating system efficiency of the scenarios

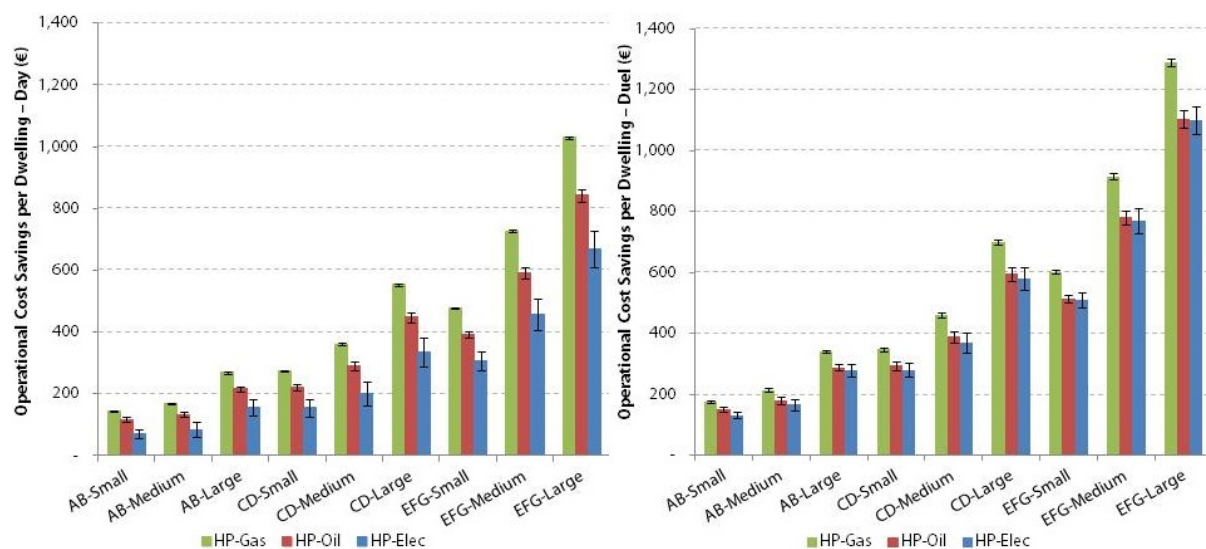
Technology	System Efficiency
ASHP with immersion (HP-E)	118%
ASHP & oil boiler hybrid (HP-O)	130%
ASHP & gas boiler hybrid (HP-G)	136%

All heat pump scenarios have system efficiencies at least 28% greater than the direct replacement (assumed 90% efficient) of existing OFCH systems. The HP-Oil and HP-Gas scenarios are shown to have higher system efficiencies than the HP-Elec scenario, which is a result of using higher COP assumptions for the hybrid system, and taking account of the electricity system efficiency. The difference between scenarios can also be viewed from an operational expenditure point of view that lends itself to the concept of a simple payback for each scenario compared to an oil boiler.

### 4.4. Operational expenditure savings

A comparison of operational expenditure (OPEX) is carried out between the three scenarios and an oil boiler to identify the annual OPEX difference. Figure 8 compares the OPEX savings using both day and dual rate electricity prices.

Figure 8: Operational expenditure savings per dwelling based on day rate (left) and dual rate (right) electricity prices



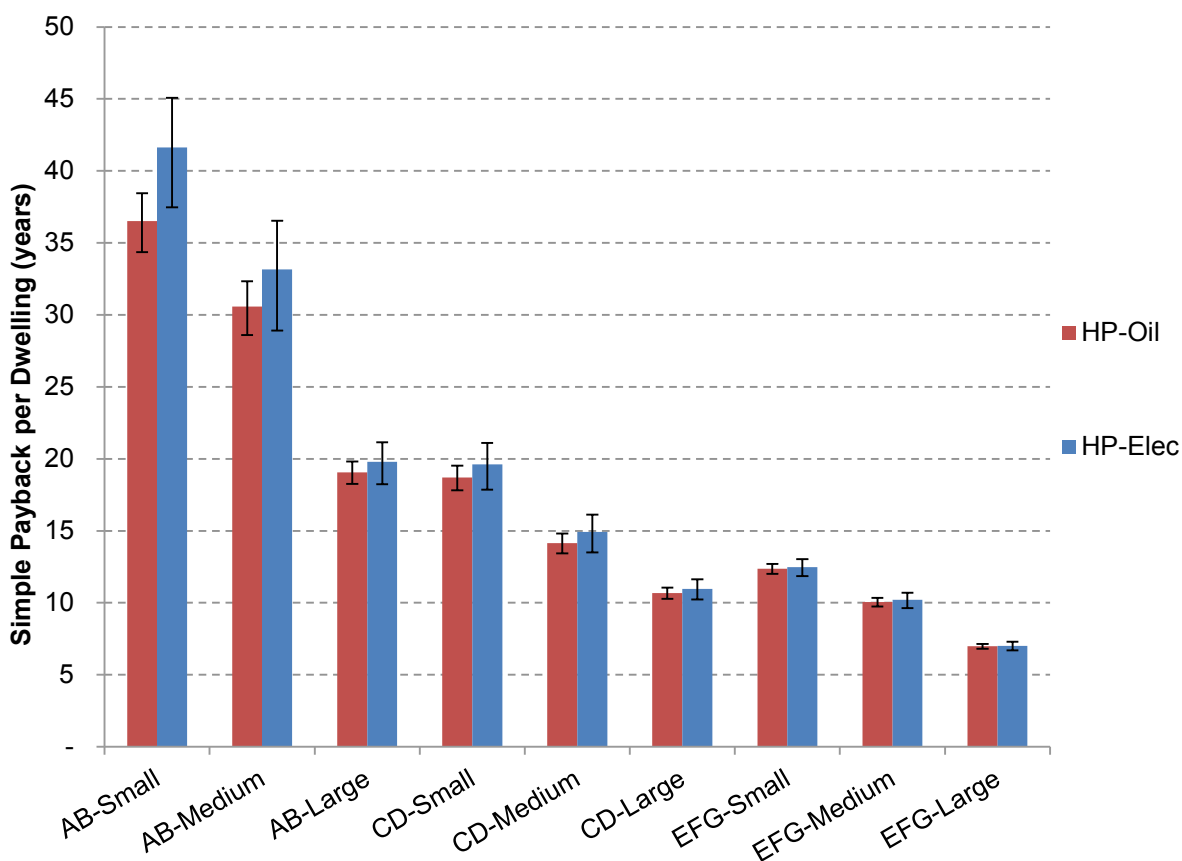
The benefit of dual rate electricity prices on OPEX savings is best seen using the HP-Elec scenario as it requires the largest amount of electricity of the three scenarios. However there are increased OPEX savings in all scenarios, as can be seen from the charts in Figure 8.

#### 4.5. Capital expenditure and simple payback

Capital expenditure (CAPEX) is an integral part of assessing the feasibility of each scenario. Table 4 shows the CAPEX assumptions used in this report. These values were gathered through interactions with industry representatives who also assisted SEAI in estimating the system sizes needed to meet the thermal demand per dwelling in each scenario.

Using the estimated annual OPEX savings (based on dual rate electricity prices) shown in Figure 8, the simple payback is calculated based on repaying the difference in CAPEX between each scenario and an oil boiler. Figure 9 shows the results of the calculation for scenario HP-Oil and HP-Elec. Scenario HP-Gas is not represented in Figure 9 due to a lack of installation cost data.

Figure 9: Simple payback per dwelling based on operational cost savings using dual rate electricity prices



As Figure 8 highlights, the OPEX savings are higher in large dwellings with low energy efficiency performance. This means that the quickest payback is achieved in these same archetypes as shown in Figure 9.

#### 4.6. Renewable heat contribution

The renewable heat (RES-H) contribution is calculated in compliance with the Renewable Energy Directive using guidelines outlined in Annex VII and also from the supporting document on defining the system boundary and seasonal performance factor of heat pumps [10] [23]. Figure 10 shows the potential RES-H contributions if all 700,000 dwellings in Ireland with OFCH systems convert to heat pumps. Table 8 highlights the potential renewable heat contribution if the dwellings in each archetype all convert to heat pumps.

It is recognised that the conversion of all 700,000 dwellings in Ireland with oil boilers is implausible in the short to medium term, however Figure 10 demonstrates the renewable contribution one dwelling in each archetype can deliver towards the national RES-H target.

Figure 10: Total renewable heat contribution per archetype and scenario

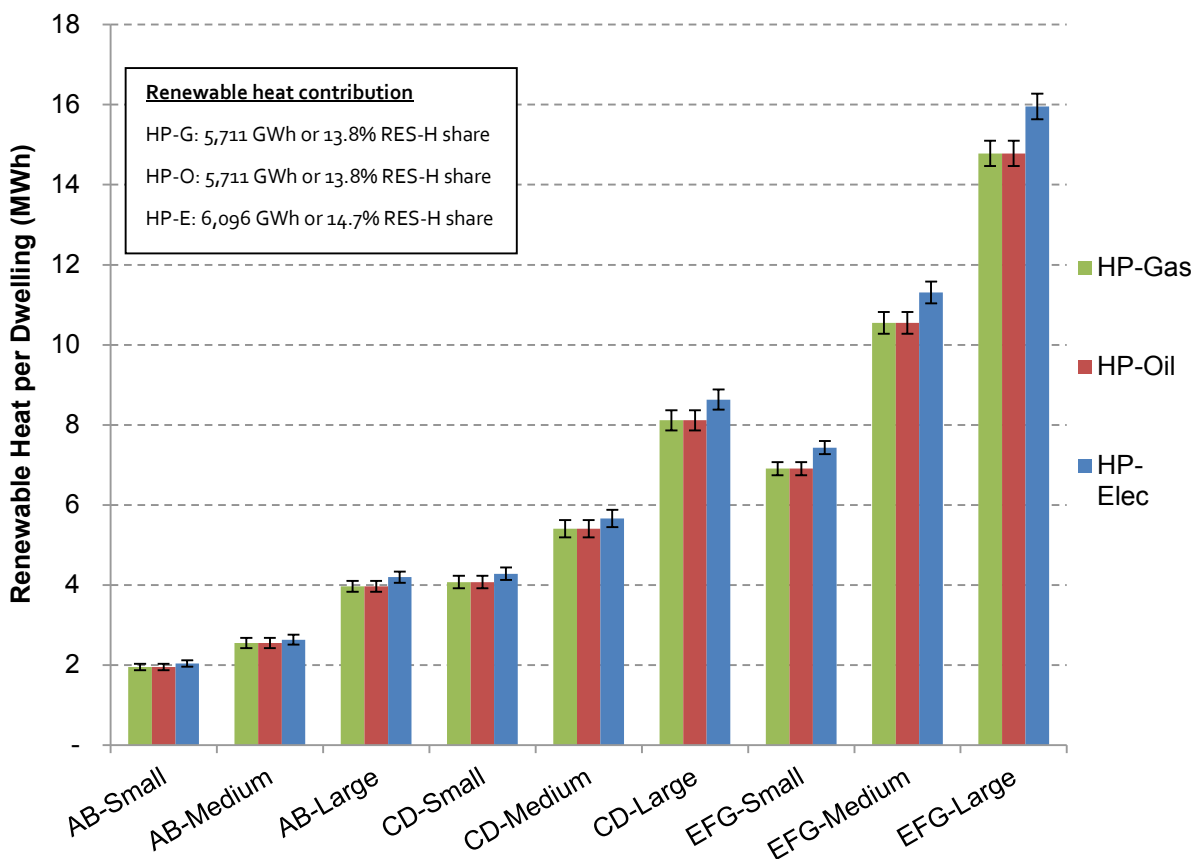


Table 8: Total renewable heat contribution per archetype if all dwellings were converted to heat pumps

	Scenario	AB-Small	AB-Medium	AB-Large	CD-Small	CD-Medium	CD-Large	EFG-Small	EFG-Medium	EFG-Large
Renewable Heat (GWh)	HP-Elec	22	43	284	208	424	2653	146	341	1975
	HP-Oil	21	42	268	198	405	2493	135	318	1830
	HP-Gas	21	42	268	198	405	2493	135	318	1830

HP-Elec contributes the greatest amount of renewable heat while the other two scenarios produce identical amounts, which is directly connected to the output from heat pumps in each specific scenario. The analysis

suggests HP-Elec can exceed the 12 % RES-H target set for 2020 and produce 14.7% of the thermal demand from renewables by converting existing oil boilers to ASHPs.

#### 4.7. Summary of high-level results

Table 9 outlines the high-level results, comparing scenarios in terms of fossil-fuel and emissions displacement while also viewing the efficiency, operational costs, renewable heat contributions, and additional electricity demands of each. The scenario using optimised condition assumptions (HP-Elec<sub>test</sub>) is re-introduced in Table 9 to show the displacement, savings, and contributions possible if field conditions could improve, closing the gap to the optimised results.

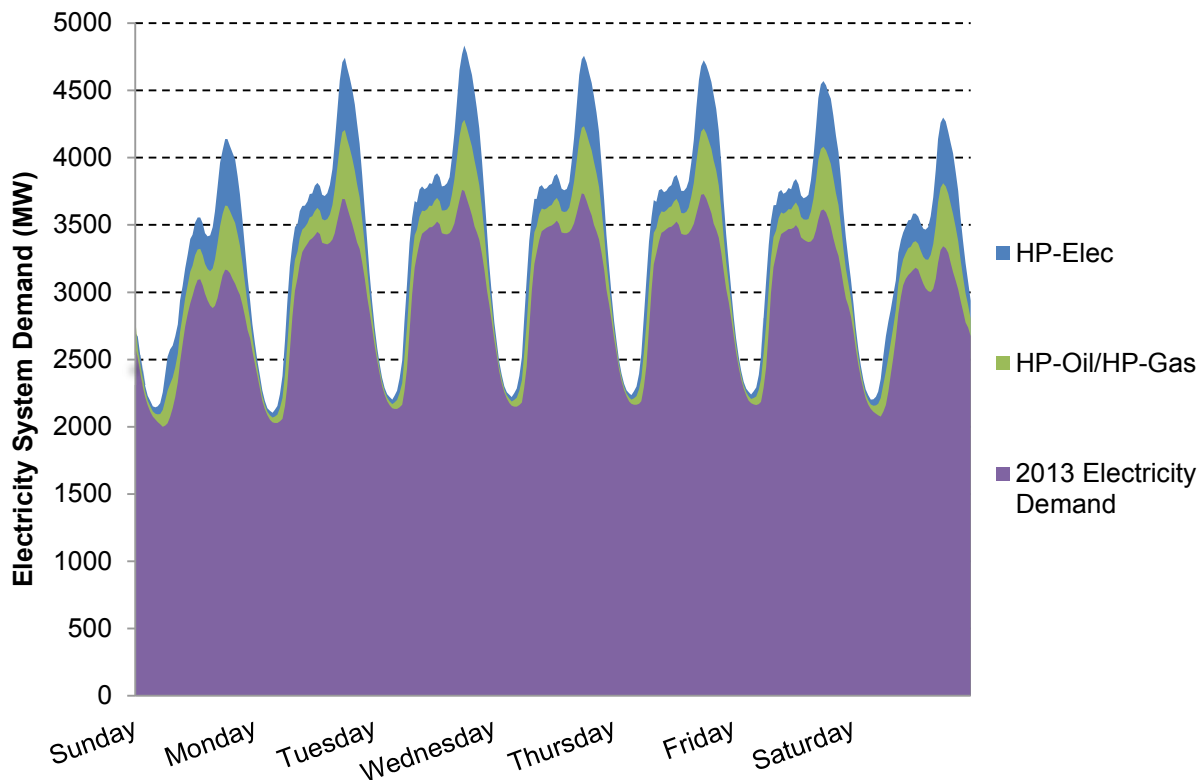
Table 9: Summary of results assuming all oil boilers are replaced with heat pumps instead of a direct replacement

	ASHP with immersion (HP-E <sub>test</sub> )	ASHP with immersion (HP-E <sub>field</sub> )	ASHP & oil boiler hybrid (HP-O)	ASHP & gas boiler hybrid (HP-G)
Oil saved (ktoe)	974	974	740	974
Primary energy saved (ktoe)	382	244	301	330
Non-ETS CO <sub>2</sub> saved (ktonnes)	2,912	2,912	2,211	2,422
System CO <sub>2</sub> saved (ktonnes)	1,353	989	1,056	1,267
Heat system efficiency	145 %	118 %	130 %	136 %
OPEX - day rate electricity (M€)	402	241	318	392
OPEX - dual rate electricity (M€)	540	411	421	494
Renewable heat (GWh)	6,872	6,096	5,711	5,711
Additional electricity demand (GWh)	3,324	4,100	2,462	2,462

#### 4.8. Impact on Ireland's electricity demand

To assess the potential effects on the electricity system demand, more detailed, high resolution analysis is required. Using half-hourly resolution electricity demand data, the changes to demand peaks and troughs can be estimated. These are identified as two areas to observe as they create strain on the electricity system, especially on generating units required to ramp up or down over short periods to meet fluctuating demand. Figure 11 shows the additional electricity requirement from the three scenarios on Ireland's system demand profile over a seven-day period in 2013.

Figure 11: Ireland's electricity demand profile for an average seven-day period in 2013 with the additional demand from the scenarios



It is shown that system demand varied by approximately 1,700 MW between the daily peak and trough in 2013 and, when additional demand from scenarios HP-Oil or HP-Gas is included, the daily peak increases by approximately 500 MW.<sup>23</sup> The effect of including the HP-Elec scenario shows an increase of 1,000 MW in the daily demand. Figure 11 shows that all three scenarios increase day time demand with only a slight increase in the night time demand. Increasing night time demand (or 'daily trough' as it is known) is positive and beneficial for the electricity system as it lowers the need for thermal plant cycling, however an approximate 60% increase in the overall variation is not a desirable effect, as seen in the HP-Elec scenario. Nevertheless, this unwanted effect might not materialise because, through smart meters and smart grid technologies, it could be neutralised and even turned into a positive through the creation of dispatchable loads.

The electricity system could benefit from loads that can be dispatched at the behest of the transmission system operator as they have the ability to offset demand peaks, creating a more stable electrical demand overall. Increasing system stability could have knock-on effects within the system, such as reducing both the size of reserve capacities required and the amount of generation unit ramping and cycling.

<sup>23</sup> The demand is identical for both scenarios as they use the same amount of electricity to operate a heat pump.

## 5. Conclusion

This report finds that replacing an existing oil boiler with a heat pump instead of a direct replacement has the potential for benefits in terms of fossil fuel usage, CO<sub>2</sub> emissions emitted, renewable heat contributed, operational expenditure, and security of fuel supply. Reductions in fossil fuel use alone will improve Ireland's reliance on imported fuels along with the national exposure to price volatility attached to the commodity. Lowering emissions has the potential to make a significant contribution to the achievement of the binding national CO<sub>2</sub> emissions targets, while converting all dwellings with oil boilers to heat pumps would also increase Ireland's renewable heat share.

These results are contingent on certain assumptions used during the analysis, such as the operational performance of a heat pump, or its ability to provide 75% of hot water demand. The results are sensitive to changes in these assumptions, for example if the operational performance measured in the field could increase towards the manufacturers' listed COP then all savings outlined in the results section would be larger and include a shorter payback. Other considerations are also central to the outcome of the analysis, such as the correct sizing and installation of the technology. The Energy Savings Trust trials in the UK found the single biggest factors behind low performing heat pumps were incorrectly sized and poorly installed systems. This factor was not considered during the analysis, nevertheless, as is evident from the field trials, this must be a critical aspect for future policy consideration in terms of guidelines or regulation. Further analysis is required to more fully establish the effects on the electricity system. Due to a lack of detailed high resolution information on how auxiliary heat sources operate in conjunction with a heat pump, this report assumes the additional electricity demand is provided by both heat sources simultaneously. This creates a situation where daily demand variation could increase by up to 60%. However it has been identified that, through smart meters or smart grid technology, a benefit from this extra electrical demand can be obtained by creating dispatchable loads that increase demand in off-peak periods, encouraging a more stable and controllable electricity demand.

This analysis demonstrates that building type and energy efficiency are two key influencers in determining fuel, emissions, and economic savings. Figure 5 – Figure 9 allude to the fact that the larger, less energy efficient dwellings experience a higher level of savings, resulting in a shortened payback period based on repayment of the difference in capital cost. This exposes the topic of *energy efficiency measures* versus *renewable energy sources*. Presenting the figures in a 'per dwelling' format allows the reader to calculate the superior option for them on an individualised basis.

## **Key considerations for policy makers and households**

Whilst the estimated impacts of a large scale shift to heat pumps from oil heating in the residential sector represent potentially significant contributions to emissions reductions, energy savings, and renewable heating, a number of considerations must be made at policy level to facilitate this paradigm shift.

Fabric upgrades such as insulation, triple glazing and draught proofing should be considered first as a lower cost way to reduce energy bills. Such upgrades should happen before fitting a new heat pump to ensure the pump is correctly sized. Given the limited budget of households (and Government) to invest in energy efficiency and/or supply-side efficiency, improvements such as a switch to heat pumps, trade-offs between energy efficiency upgrades and heat pump investments require further examination.

Given that savings realised by consumers are sensitive to changes in the operational performance of the heat pump, correct sizing and installation of heat pumps in homes is necessary to maximise their efficiency. The need for codes and standards to ensure expert system commissioning was demonstrated by the Energy Savings Trust field trials in the UK which highlighted these as significant factors in the underperformance of heat pumps in operation. Results also indicate the use of night rate electricity is an important factor for householders when calculating the operating costs and payback of installing a heat pump.

Finally, a preliminary analysis of the impact of additional electricity demand from heat pumps on the electricity system has been undertaken for this report. Large scale electrification could place additional stress on the electricity system at peak times due to the correlation between peak heat and peak electricity demands in homes. With the use of smart grid technology this effect may be mitigated and heat pump demand used to support system stability, optimising the use of renewable electricity output – elements that require further analysis.

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