



Pathways to high penetration of heat pumps

REPORT PREPARED FOR THE COMMITTEE ON CLIMATE
CHANGE

October 2013

Pathways to high penetration of heat pumps

Executive Summary	1
1 Introduction	15
2 The present and near term situation	17
2.1 <i>The current market</i>	17
2.2 <i>Findings of the literature review and industry consultation</i>	18
2.3 <i>International markets and policy review</i>	30
2.4 <i>Box 1: Heat pump associations</i>	36
3 The current and critical pathways	39
3.1 <i>Pathways described in this section</i>	39
3.2 <i>The current policy pathway</i>	39
3.3 <i>The critical pathway</i>	71
3.4 <i>Comparing the current policy path with where we need to be</i> ..	79
4 Achieving the required uptake by 2030	83
4.1 <i>Costs of heat pumps and alternative heating technologies to 2030</i>	83
4.2 <i>Barriers to uptake</i>	87
4.3 <i>Policy measures to address barriers</i>	89
4.4 <i>Impacts and assessment of individual policies measures</i>	96
4.5 <i>Policy packages to deliver the required uptake</i>	99
4.6 <i>Box 2: Impact of including transitional technologies</i>	107
4.7 <i>Recommendations on policies needed to meet the CCC's "cost-effective pathway"</i>	109
5 Conclusions and timeline	111
Annex 1: Identification of policy measures	113
Annex 2: Training and information policy measure design features and costs	116

Annex 3: Communal ground collectors for GSHP systems	121
Annex 4: Heat pumps and district heating	123
Annex 5: Policy package analysis on the split of installations by consumer type	130

Pathways to high penetration of heat pumps

Figure 1. Levelised cost of heating technologies in an off-gas, rural house with cavity walls	2
Figure 2. Levelised cost of heating technologies in an on-gas, suburban house type	2
Figure 3. Uptake of heat pumps in the domestic sector under different policy packages (total installations)	7
Figure 4. Uptake and present value of policy packages in the domestic sector	10
Figure 5. Total UK heat pump installations 2010-2012	17
Figure 6. Installed heat pumps in European countries	31
Figure 7. Simplified schematic of the modelling approach and the points within the model that various barriers are implemented	40
Figure 8. Implementation of barriers in uptake modelling	42
Figure 9. Barrier assumptions	44
Figure 10. Comparison of capital cost assumptions with data from a range of published sources (based on current cost data). Cost of heating system refurbishment (e.g. changed to emitters) are included in the cost, unless stated otherwise.	50
Figure 11. Projected uptake of heat pumps in the domestic sector in the current policy pathway	54
Figure 12. Projected heat supplied by heat pumps operational in the domestic and non-domestic sectors in the current policy pathway	54
Figure 13. Split of current policy uptake between heat pump technologies in the domestic sector	55
Figure 14. Split of heat pump uptake by technology type in the non-domestic sector	56
Figure 15. Ranges of levelised cost of energy for heat pump options in the domestic sector (based on 2017 costs).	57

Figure 16. Split of annual air to water heat pump uptake between domestic consumer types	58
Figure 17. Split of annual ground source heat pump uptake between the domestic consumer types	58
Figure 18. Comparison of the variation in rate of return (IRR) on investment in heat pumps in the on-gas suburban houses (cavity-wall) segment of the market.	59
Figure 19. Comparison of the variation in rate of return (IRR) on investment in heat pumps in the on-gas, flats (cavity-wall) segment of the market.	60
Figure 20. Comparison of the variation in rate of return (IRR) on investment in heat pumps in the off-gas, rural house (cavity-wall) segment of the market.	60
Figure 21. Impact of relaxing each barrier individually on heat pump uptake, compared to uptake in the current policy path (i.e. all barriers)	61
Figure 22. The sensitivity of air and ground source heat pump uptake to capital and hassle cost assumptions.	62
Figure 23. The sensitivity of air and ground source heat pump uptake to SPF assumptions	63
Figure 24. Sensitivity of the current policy projection to gas prices. (Upper) Low fossil fuel prices. (Lower) High fossil fuel prices.	64
Figure 25. Impact of relaxing barriers in combination, from the current policy path to the condition with all barriers relaxed.	65
Figure 26. Projected heat pump uptake in the current policy path in the case that hybrid air source heat pumps are included as a technology option.	67
Figure 27. Cumulative uptake of each heat pump technology option in the domestic sector in the current policy pathway, with hybrid air source heat pumps included as an option.	68
Figure 28. Cumulative uptake of each heat pump technology in the non-domestic sectors under the current policy path, with hybrid heat pumps included.	68
Figure 29. Structure of critical path tool	74

Figure 30. Critical Path: Total Installations	75
Figure 31. Critical path: Total TWhs of heat	76
Figure 32. Critical Path: Domestic Sector (installations)	76
Figure 33. Annual Installations under the Critical Path	77
Figure 34. Sensitivity of critical path to different assumptions	78
Figure 35. The current policy path versus the critical path (total installations)	80
Figure 36. The current policy path versus the critical path (TWh heat output)	81
Figure 37. LCOE in 2020 for gas boilers and heat pump technologies in an on-gas, suburban house with cavity walls.	83
Figure 38. LCOE in 2030 for gas boilers and heat pump technologies in an on-gas, suburban house with cavity walls.	84
Figure 39. LCOE in 2020 for gas boilers and heat pump technologies in an off-gas, rural house with cavity walls.	85
Figure 40. Change in LCOE with year of installation for heat pump and gas boilers in an on-gas, suburban house type	86
Figure 41. Change in LCOE with year of installation for heat pump and counterfactual technology in an off-gas, rural house.	86
Figure 42. LCOE in 2020 for gas boilers and heat pump technologies in a 'Domestic, House, Rural, consumer type (with insulated cavity wall construction).	87
Figure 43. Categorisation of policy measure to encourage heat pump uptake	90
Figure 44. Uptake and present value of policy packages	103
Figure 45. Uptake of heat pumps in the domestic sector under different policy packages (total installations)	104
Figure 46. Uptake of heat pumps in the domestic sector under different policy packages (TWh heat output)	104
Figure 47. Uptake and present value of policy packages (with hybrids option)	108
Figure 48. Barriers addressed under "enabling" policy measures	113

Figure 49. Barriers addressed under "incentivising" policy measures	114
Figure 50. Barriers addressed under "mandating" policy measures	114
Figure 51. District heating supply curve	127
Figure 52. Installations of GSHPs and ASHP ATWs under policy package 4	130
Figure 53. Installations of GSHPs and ASHP ATWs under policy package 5	131
Figure 54. Installations of GSHPs and ASHP ATWs under policy package 6	132
Figure 55. Comparison of total cost of ownership of heat pump options in an off-gas, rural (cavity-wall) house (based on 2025 price data)	132
Figure 56. Installations of GSHPs and ASHP ATWs under policy package 7	133
Figure 57. Installations of GSHPs and ASHP ATWs under policy package 8	133
Figure 58. Comparison of the rate of return on investment in heat pumps	134
Figure 59. Installations of GSHPs and ASHP ATWs under policy package 9	135
Table 1. Policy packages	6
Table 2. Timeline of actions to meet 2030 uptake pathways	12
Table 3. Results of second phase of the EST heat pump field trials	20
Table 4. Analysis of the distance from air source heat pump fan units at which the noise level drops to within the threshold for permitted development rights in England	23
Table 5. Summary of key findings from literature review and consultation	29
Table 6. National context and counterfactual technology	32

Table 7. Financial incentives in selected European countries as at 2010	34
Table 8. Summary of key findings from international markets and policy review	37
Table 9. Initial RHI tariffs assumed in the current policy modelling	53
Table 10. Estimated heat pumps installation required by 2050 to meet the decarbonisation target	72
Table 11. Supply growth rate assumptions	74
Table 12. Inputs to the uptake model for each policy measure	95
Table 13. Qualitative assessment of individual policy measures	97
Table 14. Policy packages	101
Table 15. Timeline of actions to meet 2030 uptake pathways	112
Table 16. Measuring the cost of the training and information policy measure	119
Table 17. Summary of main barriers to district heating deployment in the retrofit and new build sector	126

Executive Summary

Frontier Economics and Element Energy have been commissioned by the Committee on Climate Change (CCC) to analyse the actions required in the near- and medium-term to ensure sufficient heat pump uptake by 2030 to meet the 2050 carbon target. This work will be feeding into the upcoming 4th carbon budget review.

As part of the analysis for the 4th carbon budget, the CCC presented a central scenario which involved a total of around 160 TWh of heat pump output annually by 2030, including 81 TWh from the domestic sector, coming from 6.8m heat pumps.

Our analysis suggests that achieving uptake of heat pumps consistent with this “cost-effective” CCC scenario is achievable and could increase economic efficiency once the value of carbon saved is factored in. However, achieving this uptake would entail the introduction of major policy changes, which could result in high costs to some households. Our analysis suggests that to achieve uptake consistent with the “cost-effective” path the following actions would be required.

- Enhanced heat pump certification (requiring installer and consumer training) with sustained information campaigns would need to be implemented this decade.
- Heat pump uptake in new homes would need to be stimulated by the end of the decade through tightening new build carbon standards.
- Beyond 2020, the uptake of heat pumps in suitable off-gas grid homes would need to be incentivised.
- To reduce financial barriers and consumer hurdle rates, the Green Deal or a similar loan guarantee arrangement for heat pumps should be made available.

Beyond 2030, the suitability of the housing stock could become a major barrier to mass-uptake of heat pumps. Therefore, measures to improve the energy efficiency of the housing stock may be needed beyond 2030, particularly in “harder-to-treat” homes.

The following outlines this analysis in more detail.

Heat pumps are likely to be an important part of meeting 2050 carbon targets

Meeting the UK’s 2050 greenhouse gas reduction target cost-effectively is likely to require a close to full decarbonisation of heat production in the building

sector. Analysis carried out by the CCC and others suggests that rollout of heat pumps is likely to form a major part of this.

In the 2020s we project that, once the value of carbon is factored in, heat pumps become a cost-effective option in some home types, in particular new and off-gas grid homes. Figure 1 shows the progression of levelised costs, including the value of carbon, in an off-gas grid rural house with cavity walls. Here, some types of heat pump become cost-effective relative to the counterfactual by 2020. Figure 2 shows levelised costs in an on-gas grid suburban house. In this case, heat pumps are not quite cost-effective by 2030. Full results, including breakdowns of the components of levelised costs are provided in Section 4.1).

Figure 1. Levelised cost of heating technologies in an off-gas, rural house with cavity walls

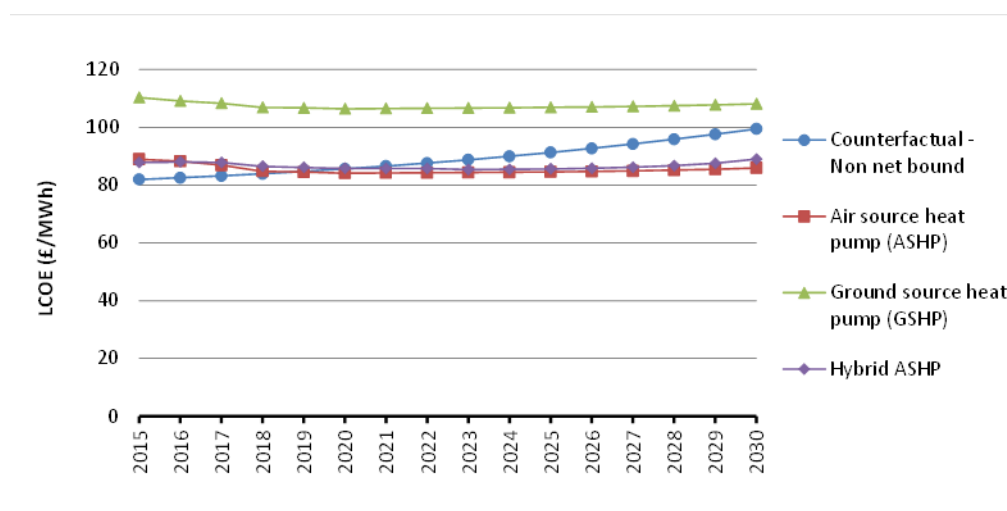
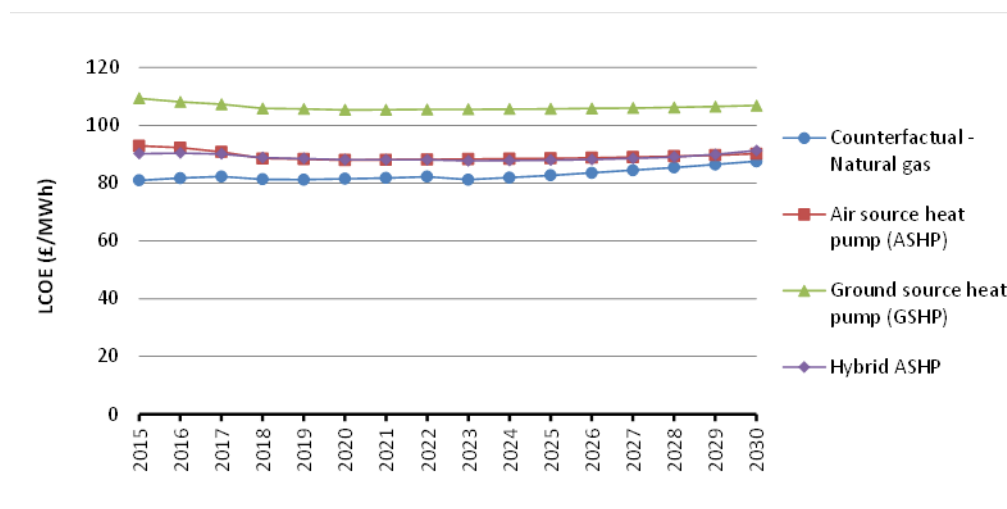


Figure 2. Levelised cost of heating technologies in an on-gas, suburban house type



Under the CCC's "Stretch" heat scenario¹ for meeting the 2050 carbon target, total heat pump uptake producing around 365 TWh of heat output by 2050 would be required. This includes 31m domestic installations, representing more than 80% of properties. We assessed the roll-out of heat pumps needed by 2030 to meet this scenario. We looked at two pathways.

- **"Cost-effective path"**. This pathway is consistent with meeting the first four carbon budgets and the 2050 target at least cost². It involves a total of around 160 TWh of heat pump output annually by 2030. This includes 81 TWh from the domestic sector, coming from 6.8m heat pumps. Throughout the rest of the report we refer to this as the "cost-effective" path.
- **"Critical path"**. This is the minimum level of heat pump uptake required to make meeting the 2050 target possible, given "hard constraints"³ on uptake. We have undertaken new modelling in this project to estimate this path. To stay on the critical path, we estimate at least 41 TWh of annual heat pump output would be needed as a minimum by 2030. This includes 30 TWh from the domestic sector, coming from 2.5m heat pumps.

We now present our analysis of how these pathways could be met under different policies.

Based on current policy, the roll-out of heat pumps by 2030 is projected to be below the critical path

The UK heat pump market currently sees around 20,000 installations per year, primarily of domestic air-source heat pumps (ASHPs). This compares to around 1.6 million gas boilers installed per year⁴. Heat pump installations have generally been focused on well-insulated homes seeking a replacement for oil-based heating.

We modelled uptake of heat pumps under current policies, including the Renewable Heat Incentive (RHI) in non-domestic and domestic sectors until

¹ See CCC (2012) *2050 Target – achieving an 80% reduction including emissions from international aviation and shipping*

² Based on 'top-down' cost-minimisation modelling for the CCC for the Fourth Carbon Budget.

³ We define hard constraints as those that are impossible, or very difficult, to change through feasible policy measures.

⁴ DECC (2012), *The future of heating: a strategic framework for low-carbon heat in the UK*.

2020, using the Element Energy heating technology uptake model (a description of this model can be found in Section 3.2.1)⁵.

We project output of heat pumps taken up in 2030 to be 13 TWh (coming from 0.7m installations)⁶, with air-source heat pumps making up the majority. If the option for hybrid heat pumps is included in the modelling, output of heat pumps taken up in 2030 reaches 14 TWh (coming from 1.0m installations). Uptake is also sensitive to a number of other factors, in particular fossil fuel prices and seasonal performance factors.

These uptake levels are below the levels implied by both the “critical path” and the “cost-effective path”. Therefore, for carbon targets to be met, additional policy measures are needed to promote uptake in the 2020s.

Key barriers to achieving the required level of uptake include cost, awareness, confidence, suitability and installer capacity

The high capital cost of heat pumps relative to the conventional gas boiler alternative is a major barrier to uptake in existing homes on the gas grid. In new build homes there has been a lack of uptake due to the relatively high costs of heat pumps, and the fact that they are not currently needed under building regulations.

Another barrier to uptake has been consumer confidence. In particular performance of heat pumps has sometimes been below expectations, resulting in a lack of confidence among consumers. Consumer awareness around heat pumps is also limited and represents a barrier to uptake.

Looking forward, rapid scaling of demand could cause a number of bottlenecks in the supply chain.

We assessed six main policy types that could be effective in tackling these barriers

To identify effective policies, we started from the list of key barriers and identified a range of policies that could address each one. We then filtered these policies against a set of criteria, including effectiveness in tackling barriers, flexibility, risks, distributional impacts and impacts on cost dynamics. Finally, we reviewed international policies to draw in relevant learning.

⁵ This model excludes gas absorption heat pumps and district-scale heat pumps. In the central case hybrid heat pumps are also excluded but we include them as a sensitivity.

⁶ By removing all non-financial barriers to uptake such as awareness, confidence, hassle, time to research technology and performance the uptake rises to 2.1m heat pumps by 2030. So financial barriers are the biggest obstacle to achieving the 0.7m heat pumps consistent with the “cost-effective” path.

We identified six policies through this process, and following discussions with the CCC.

- **Enhanced certification (requiring installer and consumer training) with sustained information campaigns.** This includes requirements on training of heating installers as well as training of consumers by installers.
- **Extension of the Renewable Heat Incentive (RHI) operating subsidy beyond 2020.** The RHI is a subsidy paid for each kWh of heat produced based on deemed heat usage.
- **Capital grants.** This is a “one-off” upfront payment to consumers to offset the capital cost of heat pumps.
- **Loan guarantees and social finance.** These improve the access to finance for consumers installing heat pumps. One variant is a Green Deal-style loan at a real 7% interest rate⁷. The second is an idealised ‘social financing’ measure where consumers receive loans at a social discount rate (3.5%) and invest if the return on investment exceeds this rate.
- **Tightened carbon emissions standards on new build.** This policy measure would first tighten the carbon standard in Part L of the Building Regulations in 2016, with an option for further tightening in 2020.
- **Carbon emissions standard on heating system replacement.** This is a minimum standard on new heating systems based on CO₂ performance. This would replace the current energy efficiency requirement on boilers with a requirement that the average lifetime carbon intensity of new heating systems is less than 180gCO₂/kWh⁸ (subject to suitability requirements being met). It could be targeted at specific property types.

Table 13 summarises how these policy measures were modelled. More detail on the measures is provided in Section 4.3.

⁷ Green Deal loans are modelled at an interest rate of 7% with repayments paid back through consumer bills. RHI receipts are included in the Golden Rule calculation.

⁸ Even if a gas condensing boiler were 100% efficient it could only achieve around 184 gCO₂/kWh based on standard values from the Carbon Trust. Carbon Trust (2011), *Conversion Factors*.

To reach the “cost-effective path” a combination of policies will be required

We analysed ten different policy packages targeting the domestic sector⁹ which use different combinations of these measures. These packages were developed in discussion with the CCC by considering the range of barriers that needed to be overcome. The impact of these policy packages is summarised in Table 1.

Table 1. Policy packages

	P1: RHI- driven uptake	P2: Capital subsidy	P3: Green deal	P4: New home standard	P5: Off-gas standard	P6: All homes standard	P7: Mandate combo	P8: RHI and Green Deal	P9: Capital subsidy and off- gas standard	P10: Social finance and RHI
Installer/consumer training & info campaigns	2015-2030	2015-2030	2015-2030	2015-2030	2015-2030	2015-2030	2015-2030	2015-2030	2015-2030	2015-2030
Extension of the RHI beyond 2020	to 2030							to 2030		to 2030 (optimised)
Capital grants		2020-2030							2020-2030	
Loan guarantees and social finance			Green Deal to 2030				Green Deal to 2030	Green Deal to 2030		Hurdle rates set to social discount rate
Tightened carbon emissions standards on new build	2016-2030 (<10-14kg)	2016-2030 (<10-14kg)	2016-2030 (<10-14kg)	2016-2020 (<10-14kg)	2016-2020 (<10-14kg)	2016-2020 (<10-14kg)	2016-2020 (<10-14kg)	2016-2020 (<10-14kg)	2016-2020 (<10-14kg)	
				2020-2030 (<6kg)	2020-2030 (<6kg)	2020-2030 (<6kg)	2020-2030 (<6kg)		2020-2030 (<6kg)	
Carbon emissions standard on heating system replacement					2020-2030 (off-gas grid)	2020-2030 (all homes)	2025-2030 (all homes)		2025-2030 (off-gas grid)	

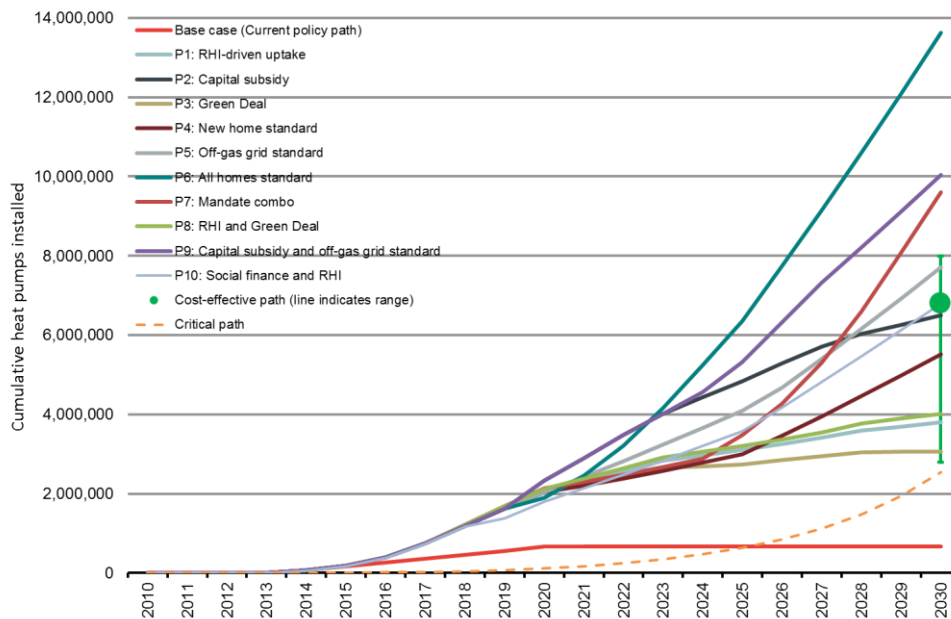
The impact and efficiency of these packages was assessed using the Element Energy heating technology uptake model. This is an uptake model (rather than the optimisation model used to assess the cost-effective path). It captures the fact that policies will not always ensure heat pumps are installed when and where they are most cost-effective and it allows us to measure the relative efficiency of policies.

⁹ We did not model policy packages for the non-domestic sector. This sector is highly diverse and more specific modelling of this sector would be valuable in understanding the impacts of different policy options.

Our estimation of the impact of these packages on heat pump uptake and output in the domestic sector is presented in Figure 3.

- All packages comfortably exceed the **“critical path”** level of 2.6m heat pumps installed. Most packages also exceed the critical path level 30 TWh in homes by 2030, with the exception of Package 1 (RHI) and Package 3 (Green Deal).
- Five packages exceed the **“cost-effective path”** level of heat pump uptake in terms of number of installations and/or TWh (6.8m heat pumps, 81 TWh). Four of these are packages that involve carbon standards on heating system replacement in existing homes: Package 5 (Off-gas standard), Package 6 (All homes standard), Package 7 (Mandate combo) and Package 9 (Capital subsidy and off-gas standard). The fifth combines social financing of heat pumps with an ‘optimised’ RHI.

Figure 3. Uptake of heat pumps in the domestic sector under different policy packages (total installations)



Source: Element Energy and Frontier Economics.

Figure 4 summarises the effectiveness of the policy packages. There are two main messages from these results.

- **Seven policy packages have a positive net present value (NPV)¹⁰ and an average cost per tonne of carbon saved that is below the value of carbon.** The level of uptake in these packages is in line with those suggested by the “cost effective” path suggesting that this is desirable and achievable.
 - The highest NPV comes from Package 5 (off-gas grid standard). This results from the higher costs of heating alternatives (e.g. oil and resistive electric heating) in these homes and the higher carbon savings that can be achieved from switching to heat pumps.
 - Other mandating policies (Package 6 and Package 7) have lower NPVs as, although they include off-gas grid homes, they result in some installations in home types where heat pumps are not cost-effective in saving carbon. Package 4 (new homes standard) delivers a positive NPV, reflecting the cost-effectiveness of heat pumps in new homes. But the NPV is lower than other mandating policies because it does not include installation in existing off-gas grid homes.
 - Package 10 (social finance and RHI) delivers a higher NPV than Package 1 (RHI). In this package the RHI tariff has been ‘optimised’ so as to deliver uptake in the most cost-effective property types and to limit the overall subsidy cost¹¹. This package suggests that there is scope to improve the efficiency of the RHI and that measures to improve consumers’ access to finance and lower their required hurdle rates could be important.
 - Package 2 (capital subsidy) has a large negative NPV which partly reflects that capital subsidies do not always encourage uptake in properties, or heat pump types, which are most cost-effective in saving carbon.

The average cost per tonne of carbon saved ranges from £38 to £120/tonneCO₂. To put this in context, the DECC carbon price (‘non-traded’) rises from £59/tonneCO₂ in 2013 to £76/tonneCO₂ in 2030 and £182/tonneCO₂ by 2045.

¹⁰ In our assessment of NPV we assess all resource benefits/costs relative to the base case, including capital costs, operating costs and carbon savings.

¹¹ To achieve this, the RHI tariff has first been optimised for each property type in order to provide a five year simple payback period. The maximum level for any property type has then been capped at a level of 30 £/MWh for ASHP and 60 £/MWh for GSHP systems. The cap means that substantial uptake will only occur in the more cost-effective property types and the tariff optimisation avoids large rents being paid in segments where heat pumps are most cost-effective, but it does imply that some of the uptake may not be cost-effective.

These packages were modelled without the option of hybrid heat pumps. NPVs are generally higher when modelled with hybrids included (see Section 4.5) suggesting these should be included in policy incentives.

- **The distribution of costs varies across packages.** Unsurprisingly, the policy packages which focus on subsidies have a high cost to government (e.g. Packages 1, 2 and 8).

Package 10 also focuses on subsidy. However, because consumers invest on the basis of social discount rates in this package, much lower subsidies are required to induce investment, with subsidy costs only slightly higher than the base case. On top of this, tariffs are set such that uptake is focused on cost-effective property and heat pump types and towards the late 2020s when heat pumps are most cost-effective. These factors greatly reduce subsidy costs and result in savings to government compared to the base case.

Packages that are heavily reliant on standards (e.g. Packages 6 and 7) result in high direct costs for consumers. In these cases consumers could incur sudden and high capital costs when they replace their heating system, potentially including extra financing costs not captured in this cost assessment¹². The negative effects of this could be reduced by Green Deal (or similar) financing to the extent this can lower financing costs.

Finally, it is notable that, under the assumptions used for modelling uptake, subsidy-based policies (Packages 1, 2, 8 and 10) also result in some costs to consumers over the lifetime of the heat pump¹³.

¹² For example, say consumers needed to finance these capital costs with a 10-year loan at a 7% interest rate, the present value of the capital costs facing consumers would increase by around 20% for each installation. This would increase the costs to consumers by £3bn in Package 6 and £2bn in Package 7.

¹³ The reason for this is that in some cases subsidy induces investment that achieves payback over the consumer's time horizon but which has a negative NPV for the consumer over the life of the investment. This is due to removal of subsidy after seven years and rising electricity costs.

Figure 4. Uptake and present value of policy packages in the domestic sector

	Base case	P1: RHI-driven uptake	P2: Capital subsidy	P3: Green deal	P4: New home standard	P5: Off-gas standard	P6: All homes standard	P7: Mandate combo	P8: RHI and Green Deal	P9: Capital subsidy and off-gas standard	P10: Social finance and RHI
UPTAKE											
Heat pumps installed by 2030 (cumulative)	0.7	3.8	6.5	3.1	5.5	7.7	13.6	9.6	4.0	10.0	6.2
Heat pump output in 2030 (TWh)	5	29	57	23	40	75	147	100	32	99	45
BENEFITS/COSTS											
Total NPV, £m (A+B+C)	-	-391	-1,957	42	1,048	6,078	3,110	3,093	-1,026	3,145	944
Government, £m (A)	-	-3,194	-6,902	-521	-186	-265	-19	-521	-4,394	-848	347
Consumers, £m (B)	-	-476	-955	-1,029	-3,045	-9,921	-23,696	-13,310	-191	-12,490	-5,658
Carbon, £m (C)	-	3,482	5,693	1,802	4,402	10,009	19,411	13,379	3,798	12,499	5772
COST-EFFECTIVENESS											
£cost/tonne CO₂ saved	-	98	120	80	73	38	85	81	113	73	77

Note: All costs/benefits are measured relative to the base case. To determine uptake we used retail gas and electricity prices. We then calculated overall NPVs using long-run variable costs (LRVCs) of gas and electricity in accordance with DECC appraisal guidance. Government costs are subsidy costs/savings and £81m arising from an information campaign in all packages. There are other distributional impacts on margins for retail firms, network firms as well as tax revenues not included in the distributional analysis (hence impacts on consumers, government and carbon do not sum to the NPV).

For the “cost-effective pathway” to be met, action is required in the near term

Our modelling suggests that an uptake of heat pumps consistent with the “cost-effective” CCC scenario is achievable and could increase economic efficiency once the value of carbon saved is factored in. However, it would entail the introduction of major policy changes, which could result in high costs to some households.

The modelling suggests that the most efficient policy packages are those which impose tighter carbon standards on off-gas grid homes and new build or which combine an ‘optimised’ RHI with social finance.

To get as close as possible to the benchmark set by these packages and achieve uptake consistent with the “cost-effective path”, the following four policies would need to be implemented.

- Enhanced heat pump certification (requiring installer and consumer training) with sustained information campaigns implemented this decade as a relatively low cost method of improving consumer awareness and confidence.
- Heat pump uptake in new homes would need to be stimulated by the end of the decade through tightening new build carbon standards.
- Beyond 2020, the uptake of heat pumps in suitable off-gas grid homes should be incentivised. This could be achieved through an extended and efficiently-designed RHI or a carbon standard on heating system replacement for off-gas grid homes.
- To reduce financial barriers and reduce hurdle rates required by consumers to invest, the Green Deal or a similar loan guarantee arrangement for heat pumps would need to be available.

Retaining the RHI until 2020 is also likely to be important in building the heat pump market, developing the supply chain and maintaining investor confidence.

Beyond 2030, the suitability of the housing stock could become a major barrier to mass-uptake of heat pumps. Delivering output from heat pumps of 365 TWh (and around 31m installations) by 2050 implies almost all properties must be suitable for heat pumps. Therefore, measures to improve the energy efficiency of the housing stock may be needed beyond 2030, particularly in “harder-to-treat” homes.

Table 2 summarises our recommended timeline of actions to achieve heat pump take-up which is consistent with the “cost-effective pathway”.

Table 2. Timeline of actions to meet 2030 uptake pathways

Date	Action
Present-2020	RHI support
2015-2030	Regulate for enhanced installer and consumer training
2015-2030	Information campaigns
2016-2020	New home carbon standard of < 10-14 kgCO ₂ /m ² /year
2020-2030	New home carbon standard of < 6 kgCO ₂ /m ² /year
2020-2030	Green Deal or other loan guarantees made widely available for heat pump installations
2020-2030	An 'optimised' RHI or off-gas grid carbon standard to focus installations on suitable off-gas grid properties.

1 Introduction

A close to full decarbonisation of heat production in the building sector is likely to be required to meet the UK's 2050 greenhouse gas reduction target cost-effectively. Analysis carried out by the Committee on Climate Change (CCC) and others suggests that rollout of heat pumps is likely to form a major part of a cost-effective decarbonisation of the heat sector.

The penetration of heat pumps in the UK is currently low. Annual installations of heat pumps are currently around 20,000, compared to around 1.6 million gas boilers. A substantial increase in uptake would be required to put the UK on track to meeting the long term climate change targets where total heat pump output of around 160 TWh per year is required, including 6.8 domestic installations, by 2030 and 365 TWh, including 30.6m domestic installations (over 80% of homes) by 2050 under the CCC 'Stretch' scenario.

Frontier Economics and Element Energy were commissioned by the CCC to analyse the actions required in the near- and medium-term to ensure that sufficient uptake of heat pumps can be achieved by 2030 to allow carbon targets to be met. Expert advice and review in this work was provided by Dr Adam Hawkes of Imperial College.

There are four main sections in this report.

- We begin by looking at the present and near-term situation. This includes an analysis of the current status of the heat pump market along with current barriers¹⁴ to uptake and progress in addressing these, based on a literature review and stakeholder interviews.
- We then forecast heat pump uptake under current policies to 2030. This forecast uptake is compared to both a "critical path" (the minimum level of uptake needed to make meeting 2050 carbon targets possible under a 'Stretch' scenario) and a "cost-effective path" (the level of uptake consistent with meeting the 2050 and all interim carbon targets most cost-effectively).
- We then analyse and assess new policy packages that break down barriers to uptake and allow the "cost-effective" level of heat pump uptake to be achieved by 2030.

¹⁴ Note we only consider consumer-facing barriers to uptake of heat pumps. We do not consider wider infrastructure barriers such as the capacity of electricity network infrastructure to meet additional demand from heat pumps.

- Finally, we draw together the analysis carried out in the previous tasks into a timeline of actions to 2030 that are needed to allow the level of heat pump uptake consistent with the “cost-effective path” to be achieved.

2 The present and near term situation

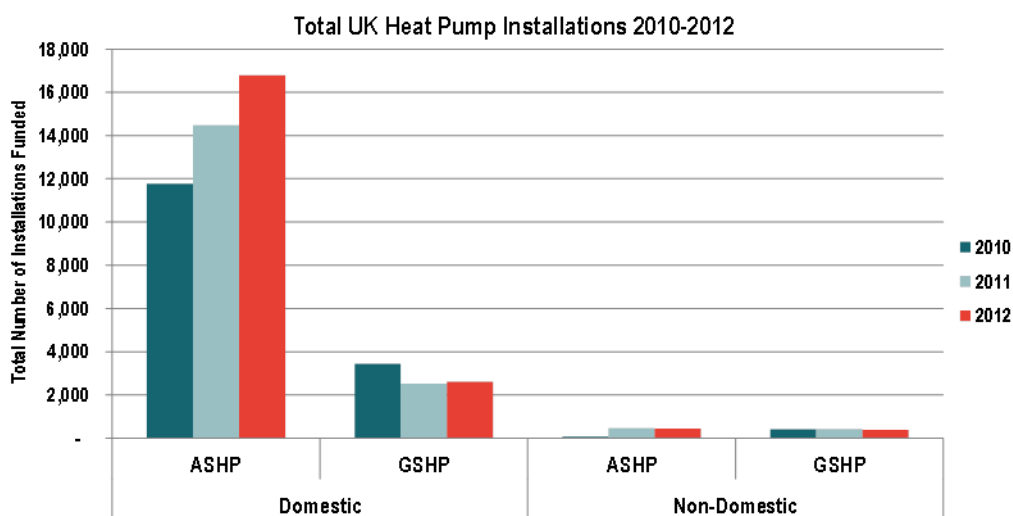
To analyse the present situation, we have undertaken an analysis of the current market, reviewed UK and international literature review, and consulted widely with the heat pump industry.

The outputs of this analysis have been revised data and assumptions to underpin the analytical work and insights from industry experts, including heat pump manufacturers, trade bodies and end-users which have informed our view on barriers and the policies that are required to overcome them. We now present the key findings of this work.

2.1 The current market

The heat pump market in the UK is currently small, with around 20,000 units installed in 2012 across all technologies and sectors. In terms of units installed, the market is dominated by domestic air to water heat pumps, which accounted for around 17,000 of the units deployed in 2012.

Figure 5. Total UK heat pump installations 2010-2012



Sources: Heat Pumps United Kingdom, 2012 and 2013 editions; BSRIA, Report 55385/14 (March 2012) & 56030/15 Edition 2 (April 2013)

The market for air to water heat pumps has been growing steadily over the last few years (21% from 2011-2012). By contrast, the ground source market has suffered, declining significantly over recent years. This has happened despite the eligibility of ground source heat pumps for Phase 1 of the non-domestic RHI and support under the Renewable Heat Premium Payment for installations in off-gas homes (alongside air to water systems).

The chief cause for the decline in the ground source industry is believed to be the uncertainty regarding the RHI and specifically the hiatus between the announcement of the policy and its delivery. The industry believes that projects have been delayed while potential investors wait for greater certainty regarding the tariffs and eligibility criteria. While the non-domestic RHI has supported ground source, the tariffs were felt to be insufficient in comparison to the biomass tariff, resulting in biomass take-up at the expense of ground source in the non-domestic sector.

While the air source market has shown some growth over recent years, the uncertainty surrounding the RHI has similarly been identified as a barrier to more rapid growth of the air source market.

Early heat pump markets

The early domestic market for retrofit ASHPs has mainly been in off-gas properties, with a particular demand in properties with oil-based heating systems. The combination of the favourable economics associated with replacing an oil boiler with a heat pump, and benefits of removing the hassle of fuel deliveries has facilitated this market.

Many retrofit installations have been in social housing. This is likely to be in part due to the more long-term outlook on payback periods by of social landlords, but also due to the particular focus on the sector of programmes such as CERT and the RHPP.

2.2 Findings of the literature review and industry consultation

We now present the findings of the literature review and consultation in the following areas:

- performance;
- awareness and consumer acceptance;
- planning and noise;
- suitability; and
- cost and economics.

The present and near term situation

2.2.1 Performance

Poor performance of heat pumps is both a real barrier and an issue of consumer perception¹⁵. Phase 1 of the recent EST heat pump field trials, undertaken between April 2009 and April 2010, identified significant under-performance in terms of system efficiencies. Average results were disappointing across both air source and ground source installations, but particularly in the case of air source. The field trials have highlighted some important issues concerning heat pump design, installation and commissioning that will need to be addressed by the industry. The impact of the EST field trials on public perception is likely to be relatively limited. However, issues concerning exhaust air heat pump¹⁶ installations have received mainstream media attention and do risk feeding negative perception of heat pump technology more widely.

The EST Field Trials

The Phase 1 results of the EST field trials demonstrated heat pump performance significantly below expectation. The mean system efficiency recorded for air to water systems was 1.82 (22 units, range of 1.2 to 2.2), while for ground source systems a mean of 2.39 was recorded (49 units, range of 1.55 to 3.37). A number of issues were identified as major contributors to the poor performance, including:

- under-sizing – of the heat pump, the hot-water cylinder¹⁷ and, in the case of ground source, the boreholes /ground loop;
- flow temperatures too high – both in radiator and underfloor emitter systems
- poorly designed ground loop; and
- controls – over-use of circulation pumps and reliance on immersion heater.

A second phase of the EST trials was undertaken between April 2011 and March 2012. The second phase set out to address the technical issues identified at a number of the Phase 1 installations and to then monitor the performance of the systems for a further period to identify and measure any improvement. The interventions employed at these sites ranged from major works, including

¹⁵ We discuss consumer perception in the next section.

¹⁶ Exhaust air heat pumps extract air from warmer areas of the property (e.g. bathrooms, kitchens). The heat is removed from the air as it is transferred through the heat pump's refrigerant circuit and then discharged outside.

¹⁷ This was also subject to oversizing.

replacing heat pumps, to minor changes to the control strategy or adding additional pipework insulation.

The second phase of the trials has demonstrated a significant improvement in system performance compared to Phase 1. The results are summarised in the table below.

Table 3. Results of second phase of the EST heat pump field trials

		Seasonal Performance Factor (H2) ¹	Seasonal Performance Factor (H4) ²	System efficiency ³	Proportion of systems considered renewable
Air-source	Average	2.68	2.41	2.11	9/15 (note that 5 out of the 9 heat pumps considered renewable were completely new installations and were MCS 3005 compliant).
	Standard deviation	0.45	0.44	0.44	
	Standard error	0.12	0.11	0.10	
	Number of systems	15	15	17	
Ground-source	Average	3.10	2.82	2.30 ⁴	20/21
	Standard deviation	0.40	0.42	0.47	
	Standard error	0.09	0.09	0.09	
	Number of systems	21	21	27	

Notes:

¹ SPF(H2): System boundary for efficiency calculation includes the heat pump unit and the equipment to make the source energy available to the heat pump (e.g. a fan or pump).

² SPF(H4): System boundary includes the heat pump unit, the equipment used to make the source energy available to the heat pump, the auxiliary electric heater and domestic hot water immersion and all auxiliary pumps including those on the heat sink (e.g. central heating circuit, pumps and buffer tank)

³ System efficiency: System boundary includes all components used in the calculation of SPF(H4), but considers the heat of domestic hot-water used by the householder, not that supplied to the hot-water cylinder (so cylinder losses, for example, are included in the system efficiency calculation)

⁴ Average system efficiencies measured in Phase 2 appear to be lower than those measured in Phase 1 (2.3 and 2.39 respectively). It is important to note that system efficiency is strongly influenced by ambient temperature and the amount and temperature of hot-water consumption, therefore these figures are not directly comparable. Analysis of weather-corrected system efficiencies obtained in the Phase 2 trial has shown that 17 of 21 heat pumps that received either major or moderate interventions between Phase 1 and Phase 2 demonstrated improved system efficiency as a result.

Source: Detailed analysis from the second phase of the Energy Saving Trust's heat pump field trial

The interventions have resulted in a significant improvement in system efficiency (note that the Phase 2 results also include a number of new systems, not included in Phase 1). The ground source system efficiencies are on average higher than the air source efficiencies, as expected given that ground temperatures are higher

The present and near term situation

than air temperature during the winter heating season. It is interesting to note that the seasonal performance factors (SPF) for water heating alone were found to be practically the same for ground and air source systems. This has implications for performance in well-insulated new build properties, where the water heating load is a greater share of the overall demand for heat. In these cases the performance difference between ground source and air source systems might be expected to be narrower.

A further significant result of the EST Phase 2 field trials is that a relatively high number of air source systems did not achieve the minimum SPF required to be considered renewable under the EU Renewable Energy Sources Directive. This requires a minimum SPF_{H2} of 2.5, a level that six of the fifteen air source systems failed to achieve. Note that the domestic phase of the RHI policy is expected to pay RHI on the deemed renewable heat output of ASHP systems based on a significantly higher assumed SPF than recorded in the EST field trials. The SPF assumptions adopted in this study are described in more detail in Section 3.2.2.

2.2.2 Awareness and consumer acceptance

A lack of awareness of heat pump technology, particularly among domestic consumers, is a key barrier to uptake. This has been demonstrated by a recent study by the EST and Ipsos Mori¹⁸, in which a survey of householders was conducted to explore their knowledge and attitudes toward a range of low carbon heating options and also to better understand purchasing behaviour. This study provided a number of insights that have implications for the heat pump market.

Awareness of heat pumps is low

When asked to describe their state of knowledge of a range of heating appliances, 68% of the householders surveyed stated that they had never heard of air source heat pumps and only 12% said they had heard of them and understand what they are. The same responses for ground source heat pumps were 53% and 28% of the householders respectively.

Householders are sceptical about heat pumps

After being provided with information and asked how they feel about different heating appliance options, 40% said they felt very or fairly negative about air source heat pumps, compared to 29% that felt positively. Ground source fared a little better, with 30% feeling very or fairly negative and 38% feeling fairly or very positive.

¹⁸ Homeowner's willingness to take up more efficient heating systems, Ipsos Mori and Energy Saving Trust, DECC, March 2013

The reasons given for attitudes toward air source systems included concerns about noise, the visual appearance of the external unit, concerns about vulnerability of the external unit to tampering and scepticism that the system would provide sufficient heat on cold days.

Breakdown or loss of performance of existing systems is by far the most likely trigger for investing in a new heating appliance.

Unsurprisingly, by far the most common reason given for heating system replacement was breakdown or loss of performance (70% of those who had replaced their system said this was the reason). Very few said they were likely to consider purchasing a new system at other potential 'trigger' points, such as moving into a new home, selling or renting out their house. The distressed nature of purchasing compounds the lack of awareness of heat pumps, as consumers are unlikely to consider new heating system options under these circumstances. Outside of a breakdown of their existing system the motivation for considering replacing a heating system most commonly given was if energy prices rose or a cheaper to run system became available.

When making a heating system purchase, the boiler service / repair man is the most important source of advice

The survey found that when replacing a heating system, more than 40% of householders sought advice from the service engineer. For heat pump uptake to become more widespread, it will be important to ensure that the existing network of heating engineers provides advice about heat pumps and offers products. The survey found that 25% of people asked friends or family for advice, which also demonstrates that good word-of-mouth will be an important factor.

2.2.3 Planning and noise

Noise from the external fan and compressor unit of an air source heat pump is a potential source of nuisance both for the occupants of the building served by the heat pump and for their neighbours. Noise levels have been recognised as a potential consumer acceptance issue and a limiting factor on suitability of air source heat pumps in some areas (e.g. dense urban settings).

Noise is much less of an issue for ground source heat pumps, as they do not require an external fan. For ground-coupled systems the heat pump is commonly located internally and as such is designed to operate within acceptable noise limits for an internal appliance.

In an effort to facilitate the uptake of heat pumps, alongside other renewable energy technologies, air source heat pumps have been included under permitted development rights in England. Subject to certain criteria being met, it is not necessary to obtain planning permission for the installation of an air source heat pump. One of these criteria relates to noise, as follows:

The present and near term situation

“The noise level should not exceed 42dB $L_{Aeq(5min)}$ at 1m from the window of a habitable room in the façade of any neighbouring dwelling.”

The Building Performance Centre provided a study of the noise generated by air source heat pumps for DECC. Noise levels from a range of air source heat pump installations was measured and found to be in the range of 50 to 60 dB at 1 metre from the unit (in line with the fan). These noise levels were broadly in line with the manufacturers’ specifications.

The study went on to analyse the distance at which the noise from these units would have dissipated to the 42 dB L_{Aeq} level stipulated by the permitted development planning requirements. The results of this analysis are shown below.

Table 4. Analysis of the distance from air source heat pump fan units at which the noise level drops to within the threshold for permitted development rights in England

Table 4-3: Distance from unit at which noise level would be L_{Aeq} 42 dB (m) (free field)			
Site Code	ASHP Description	Without tonal correction	With tonal correction
		0 25 50	0 25 50
478	8.5 kW Manufacturer A	9	9
479	8.5 kW Manufacturer A	10	11
422	8.0 kW Manufacturer B	10	18
422	6.0 kW Manufacturer B	4	8
418	8.0 kW Manufacturer B	11	14
443	8.2 kW Manufacturer C	28	45
440	9.0 kW Manufacturer D	16	20
474	9.1 kW Manufacturer E	16	16
475	5.5 kW Manufacturer E	20	25
486	8.0 kW Manufacturer F	8	11

Source: Acoustic Noise Measurements of Air Source Heat Pumps (EE0214), Building Performance Centre (for DECC), September 2011

For the majority of the units the distance to achieve the 42 dB level is in the range of 10 to 20 metres (without tonal correction¹⁹). This implies quite a

¹⁹ The human ear is particularly sensitive to ‘tonal’ noise, i.e. noise in which a particular pitch can be identified. To mitigate for the presence of tonal noise the separation distance over which the noise level is considered to dissipate to an acceptable level is increased (the tonal content is effectively modelled as an

substantial separation distance between the fan unit and neighbouring buildings that would be expected to be a significant constraint in areas of high housing density and particularly in flatted developments.

As a result of the 42 dB noise level threshold, a large number of air source heat pump installations still require planning permission (one manufacturer consulted estimated 40% of installations require planning permission). This creates a significant additional time burden and hassle factor to installation of an air source heat pump. The industry believes that a relaxation of the noise threshold to 45 dB would significantly reduce this barrier and argues that this would not infringe on the amenity of neighbouring occupants.

In addition to the noise threshold the permitted development rights also put a limit on the permitted size of the outdoor unit of 0.6 m³. This can restrict permitted development for larger systems, as the size of fan and compressor increases. Air source systems of greater than 9 kW may require planning permission on the basis of the outdoor unit size.

2.2.4 Suitability

The suitability of ground and air source heat pumps varies significantly across all property types, particularly in relation to how well-insulated the property is and the space available to fit the heat-pump based heating systems. The AEA methodology for assessing the suitability used here considers the following three constraint categories:

- space constraint assumptions surrounding the ability to install basic components of a low carbon heating technology;
- heat grade constraints i.e. matching the heating requirements of a property with the output of a low carbon heating technology which generally operate at lower flow temperatures; and
- an 'other factors' category which takes into consideration any extra constraints such as noise and environmental factors.

Some of these suitability assumptions were challenged through the consultation:

- While there are noise and visual impacts of air source heat pump external units on the façade of a block of flats, the practice of installing roof-mounted heat exchangers is common. Servicing blocks of flats with ground source heat pumps fed by a communal ground array is also a feasible solution, avoiding any issues of noise or visual amenity.

increase in the dB noise level). The increase in separation distance due to tonal correction varies between heat pumps due to variation in the tonal content of the noise spectra.

The present and near term situation

- There is a common assumption that ground source installations are only suitable for rural, off gas properties as these properties have lower space constraints for boreholes. However one manufacturer we consulted estimated that 50% of their ground source installations are in central London.

Compatibility with incumbent emitters

The compatibility of low flow temperatures produced by heat pumps was also discussed through the consultation. The requirement to replace emitters, such as installing low temperature radiators (or under floor systems) and hot-water tanks can be a significant additional cost and also carries a large ‘hassle factor’ for consumers. A number of consultees remarked that it is not always necessary to replace emitters, as existing radiator systems are frequently oversized. However, particularly given the findings of the EST field trial, which have clearly demonstrated the sensitivity of heat pump performance to the design of the distribution system, it seems reasonable to assume that a certain level of modification will be required to achieve good system performance.

Some manufacturers offer a smart (fan) radiator solution which heat up a room more quickly and with a more even temperature gradient. However these systems cost more, require both plumbing and electrical work, and are slightly noisier and therefore unsuitable for bedrooms.

2.2.5 Costs and economics

Installation costs are clearly a significant barrier to uptake of both ground source and air source heating systems, as capital costs are substantially higher than those of incumbent systems, such as gas and oil boilers. A number of prior studies have been carried out to gather and analyse cost data for heat pumps and a limited amount of further data has been gathered through the industry consultation during this study. This evidence on installed costs for heat pump systems is discussed in more detail in Section 3.

Potential for cost reduction

The potential for installed costs of air source and ground source units to decrease over time has been explored through the consultation. The general consensus seems to be that the opportunity for reduction of equipment costs is limited²⁰. The major components of heat pump systems, such as the compressors, are common to those used in air-conditioning units and are manufactured in vast

²⁰ Capital cost reduction of around 10% by 2030. This is consistent with the learning rates published in a recent report by Sweett Group on the costs of renewable heating technologies: ‘Research on the costs and performance of heating and cooling technologies’, Sweett Group for DECC, 21st February 2013

numbers. No significant economies of scale are therefore expected to result from growth of the heat pump industry.

Up to 50% of the upfront cost of heat pump systems is the installation cost (potentially even more for ground source systems). This is expected to be a source of future cost reduction as the installer base grows. Increased familiarity with heat pumps among heating engineers will result in reduced time on-site for the installation. As the market matures, competition between installers will also drive down installation costs.

Particularly significant installation cost reductions may be achievable for ground source systems. The cost of a borehole, sized to the heat demand of a typical size house (e.g. 3-bed semi) is £3,000 – 4,000 although this can vary significantly depending on the location and ground conditions. The drilling industry has contracted due to the loss of ground source market over recent years and currently has little capacity. As a result drilling rigs have to be transported long distances between installations. As the market grows, a regionalised drilling industry will develop. This has the advantage of reducing the transport distances for drilling equipment and also that local expertise will develop with knowledge of the particular geological conditions in the area. This is likely to reduce time and costs for installation of borehole systems.

Ground source heat pump cost considerations

The installed costs of ground source systems are considerably higher than air source systems, particularly when coupled to a borehole system. However, a number of factors must be considered when comparing these costs to ensure consistent analysis.

- For borehole coupled ground source systems, a large part of the cost is related to drilling the borehole. The lifetime of this infrastructure is far longer than that of the heat pump. Therefore, the replacement cost of the ground source system is significantly reduced compared to the initial installation cost.
- In certain installations it will be possible to couple multiple dwellings to a single ground array (this is clearly the case in flats and could also be a good solution in new build housing estates and certain retrofit housing projects). In these cases it might be preferable to drill fewer, deeper boreholes, which would typically be lower cost than individual boreholes per dwelling. Depending on the number of homes it may also be possible to factor in some diversity of heat demand, enabling the capacity of a communal ground array to be reduced (this is discussed in more detail in Annexe 4).

The present and near term situation

2.2.6 Supply-side issues

The upstream supply chain, i.e. manufacturing capacity, is not seen as an issue for the growth of the heat pump market. There is some UK manufacturing capacity (e.g. Mitsubishi factory, Kensa, Dimplex) but this is limited and investment has been deterred by policy uncertainty. However, there is a large international manufacturing capacity that can easily meet any envisaged growth in UK demand.

There is potential for downstream supply chain issues, due to the lack of capacity of the installer base and lack of specific skills in heat pump installation; although many installers in RHPP only do 1-2 installations per year at the moment and therefore could have capacity to switch. As demonstrated by the EST field trials, the performance of heat pumps is critically dependent on proper system design, e.g. sizing of the heat pump, hot-water storage, sizing of emitters, achieving correct flow temperatures etc., and proper installation and commissioning.

Currently there is a lack of capacity of trained heat pump installers, as companies have not invested in training while there is policy uncertainty and weak demand. This lack of capacity could be a constraint on the growth of the market once Phase 2 of the RHI starts to stimulate demand. The lack of drilling rigs and expert contractors is a particular concern raised in a number of consultation interviews.

A further concern raised by a number of consultees is that the incentive regime could attract non-specialists from other industries to diversify into the heat pump market. Given the importance of installation quality to heat pump performance, this is seen as a key risk to the industry as a glut of poorly installed and poorly performing systems will quickly create a negative perception of the technology. The Microgeneration Certification Scheme will need to be properly resourced to ensure the barriers to entry are appropriate and that design standards are maintained.

2.2.7 Policy and other enabling measures

The need for regulation and policy to drive the uptake of heat pumps was recognised by all consultees. However it was also recognised that the RHI may not provide an affordable means of achieving a target of 6.8 million heat pumps in the residential sector from a government perspective. It was suggested that a favourable policy would be to drive the uptake in new builds through regulation and reserve incentive-based measures for stimulating the more difficult retrofit market.

Examples of previous good policy measures recognised included the Merton Rule, which was effective in driving uptake of heat pumps. The Microgeneration certification scheme (MCS) has also had a beneficial effect on quality of installation, although there was some concern that barriers to becoming

The present and near term situation

accredited are not high enough and that the market could be flooded by under-trained installers once the incentive regime is in place.

Furthermore the heat pump market would be better served by a firm commitment from government 5-7 years prior to when policies are to be effected. This will provide a sensible investment timeline for the heat pump industry to adjust itself to meet the future requirements resulting from policy changes and also allowing boiler manufacturers to hedge their risks by investing in heat pump technologies.

Enabling efforts from within the industry

The heat pump industry itself has been involved in a number of activities in an attempt to address the barriers to uptake. A number of manufacturers consulted have developed automated control systems. This has been an attempt to address the reduction in heat pump performance caused by user interaction. Other initiatives from manufacturers have included working with the electricity distribution network operators to assess the impact of heat pump uptake on distribution networks and identify potential solutions.

Manufacturers have also developed online educational resources (i.e. a homeowners portal) to serve as an aid for consumer confidence by reducing the awareness issues surrounding heat pumps.

Alongside manufacturers, industry organisations also welcome the EU Ecodesign Directive, as they believe energy labelling will help to improve awareness of heat pumps and also drive the industry to achieve improved standards.

Renewable heat zones

A significant issue surrounding the uptake of heat pumps is an immature downstream supply chain (lack of trained installers etc.). A possible enabling policy suggested during the consultation was the creation of renewable heat zones.

This would involve designating regions where manufacturers, installers, and district network operator could align their efforts to penetrate the off-gas market. Through learning how to address each individual barrier on a smaller scale this would create a strong foundation. The lessons learned therefore could be rolled out on a larger scale.

In summary however there was common consensus that policy and regulation will play as key a role as incentives when stimulating the uptake of heat pumps in the UK.

The present and near term situation

2.2.8 Summary of key findings

Table 5. Summary of key findings from literature review and consultation

Key Findings	Summary
Performance and sizing	<ul style="list-style-type: none"> Incorrectly sized heat pumps have resulted in poor performance impacting confidence. The second phase of the EST field trials demonstrated a significant performance improvement compared to phase 1. However a significant number of ASHPs still did not achieve the minimum SPF required to be considered renewable under the EU Renewable Energy Sources Directive
Awareness	<ul style="list-style-type: none"> Current awareness of heat pump technology remains low among domestic consumers. The point of contact for domestic consumers is the technician at the point of repair. The main trigger for investing in a new heating system is the breakdown of the existing system. Until the industry has confidence in heat pumps awareness will remain low, and continue to be a significant barrier towards the uptake of heat pumps.
Planning and noise	<ul style="list-style-type: none"> Elongated planning processes can delay the installation of commercial-scale GSHPs and therefore make them less attractive. Unless permitted development rights are addressed, noise from ASHP will represent a significant barrier, particularly in densely populated urban areas.
Suitability	<ul style="list-style-type: none"> Poor insulation also impacts the suitability of properties. Space constraints in buildings for ASHPs, and sufficient land for GSHPs impacts their respective suitabilities. Refurbishment costs associated with the installation of new emitters due to poor compatibility with the existing systems represent a significant barrier for certain property types.
Costs	<ul style="list-style-type: none"> There is little room for reducing the costs of heat pump systems as the majority of components are drawn from a mature HVAC market. Cost efficiencies exist in other areas of the supply chain e.g. borehole drilling and installation.
Confidence	<ul style="list-style-type: none"> The uncertainty surrounding government policy has had a negative impact delaying investment from industry. Displacing the incumbent gas grid will prove difficult as consumers are extremely comfortable with gas.
Supply and growth	<ul style="list-style-type: none"> A large manufacturing capacity exists in the UK which can already meet local demand. Supply constraints are associated with downstream elements of the supply chain such as a lack of trained installers.
Technological	<ul style="list-style-type: none"> There is a necessity for environmentally-friendly refrigerant which may require a change in European refrigerant standards (e.g. to phase-down or ban HFC refrigerants). This regulation could result in additional costs.

The present and near term situation

RHI	<ul style="list-style-type: none"> • The delay of the RHI scheme has had a negative impact on the heat pump market. • The launch of the domestic RHI is critical for kick-starting market growth. • There is a mixed attitude towards the level of tariff as some manufacturers believe one that is too high would inflate the market beyond a level of sustainable growth.
Network upgrading	<ul style="list-style-type: none"> • Clustering of heat pumps will result in the requirement for network upgrading by district network operators. This cost could potentially be passed onto consumers resulting in another barrier, although it is anticipated that these costs will be socialised.
Policy and Regulation	<ul style="list-style-type: none"> • Policies such as the Merton Rule have been a strong driver for ground source heat pump uptake in the past. • The heat pump uptake targets would be difficult to meet cost effectively through incentive schemes alone, and some form of regulation will be required to aid that targets are achieved.
Enabling measures and industry activities	<ul style="list-style-type: none"> • Manufacturers have developed control systems which reduce the consumer control element to help reduce performance issues from poor use. • Manufacturers have also developed online educational resources to improve awareness around heat pumps.
Renewable Heat Zones	<ul style="list-style-type: none"> • The creation of regional zones where each segment of the supply chain can be addressed individually will help to stimulate market growth and create a strong base which can be then rolled out.
Hybrid air source heat	<ul style="list-style-type: none"> • Hybrid air source heat pumps are expected to play a major role in the development of the heat pump market as the gas boiler component can deal with peak winter loads resulting in higher overall system SPF's.

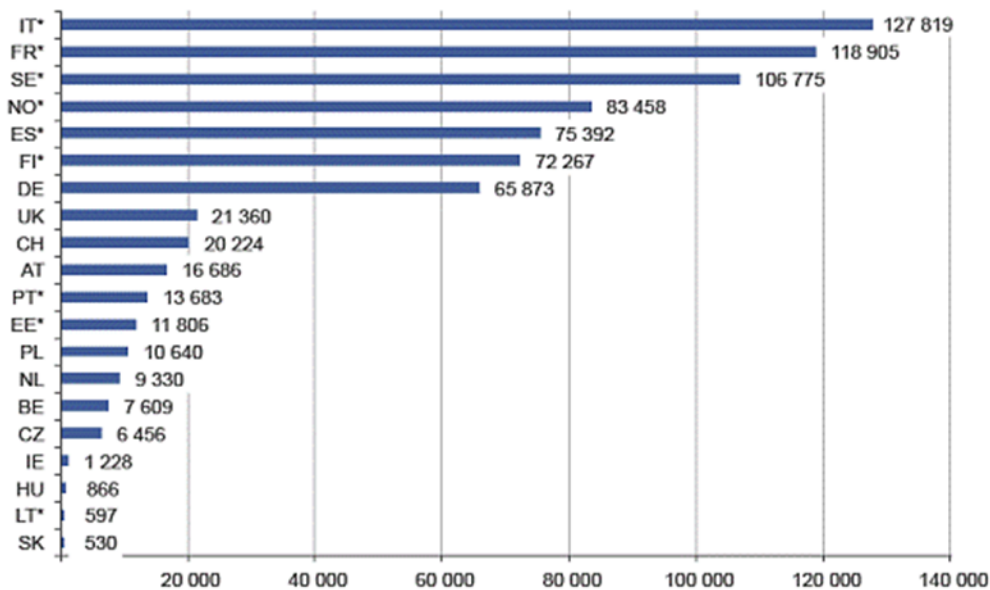
2.3 International markets and policy review

Compared to some international markets, the heat pump market in the UK is relatively immature. Therefore examination of the conditions that led to successful (or failed) establishment of heat pumps or similar heating technology as mainstream systems in other countries is useful. Information gleaned can be used to bound policy and uptake scenarios in the UK, and provide insight to effective policy, commercial, institutional and consumer arrangements.

The context of international approaches is often significantly different from the context in the UK, we have taken this into account when assessing measures. Importantly, policy instruments change frequently, and as such specific information presented here is simply a snapshot of arrangements covered in the reviewed literature.

Figure 6 shows installed heat pumps in European countries.

The present and near term situation

Figure 6. Installed heat pumps in European countries

On average, uptake of heat pumps has been accelerating over the past decade. In the rest of Europe this is largely motivated by energy efficiency and renewable energy ambitions, and underpinned by financial incentives, minimum standards regulation and labelling, long-term development of multiple-stakeholder partnerships, and progressive build-up of credibility and trust in the technology via effective quality control, information campaigns and independent testing. Prime examples of this success are apparent in Sweden and Switzerland, where heat pumps now occupy the largest market share of all heating system installations. Further useful examples can be taken from Netherlands, France, and North America.

2.3.1 National context and counterfactual technology

The UK heating market is currently dominated by piped natural gas, delivered via extensive distribution networks, and combusted in boilers to provide heat. This system is well-established, cheap, reliable and efficient, and is significantly different to the previously-incumbent infrastructure in the two other European countries where heat pumps have become dominant; Switzerland and Sweden. However, parallels to the UK situation do exist, most notably the Netherlands as shown in Table 6.

Table 6 demonstrates that a relationship between national context and heating market development clearly exists. The two countries where gas has become dominant (Netherlands, UK) benefitted from significant domestic gas reserves, gas infrastructure development aided by uptake of gas in power generation, and higher population densities enabling cost-effective rollout of gas distribution

infrastructure. Conversely, the two countries where heat pump uptake has been strong (Sweden, Switzerland) have relatively lower population densities, abundant electricity (largely hydro and nuclear), and negligible domestic gas reserves.

France also has negligible conventional gas reserves (and, at the time of writing, a moratorium on unconventional gas development), and reliance on nuclear power generation with low marginal cost undermining a gas power generation anchor that might aid gas infrastructure development. These elements of national context go a long way to explaining the relative success of various heating paradigms, and provide crucial background for interpretation of the success of policy measures in each jurisdiction.

Table 6. National context and counterfactual technology

Country	Heating fuel/technology	Country characteristics
UK	1970: Solid and Oil	Population density: High
	1990: Gas	Gas connections: 82%
	2010: Gas	Conv. gas reserves: Significant
Sweden	1970: Oil	Population density: Low
	1990: Electricity and District Heat	Gas connections: 1-2%
	2010: Heat Pump and District Heat	Conv. gas reserves: Negligible
Switzerland	1970: Oil	Population density: Intermediate
	1990: Oil and Gas	Gas connections: 35%
	2010: Heat Pump and Gas	Conv. gas reserves: Negligible
Netherlands	1970: Oil and Gas	Population density: Very high
	1990: Gas	Gas connections: 97%
	2010: Gas	Conv. gas reserves: Significant
France	1970: Coal / Biomass Solid	Population density: Intermediate
	1990: Oil and Gas	Gas connections: 41%
	2010: Oil, Gas, Biomass and Electricity	Conv. gas reserves: Negligible

Source: Adapted from Griffin (2000), EHPA (2010), IEA Statistics and Eurogas (2012)

The Netherlands and France have all shown strong uptake of heat pumps in recent years according to EHPA (2010). Based on the evidence available, this appears to have largely been driven by subsidy arrangements, where significant capital grants have been offered to offset the relatively high upfront cost of heat pumps. Capital grants through the RHPP (and CERT) have also been important in supporting the market in the UK over recent years. Further information on recent financial incentives is presented below.

The present and near term situation

2.3.2 Performance standards, labelling, and building regulations

A large portion of the heat produced by a heat pump can be considered renewable. In many jurisdictions, regulations to increase the share of renewable energy resources have matured over the past two decades, leading to the recent Renewable Energy directive (EC, 2009) and further instruments in Europe. Treatment of heat pumps is outlined in this directive (see Annex VII), specifying that in order to be included in output eligible against a country's target;

- heat pumps must reduce primary energy consumption by a reasonable margin, and
- only the renewable portion of a heat pump's output is counted (i.e. electricity consumption is netted off output).

A further relevant directive is the recast Energy Performance in Buildings Directive (EPBD) (EC, 2010). The EPBD requires Member States to establish procedures requiring consideration of heat pumps (among other measures) for new build or major renovations to buildings. Member States may also set minimum requirements for renewables in buildings, which was shown by Kiss et al (2012) to be crucial in creating a market for heat pumps in Switzerland: In 1997 the Zurich canton adopted a renewable energy standard for buildings requiring that no more than 80% of building energy requirements be served by non-renewable sources. Heat pumps were a competitive way to achieve this standard and thus gained significant market share. The standard was later adopted by the majority of cantons in Switzerland.

A similar and more recent example of renewable energy requirements in buildings is from Germany, where (since 2009) the federal renewable energy heat law (EEWärmeG) requires new build properties to source 50% of calculated heat load from renewables. This approach was extended in 2010 in the state of Baden-Württemberg where boiler replacement in existing residential buildings requires a 10% contribution from renewables. There are now plans to apply the requirement to non-residential buildings and to increase the contribution to 15% (EHPA 2010). Renewables requirements, specifically where they relate only to heat, can be a strong driver of heat pump adoption.

Performance standards and labelling are also an important element of regulations supporting heat pumps, providing an element of quality control and enabling information on performance to be disseminated to stakeholders. In Switzerland, Germany and Austria a labelling scheme was adopted for heat pumps called DACH in 1998, and was cited by Kiss et al (2012) as an important quality control measure, leading to increased confidence in the technology. Performance standards and labelling in Europe are set to be driven by the Ecodesign Directive (EC, 2009) and the Energy Labelling Directive (EC, 2010), with the EU Ecolabelling scheme also playing a role. Initial indications are that these initiatives will serve to promote heat pumps as efficient technologies.

2.3.3 Financial incentives

The vast majority of financial incentives available for heat pumps are in the form of grants, subsidies and tax reductions. All of these arrangements tend to reduce the capital cost of equipment and installation faced by the consumer, although timing of support varies on a case-by-case basis (i.e. some mechanisms offer support after capital outlay, some before). Due to the high upfront cost of heat pumps relative to other heating technologies, capital grants are an effective mechanism.

Table 7. Financial incentives in selected European countries as at 2010

Country	Instrument Type	Data	Notes
Belgium	Tax reduction	40%	Maximum €2770. SPF > 3.
Finland	Tax reduction	60% of labour costs	Maximum €3000
France	Tax reduction	40% of labour costs	Maximum €8000
Germany	Grant	€450 - €1200 air-source €900 - €2400 ground-source	SPF > 3.7 for air-source SPF > 4.2 for ground-source
Ireland	Grant	€2000 - €3500	Retrofit only
Italy	Tax reduction	55% of total cost, deducted in equal instalments over 5-years	High SPF requirements
Netherlands	Grant	€500/kW _{th}	Maximum €1000
Norway	Grant	€1100	Air-air systems excluded
Sweden	Tax reduction	50% of labour costs	Maximum €5000
UK	Grant	£1300 - £2300	Only applicable for properties off the gas distribution network

Source: Adapted from EHPA (2009), Menkveld and Beurskens (2009), EST (2013). Note that data is taken from a variety of sources relates to mechanisms available in a variety of difference time periods.

2.3.4 Technology procurement

As described in Kiss et al (2012) and Karlsson et al (2003) a technology procurement programme was operated in Sweden from 1993 to 1995. A “Buyer’s group” alongside Swedish Agency for Economic and Regional Growth ran a competition for manufacturers to produce HPs with improved characteristics – lower cost and higher efficiency. The buyer’s group guaranteed to purchase at least 2,000 of the systems. Following the procurement programme, on-average annual growth in heat pump installations in Sweden was 35%.

The present and near term situation

The procurement programme was balanced across purchase of systems and other activities. Kiss et al (2012) noted that 25% of this procurement budget was used for evaluation of installations, and 50% for information dissemination activities. This balance was cited as an important driver building confidence in the technologies and dispelling some negative perceptions present at the time.

2.3.5 Heat pump associations

The formation, support for and effectiveness of stakeholder associations are frequently cited as important catalysts for technology introduction. These organisations can serve to:

- coordinate, align and share activity and best practice in the technology supply chain;
- focus research and development activity on market requirements, and facilitate dissemination of and participation in international initiatives;
- avoid expensive duplication and information-related misunderstanding by maintaining and/or facilitating common facilities, methodologies and benchmarks for testing and labelling;
- raise consumer awareness and trust in unfamiliar technology; and
- enable a diverse set of policy decision makers to participate and align support measures.

Rognon (2008) and Kiss et al (2012) have presented a view of the importance of these organisations in Sweden and Switzerland, and the EHPA (2009) provides information about organisations in other European countries. Box 1 presents the history and structure of the key examples.

Box 1: Heat pump associations

The **Swiss Heat Pump Association** (FWS) was founded in 1993 by the Swiss Federal Office of Energy (SFOE). It acted as a “platform” for engineers, contractors, manufacturers, energy-suppliers and government. SFOE initially managed budget and contracts, but later FWS became more independent in setting and managing work, although budget still controlled by SFOE. After an initial attempt at subsidisation in 1993 – 1995 (approx. €1,600 subsidy per installation, 1995 basis), SFOE/FWS favoured training and testing as the key approach. For example, FWS established a test centre and organised local training and information events with installers, manufacturers, and utilities. A “heat pump doctor” also operates from FWS, offering a complaints service to rectify manufacturing or installation faults.

The **Swedish Heat Pump Association** (SVEP) was founded in 1981 and organises 700 members, including manufacturers, installers, drilling companies, and others. There is no direct government involvement. It is the focal point of activity for new legislation and standards, coordinates national research, and organises/disseminates international initiatives (EHPA, 2009). SVEP also administers a consumer complaints board since 1989, which handles approximately 80 cases per year.

2.4.1 Summary of key findings

Table 8. Summary of key findings from international markets and policy review

Key Findings	Summary
National context and counterfactual technology	<ul style="list-style-type: none"> Countries where heat pump uptake has been strong (Sweden, Switzerland, France) tend to have low population densities, abundant hydro or nuclear electricity and negligible domestic gas reserves.
Performance standards, labelling and building regulations	<ul style="list-style-type: none"> In Switzerland and Germany renewable energy standards on new buildings have helped drive uptake of heat pumps. Performance standards and labelling schemes have been used in Switzerland, Germany and Austria leading to increased consumer confidence in heat pumps.
Financial incentives	<ul style="list-style-type: none"> In other countries subsidies (or tax breaks) which reduce the capital cost facing the consumer have been the most prominent.
Technology procurement	<ul style="list-style-type: none"> In Sweden mass procurement of 2000 heat pumps with improved characteristics help stimulate the market in the 1990s.
Heat pump associations	<ul style="list-style-type: none"> The role of industry associations in coordinating activity and raising consumer awareness is frequently cited an important factor in Switzerland and Sweden.

3 The current and critical pathways

In this section, we first describe the pathway for the uptake of heat pumps to 2030 under current baseline policies. We then show how this compares to a critical path (which is the minimum level of heat pump uptake required to allow 2050 targets to be met with a high contribution from heat pumps) and a cost-effective path (which is the pathway consistent with meeting carbon targets at least cost in the CCC ‘Stretch’ scenario). This allows us to judge the extent to which new and additional policy measures are required up to 2030 to allow 2050 targets on heat pump uptake to be met.

Pathways described in this section

In this section we describe three pathways for heat pump uptake.

Current policy path. The level of uptake projected under current baseline policy assumptions.

“Critical path”. The minimum level of heat pump roll-out needed to keep open the possibility of achieving levels of heat pump penetration consistent with the CCC ‘Stretch’ scenario in 2050.

“Cost-effective path” under the CCC ‘Stretch’ scenario. The pathway of heat pump roll-out that is estimated to meet the 2050 and interim carbon targets cost-effectively (assuming a rising carbon price in line with DECC projections). This path is based on ‘top-down’ cost-minimisation modelling for the CCC for the Fourth Carbon Budget.

3.2 The current policy pathway

The current policy pathway has been modelled using a willingness-to-pay modelling methodology. This model was developed for an earlier study for the Committee on Climate Change and has been revised for this study²¹. The key revisions have been to incorporate new data published since the earlier work, for example on technology costs and performance, and gathered through the industry consultation.

3.2.1 Modelling methodology

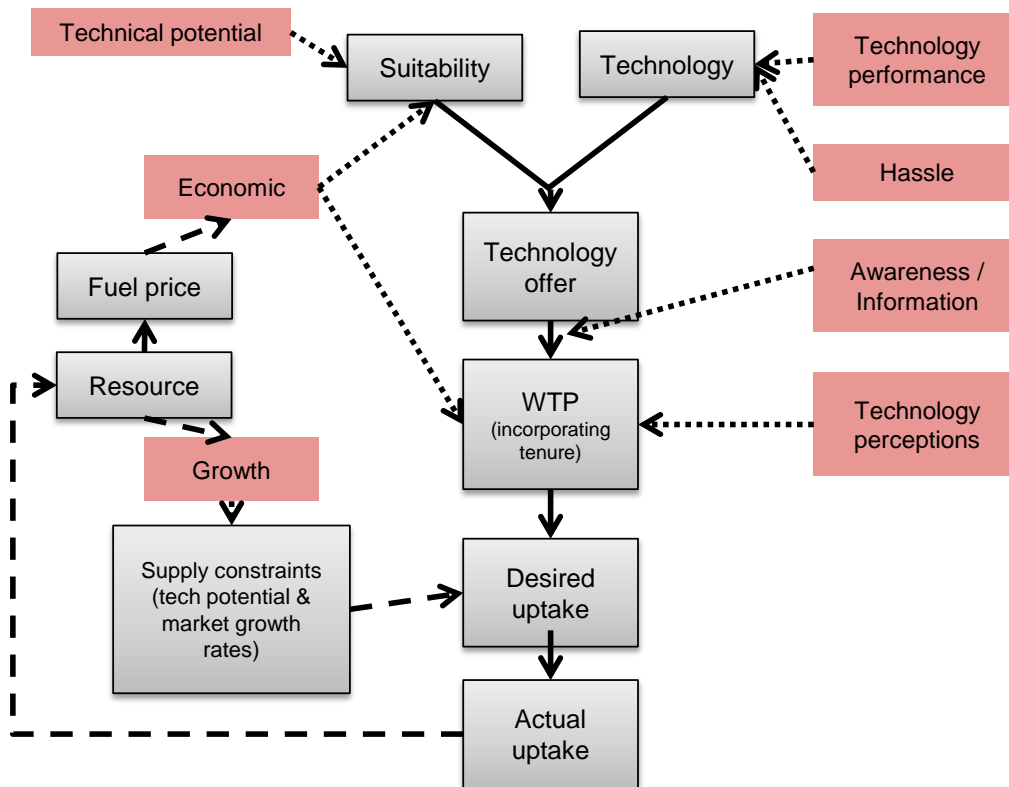
A quantitative uptake modelling approach was used to provide insights into the rate of uptake of heat pumps that might result under different policy scenarios.

²¹ Element Energy and NERA (2010) *Achieving deployment of renewable heat*

Where possible, the barriers to uptake have been implemented quantitatively within the model, for example as an increase in the installation costs, in order to explore the severity of the impact of barriers on uptake.

A simple schematic of the modelling approach is shown in the figure below.

Figure 7. Simplified schematic of the modelling approach and the points within the model that various barriers are implemented



The model contains a highly simplified representation of the building stock, based on a limited set of domestic and non-domestic building archetypes. The cost-effectiveness of heat pumps in each of these building archetypes, or market segments, is calculated through time, based on a set of technology performance characteristics, technology cost projections and energy price projections²².

The cost-effectiveness of heat pump technologies represents a ‘technology offer’ to the consumer. For each market segment, the consumer’s attitude toward investing in a new heating appliance is represented by their Willingness-to-Pay (WTP) curve. The WTP curve attempts to describe how required hurdle rates

²² Technology cost and performance assumptions are based on review of the available literature and the consultation with heat pump manufacturers. Energy price assumptions are based on DECC projections (www.gov.uk/government/policies/using-evidence-and-analysis-to-inform-energy-and-climate-change-policies/supporting-pages/policy-appraisal)

The current and critical pathways

are distributed through the population of consumers within each market segment. This distribution dictates the proportion of the population of consumers that will take up a heat pump given a particular technology offer, i.e. those consumers whose hurdle rates are exceeded by the return on investment offered are assumed to be willing to purchase the technology. The rate at which the technology is taken up among these willing consumers is dependent on the frequency with which they make a purchase of a new heating appliance. The period between purchases is assumed to be equivalent to the lifetime of the technology, i.e. consumers only purchase a new heating system when their existing system is at the end of its life.

Barriers to uptake can be represented within this modelling methodology in a number of ways:

- **Additional costs** – Certain barriers can be represented as an increase in the capital or operating costs.
- **Consumer behaviour** – Changes to the way consumers view a particular proposition can be represented by changes to the willingness to pay curve.
- **Supply and demand restrictions** – Barriers can be represented as the rate at which consumers consider making a purchase of a heat pump, the proportion of a particular segment of the stock that is assumed to be suitable for a heat pump installation or, on the supply-side, the capacity of the supply chain and the rate at which this can grow.

The model seeks to quantify the impact of a range of barriers on the rate of uptake of heat pumps in both the domestic and commercial sectors. The manner in which barriers are applied depends on the nature of the barrier, but are broadly implemented by adjusting the following parameters shown in Figure 8.

Figure 8. Implementation of barriers in uptake modelling

Parameter	Flexibility	Related barriers
Cost	Refurbishment cost	The requirement to modify the heating system for compatibility with a lower flow temperature, for example fitting larger radiators and replacing the hot-water cylinder.
	Hassle cost	The inconvenience associated with heating system refurbishment works, loss of space due to hot-water cylinder installation and ground works in the garden for ground source heat pumps are represented as a 'hassle cost'.
	Time to research new technology	Consumers are assumed to spend time researching heat pumps, due to limited initial familiarity with the technology. A value is placed on the time spent (this is a kind of hassle cost).
	Poor performance	There is evidence that heat pumps, air source in particular, have performed below manufacturer's specifications in real installations. This results in an increased operating cost.
Consumer behaviour	Confidence	Due to a lack of confidence in the performance of the technology (e.g. uncertainty over the technology lifetime), consumers are assumed to apply higher hurdle rates (i.e. shorter payback) than they might for more familiar technologies.
Demand side	Awareness	Due to low initial levels of familiarity with the technology, not all consumers making a purchasing decision are assumed to consider heat pumps, i.e. they are excluded from a proportion of the market assumed to be unaware. The awareness barrier would be expected to diminish over time if heat pumps proliferate through the stock.

	Suitability	Within each market segment, i.e. each building type, there is assumed to be a limit on the proportion of the stock that is suitable for installation of a heat pump. Constraints on suitability could result from incompatibility of heat pump characteristics with the heat demand or heat distribution system, lack of space for the heat pump, the ground array or ancillaries such as a hot-water tank, planning restrictions due to noise or aesthetic issues. Suitability could improve over time, for example as a result of upgrades to the thermal performance of dwellings.
	Aesthetics and noise	This applies specifically to air source heat pumps. The restrictions to permitted development rights based on potential noise impacts on neighbouring buildings could be a barrier to air source heat pumps, particularly in more built up areas. The visual impact of external heat exchangers could also result in planning restrictions in certain areas.
Supply-side	Growth rate	There is assumed to be a limit on the rate at which the market can grow year-on-year due to the time taken to build capacity in the supply chain. This could include, for example, training new installers, investment in new drilling rigs for ground source installations etc. Note that a shortage of trained installers could be linked with poor performance of heat pump installations, which results in a direct cost impact.

Source: Element Energy

Further detail on the assumptions used in the model to quantify each of these barriers is given in Figure 9.

Figure 9. Barrier assumptions

Barrier	Base case assumption	Evidence / Reference
Awareness	47% of decision-makers are aware of the technology at the outset. Awareness increases over time as the technologies are taken up (based on a diffusion factor)	This level of awareness of heat pumps is in line with findings of the EST / Ipsos Mori survey results. The implementation of an awareness barrier in the base case is a variation from the assumptions used in the 2010 EE / NERA study, which assumed no awareness barrier in the base case. Note that the rate of diffusion of awareness assumed in the base case is such that at the levels of uptake seen in the Current Policy Path, 100% of consumers are aware by 2020.
Time to research new Tech	Cost uplift is based on £31.59 hourly rate, and 8 hours for each technology	The time to research new technologies barrier is consistent with the EE/NERA study. Originally this is adapted from a 2006 Enviro study (REF).
Suitability	Central case suitability factors have been used. Suitability in solid-wall insulated homes is assumed to increase over time based on the CCC's high scenario assumptions for solid-wall insulation uptake (5.7m homes treated by 2030). Note that this is an upper-bound assumption on the rate of uptake	Suitability factors used are based on initial work by AEA / NERA, which were also adopted in the EE / NERA 2010 study. The suitability factors have been updated for this work in line with the more recent RHI Phase 2 assumptions document (AEA, 2012), where new data is available. Note that earlier studies have not assessed suitability for hybrid heat pumps. The constraints considered in the suitability factors include physical space, the compatibility of the heat output with the thermal demands of the application and environmental factors such as noise or visual impact. While space and environmental factors are likely to be largely applicable to hybrids (note that some manufacturers offer combi hybrid products which may alleviate space concerns to an extent), compatibility with thermal demands and existing heating systems are likely pose less of a constraint. Suitabilities

The current and critical pathways

	of solid wall insulation.	in the case of hybrids have therefore been relaxed (15% additional suitability).
Confidence	Varying levels of confidence in the technology are represented using the Willingness to Pay curves as differing attitudes toward the payback period required, e.g. a lesser level of confidence is represented with a more rapid payback requirement (or higher hurdle rate) for investment).	Willingness to pay (WTP) curves for owner-occupiers are based on quantitative consumer survey work undertaken for an Element Energy analysis into the impact of various policy interventions on the uptake rate of a range of microgeneration technologies. The WTP curves for social landlords and commercial / public consumers have been generated assuming a more rational approach to investing (i.e. 50% of the consumer population invest at a standard social or commercial hurdle rate).
Heating System Refurbishment	<p>£275/kW added in the Base Case. This is the cost associated with replacing heat emitters, the hot-water cylinder and so on, in order to adapt the heating distribution system to the heat pump.</p> <p>In the case of hybrid heat pumps the cost of heating system refurbishment was reduced by 50%. This reflects an assumption that while some refurbishment will be required to optimise heat</p>	<p>This figure has been taken from the RHI Phase 2 Assumptions document. While this cost was provided in the context of ASHP retrofit, it has also been applied in this study to GSHP. It was raised in the consultation that a lesser cost may need to be incurred in case of ground source heat pump installations as the higher efficiency of the technology means that a less optimal matching can be tolerated, and also that existing radiator systems are often oversized, such that in some cases it won't be necessary to fit larger radiators. These points were considered too anecdotal to influence the base case. Note that no heating system refurbishment cost is applied in the case of new build consumer types.</p>

The current and critical pathways

	<p>pump operation, this will be limited by the flexibility to operate the boiler at peak heating periods.</p>	
Aesthetics & Noise Concerns	<p>For a low Aesthetic and Noise barrier a 15% reduction is applied to the suitability of suburban property types and a 25% reduction for urban property types. This reduction is included in the Base Case.</p> <p>A high barrier scenario of 30% and 50% reduction in suitability applied respectively to suburban and urban properties is also included in the model.</p>	<p>There is limited data available to permit an assessment of the impact of noise on heat pump suitability in built up areas. As a result, this was not included in the base case assessment in the EE / NERA study. However, on the basis of research demonstrating that noise could be a significant constraint (assuming Permitted Development Rights thresholds are upheld), the low noise barrier has been included in the base case, providing a more conservative assessment of ASHP suitability to the stock (note that the aesthetics and noise barrier does not impact suitability for GSHPs).</p>
Heat pump performance	<p>SPFs for heat pumps have been set in the range of 2.5 to 2.75 for ASHP and 3.2 to 3.8 for GSHP systems in the domestic sector (higher in commercial applications). No improvement is assumed over time in the base case.</p>	<p>The initial SPFs are broadly in line with those measured during the EST Phase 2 field trials (slightly higher on average, although this is justifiable given the refurbishment cost included). The highest SPFs have been designated in the new build house types, on the basis that the heat emitter system can be designed for the heat pump characteristics (a low space heating component of the demand will act against this assumption).</p>

The current and critical pathways

Supply	In the emerging phase an 80% per year growth rate is permitted. This drops to 60% in the growing and 30% in the maturity years.	The market growth rates used are consistent with the High rates of growth used in the EE / NERA study (based originally on work by NERA for the CCC ²³). The use of the higher bound growth rates for this study is justified on the basis of the consultation interviews, where the view was expressed by a number of respondents that, given the demand, the industry would be able to respond rapidly (any supply constraints are related to potential shortage of trained installers rather than manufacturing capacity, which was dismissed as a barrier by the majority of respondents). Note that emergence of non-specialist or unskilled heat pump installers was raised as a potential risk of rapid expansion of the heat pump market (it is felt that this is adequately covered in the base case by reasonably conservative estimates on Seasonal Performance Factors).
---------------	---	--

Source: Element Energy

²³ Decarbonising Heat: Low-carbon heat scenarios for the 2020s, Report for the CCC, NERA & AEA, June 2010,

3.2.2 Other key assumptions

The rate of heat pump uptake forecast by the model is determined by the calculation of cost-effectiveness and how this changes over time. Cost-effectiveness is highly dependent on the assumptions regarding capital costs and operating costs, which in turn depend on the assumptions regarding heat pump performance (load factor and efficiency). Fuel price assumptions are also a key influence on operating costs and cost-effectiveness.

Capital cost data

The capital cost assumptions used in the modelling are based on a number of published sources and data provided through the consultation with manufacturers.

The most recent resource on the installed cost of heat pumps is the Sweett Group report for DECC²⁴. This report provides cost data over a large range of sizes for each type of heat pump, however the majority of samples collected were for ASHP ATW systems smaller than 20kW (33 out of a total of 35), and GSHP systems smaller than 75kW (90 out of 93). For ASHP ATA systems data was collected for a total of 5 samples. Further cost estimates are provided in the RHI Phase II assumptions report (AEA 2012), which informed the consultation on the non-domestic tariff review and the domestic RHI proposals.

The capital cost assumptions used in this study for ASHP ATW systems are taken from the AEA report, as this provided the clearer breakdown between costs attributed to the heat pump and to refurbishment of the heating distribution system (e.g. replacing emitters). These costs compare closely to the costs reported in the Sweett Group report over the lower capacity range, although are slightly higher at >10 kW scale. The costs used for GSHP systems are based on information provided by manufacturers during the consultation interviews. The same refurbishment cost (i.e. £ 275 /kW) has been added to these costs. The net result of this is GSHP costs that are very closely comparable with the costs provided in the Sweett report for ground source systems. There is little cost data available for hybrid systems. To derive capital cost estimates for hybrids the cost per kW for ASHP systems has been used with an assumption that a smaller capacity heat pump will be installed. We have assumed that the heat pump capacity can be reduced by one third compared to a pure ASHP system in the same property. In addition, the cost of a gas or oil boiler replacement is included, with a reduction for shared installation costs. The cost of refurbishing heating systems for installation of a hybrid system has been

²⁴ Research on the costs and performance of heating and cooling technologies, Sweett Group for DECC, 21st February 2013

The current and critical pathways

assumed to be lower than in the case of a single heat pump system, as the boiler can provide higher flow temperatures to meet peak heat demands. In the absence of any data on installed costs for hybrid systems, a 50% reduction in the cost of heating system refurbishment has been made.

The comparison of cost data used in this study to the various other sources is shown in Figure 10.

Reductions in capital costs of heat pump technologies of around 10% over the period to 2030 are assumed in the modelling. This relatively modest forecast for cost reduction is consistent with learning rates provided in the Sweett Group report (based on the 'medium' learning rate scenario).

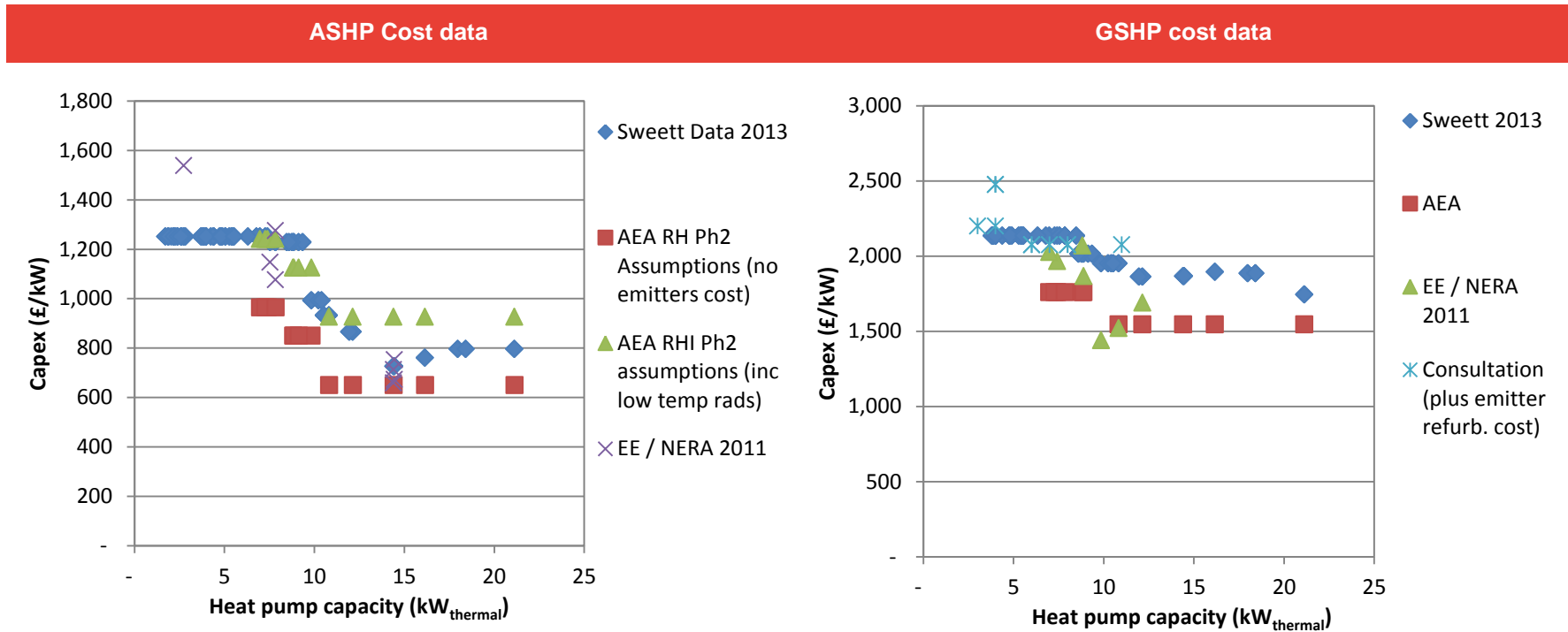


Figure 10. Comparison of capital cost assumptions with data from a range of published sources (based on current cost data). Cost of heating system refurbishment (e.g. changed to emitters) are included in the cost, unless stated otherwise.

The current and critical pathways

Load factor data

Cost-effectiveness is highly dependent on the assumptions regarding the load factor achieved. In reality, the capacity of heat pump required in a particular property is dependent on the heat loss rate of the building²⁵ and the load factor will then depend on the building's thermal load profile. In the model, the capacity of heat pump required for each building archetype is derived from the annual thermal load of the building and an assumption regarding the load factor of the heat pump. The heat pump capacity and therefore capital cost of the heat pump is very sensitive to the load profile assumption.

The load factors used in this study have been based on those used in the Sweett Group report on cost and performance of heating and cooling technologies. These load factors are somewhat higher than the assumptions used in the previous EE / NERA work on achieving deployment of renewable heat (particularly for domestic systems), resulting in lower estimations of required capacity for particular building archetypes. The sensitivity of cost-effectiveness and uptake rate to these load factor assumptions is explored.

Seasonal Performance Factors (SPF)

SPFs in the range from 2.5 to 2.75 have been applied to domestic scale ASHP ATW systems and from 3.1 to 3.8 for GSHP systems. These SPFs are lower than those assumed in other work supporting the development of the RHI, for example an efficiency of 320% for ATW systems is given in the RHI Phase II technology assumptions publication, but are still higher than the system efficiencies measured during the EST heat pump field trials²⁶. The higher assumed efficiency compared to the EST field trials can be justified on the basis of the significant allowance for modification to the heating distribution system (i.e. £ 275 /kW). Experience in more mature heat pump markets also suggests that higher system efficiencies than those recorded in the EST field trials should be achieved with well-designed and properly installed systems, although direct comparison is not possible given the different climatic conditions and thermal performance of buildings. Sensitivity to the assumed SPF will also be explored.

²⁵ Following Microgeneration Installation Standard 3005, the heat pump should be sized to meet 100% of the space heating requirement. The space heating requirement is defined as the heating output necessary to achieve a specified internal design temperature for 99% of the heating season.

²⁶ Note that the SPFs used in this research are broadly in line with those used in earlier research published by the CCC, Decarbonising Heat: Low-carbon heat scenarios for the 2020s, Report for the CCC, NERA & AEA, June 2010

Improvements to the suitability for heat pumps

The heat loss rate of the dwelling is one of the factors that have been considered in defining the suitability of the dwelling stock for heat pumps. Dwellings with high heat loss are assumed to be less well-suited to a low temperature heat distribution system and therefore less suitable for heat pumps. On this basis, the suitability factors applied in the modelling to the solid-walled segment of the housing stock are comparatively low.

A number of policy initiatives are currently in place that aim to increase the uptake of solid wall insulation, in particular the Energy Company Obligation (ECO) and Green Deal. As the thermal performance of solid-walled homes is improved by insulating, so their suitability for heat pumps should also increase. This is captured in the uptake model as an improvement in the suitability of the solid-walled segment of the housing stock over time, at a rate linked to the assumed rate of uptake of solid-wall insulation. The assumed rate of uptake of solid-wall insulation is based on the CCC's high scenario, which is relatively aggressive. In this scenario, 5.7 million solid walled homes are insulated by 2030. We explored a number of less aggressive assumptions for solid-wall insulation uptake. The uptake trajectories over the period to 2030 have been found to be relatively insensitive to these assumptions.

At the current early stages of the ECO and Green Deal policies, there is significant uncertainty surrounding the rate of uptake of solid wall insulation that will be delivered in practice. If a lower rate of uptake is observed than has been assumed in this modelling work, then the rate of improvement in suitability factor for heat pumps in the relevant segments of the stock should be revised and the cost-effective pathway for heat pump uptake reviewed.

Fuel price assumptions

The fuel price assumptions used in the uptake modelling aspects of this work are based on DECC Updated Energy & Emissions Projections²⁷. Unless otherwise stated, the DECC Central price scenarios have been used (the residential price projections are applied to domestic sector and the service sector price projections are applied to the non-domestic segments). No distinction between peak and off-peak electricity consumption has been assumed, except in the case of house types with an electric counterfactual. In these cases an Economy 7 tariff has been assumed (assumed to be a 50% reduction in the unit tariff).

Retail prices are used within the willingness-to-pay model, as these reflect the prices considered by consumers in their decision-making. The calculation of

²⁷ DECC UEP Annexe F, October 2012

The current and critical pathways

resource costs associated with heat pump deployment is based on the long-run variable costs (LRVC) of energy, which excludes the suppliers' retail margins²⁸.

3.2.3 Uptake in the current policy pathway

The current policy pathway has been modelled using the barrier assumptions shown in Figure 9. The RHI is the only policy intervention included in the current policy path^{29 30}. The following tariffs have been modelled:

Table 9. Initial RHI tariffs assumed in the current policy modelling

	Domestic	Non-domestic
Air source	7.3 p/kWh	2.5 p/kWh
Ground source	18.8 p/kWh	8.2 p/kWh

The RHI is assumed to be offered for new heat pump installations over the period to 2020 (from 2014 in the domestic sector). The RHI payments are calculated for the renewable heat output of the heat pump systems only (i.e. the electricity input subtracted from the total heat output). Furthermore the renewable heat outputs are calculated based on design SPF's for ASHPs and GSHPs presented in the MCS heat emitter guide for 4 star systems. The design SPF's used are 300% for ASHPs, and 370% for GSHPs.

The tariff is degressed between 2014 and 2020 if the annual uptake exceeds DECC's expected uptake trajectory, as published in the RHI Phase 2 Impact Assessment³¹.

The uptake under the current policy pathway assumptions is shown in the figure below.

²⁸ DECC IAG supplementary guidance, Toolkit tables, Tables 9-13

²⁹ Note that insulation of solid wall dwellings in line with the CCC's high scenario for SWI uptake has also been included in the current policy path. This assumes that 5.5m solid wall homes will be insulated over the period to 2030 (from 2005 technical potential). SWI insulation is assumed to increase suitability for heat pumps.

³⁰ The SPF's assumed in the current policy path are also consistent with the assumption that the Microgeneration Certification Scheme heat pump sizing guidelines are applied.

³¹ Renewable Heat Incentive – Domestic, IA No: DECC0099, DECC, 18/09/2012

Figure 11. Projected uptake of heat pumps in the domestic sector in the current policy pathway

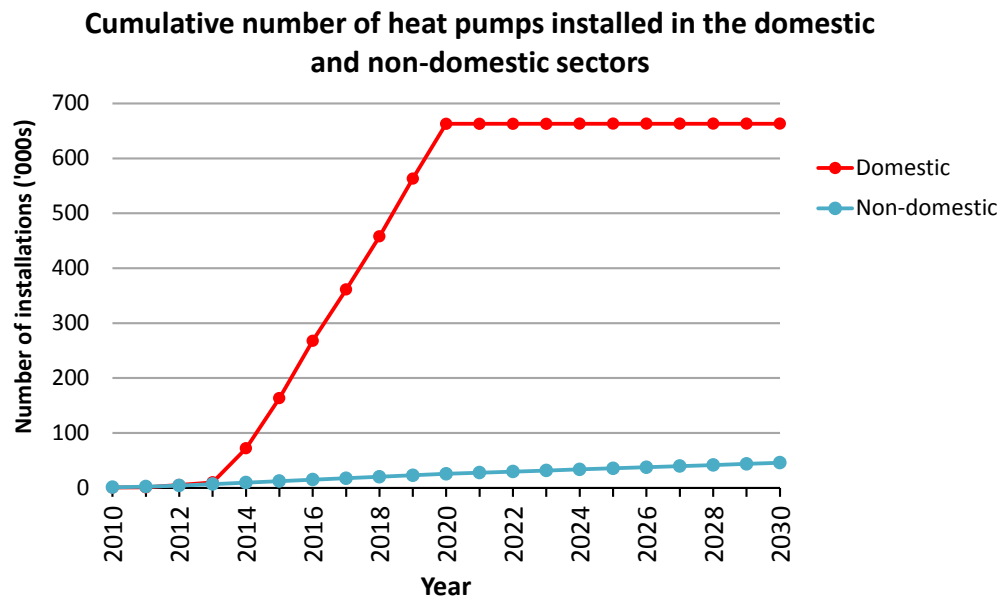
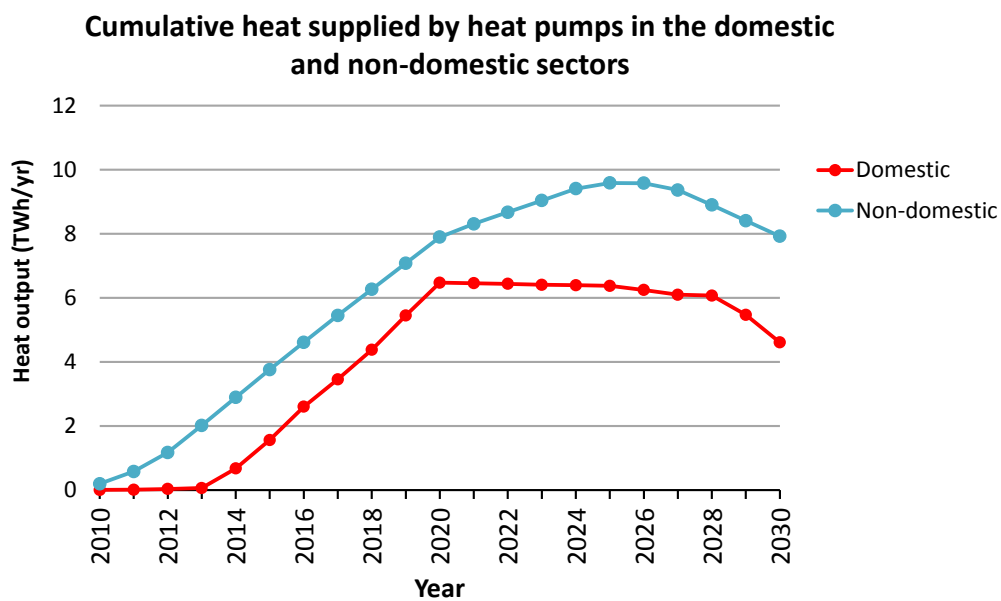


Figure 12. Projected heat supplied by heat pumps operational in the domestic and non-domestic sectors in the current policy pathway



- The cumulative number of heat pumps installed in the current policy path reaches just under 700,000 in 2020.
- Around 660,000 of these heat pumps are in the domestic sector.

The current and critical pathways

- Although the market is dominated by the domestic sector in terms of units installed, heat pumps in the non-domestic sector is responsible for the larger quantity of heat output.
- The domestic market is dependent on the RHI. The annual market drops back to a few thousand units per year after 2020.
- The market in the commercial sector does survive post RHI, mainly based on air to air heat pumps uptake (which is steady throughout the period, despite lack of support under the RHI).

In terms of the split between technologies, the model predicts that the uptake will be dominated by air to water heat pumps, as shown in the figure below. This is due to shorter simple paybacks for the air to water technology, which translates to higher uptake in the willingness to pay model, as discussed in the following section.

Figure 13. Split of current policy uptake between heat pump technologies in the domestic sector

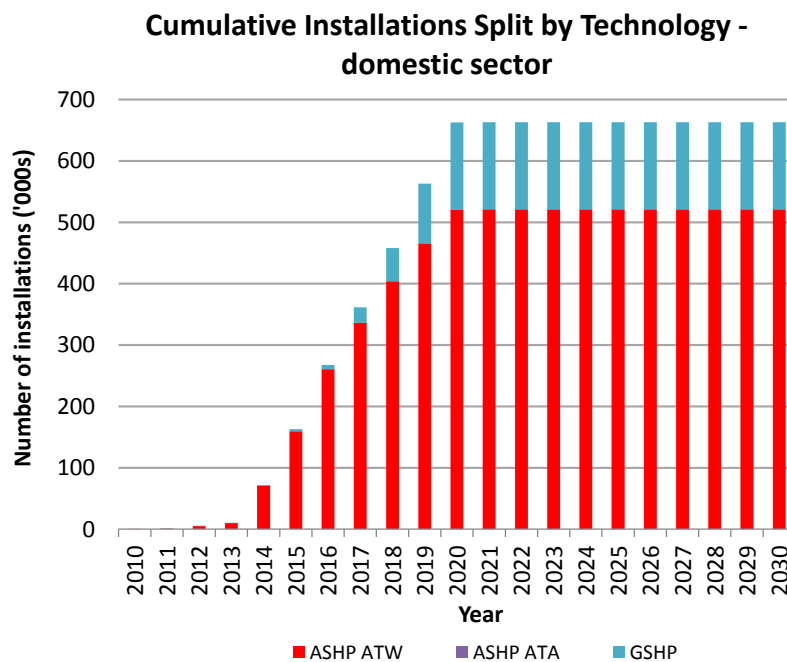
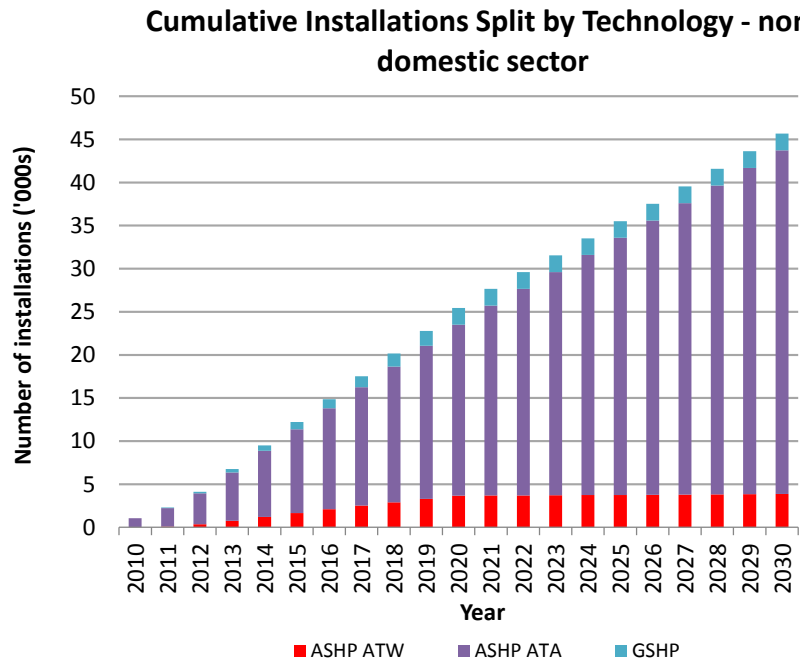


Figure 14. Split of heat pump uptake by technology type in the non-domestic sector

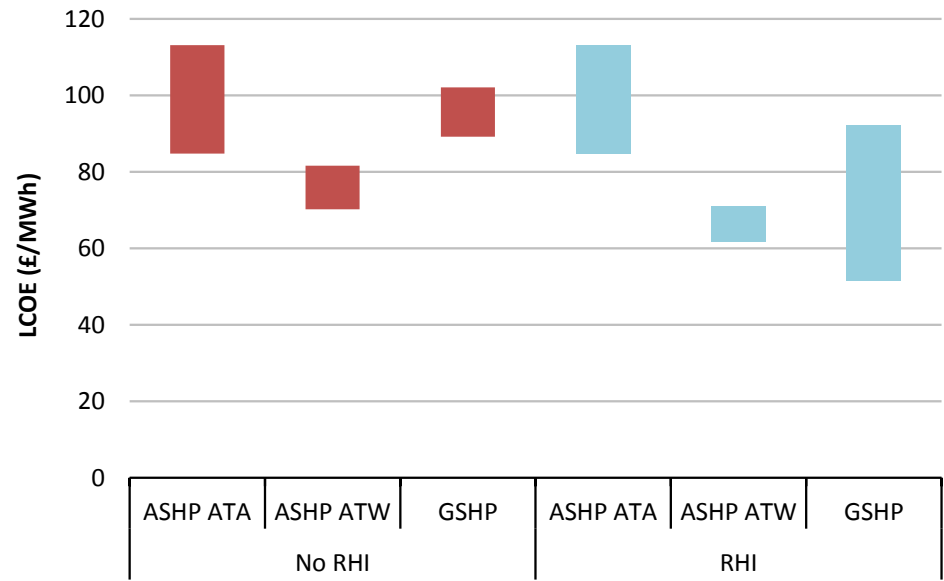
3.2.4 Cost-effectiveness of heat pump technologies in the current policy path

While the difference in uptake between air to water and ground source technologies appears heavily favour air source in the results presented above, it is informative to look more closely at the economics of the technologies.

The chart below compares the ranges of levelised cost of energy (LCOE) for the three technologies. The LCOE are calculated under 2017 cost assumptions, i.e. in the middle of the RHI period.

The current and critical pathways

Figure 15. Ranges of levelised cost of energy for heat pump options in the domestic sector (based on 2017 costs).



The LCOE comparison indicates that the economic proposition is less clear-cut than the uptake projections might suggest. Under RHI support the range of LCOE is wider for ground source technologies, but is lower than that of the air source options in some segments of the domestic stock³².

Further insight into the varying attractiveness of the technology options across the consumer segments can be gained by consideration of how the uptake is spread across the consumer types. This is shown in the charts below for the air to water and ground source technologies in the domestic sector.

³² Note that the ranges in the chart highlight the spread between minimum and maximum LCOE across the house types. This includes the new build house types, which do not receive an RHI, leading to a wide range (particularly in the case of GSHP).

Figure 16. Split of annual air to water heat pump uptake between domestic consumer types

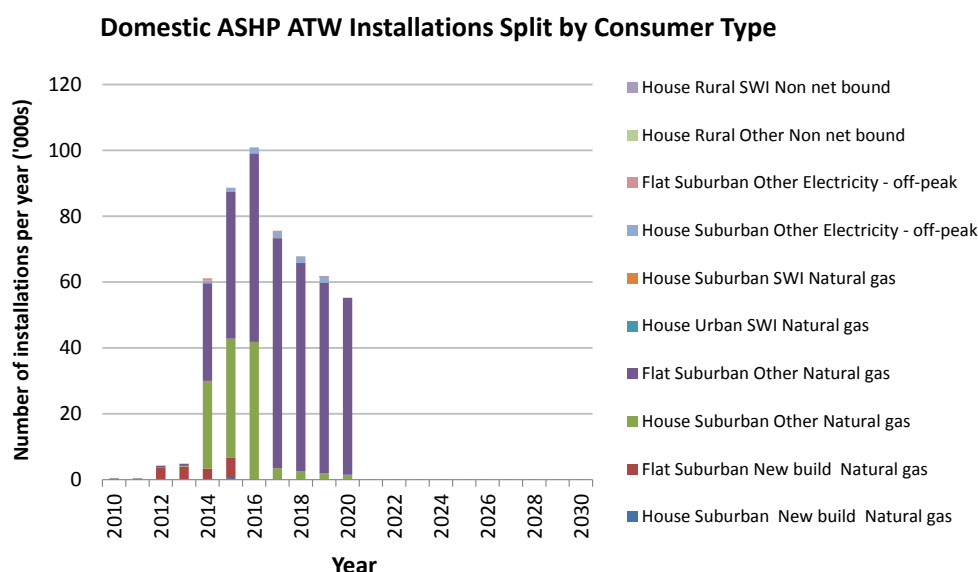
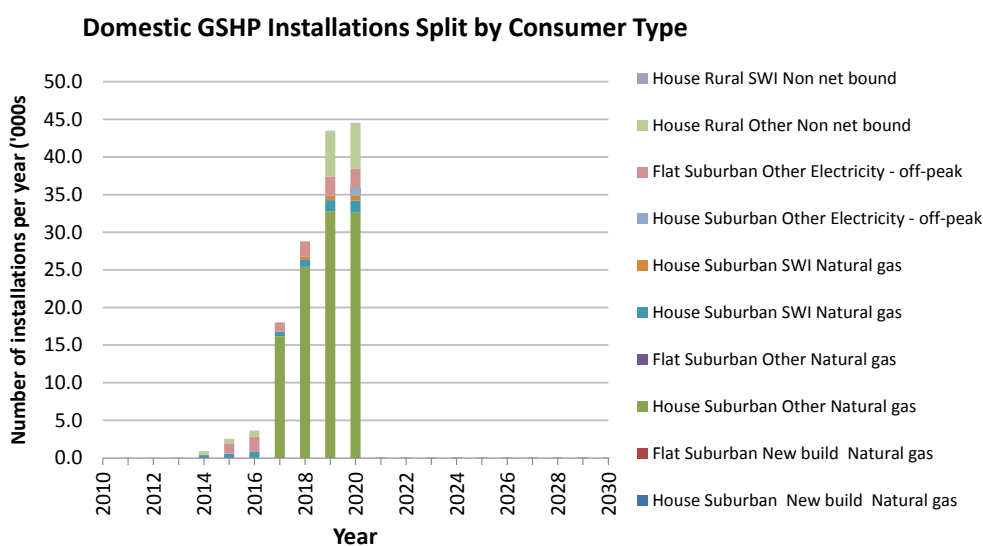


Figure 17. Split of annual ground source heat pump uptake between the domestic consumer types

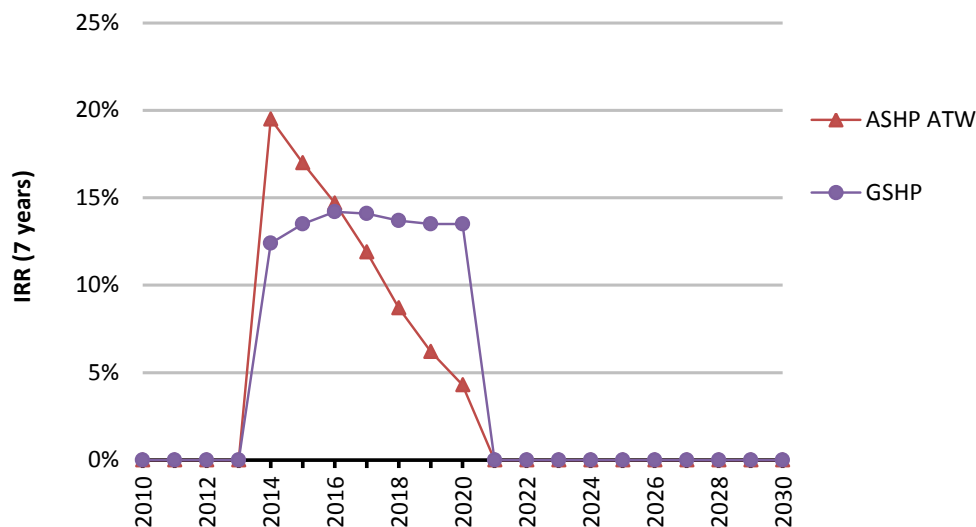


Perhaps surprisingly, the modelled uptake is dominated by the on-gas, suburban flats and houses (this is in part because these are the largest sectors in terms of overall numbers of consumers). Uptake of ground source systems is also predicted in the rural, off-gas segments of the market. There is very little heat pump uptake in the new build sector, which is consistent with the lack of RHI for these consumers (note that zero carbon homes policy is not modelled in the Current Policy Path).

The current and critical pathways

The analysis of heat pump uptake by consumer type in the domestic sector has predicted that there will be a mix of ground source and air source heat pump uptake in on-gas suburban houses. This suggests that the cost-effectiveness of the two technologies is reasonably close in this segment of the market (when incentivised by the RHI). This can be highlighted by comparing the rate of return on investment in the competing heat pump technologies in this sector of the market, as shown in the figure below.

Figure 18. Comparison of the variation in rate of return (IRR) on investment in heat pumps in the on-gas suburban houses (cavity-wall) segment of the market.



In the plot above, the rate of return (IRR) is calculated on investment in the additional capex compared to the counterfactual over the seven years that RHI payments are received³³. At the start of the domestic RHI policy in 2014 the ASHP becomes the more favourable technology, achieving an IRR that would be consistent with high levels of uptake. Over time, the IRR for ASHP systems drops, while for GSHP the return on investment stays reasonably constant over the period to 2020 (once the RHI policy elapses, neither technology provides a positive rate of return). The drop in ASHP rate of return is a result of the degression of the tariff over this period. This comparison of rates of return is consistent with the consumer type splits for each technology seen in Figure 16 and Figure 17, i.e. ASHP uptake in the initial years of the RHI and increasing levels of GSHP uptake over time.

³³ Note that the IRR figures are calculated only on the basis of the additional capex compared to the counterfactual, resulting in high figures for IRR under the RHI

The uptake modelled in the on-gas flats and off-gas, rural houses can also be explained by comparing the rates of return for each technology under the RHI, as shown in the plots below.

Figure 19. Comparison of the variation in rate of return (IRR) on investment in heat pumps in the on-gas, flats (cavity-wall) segment of the market.

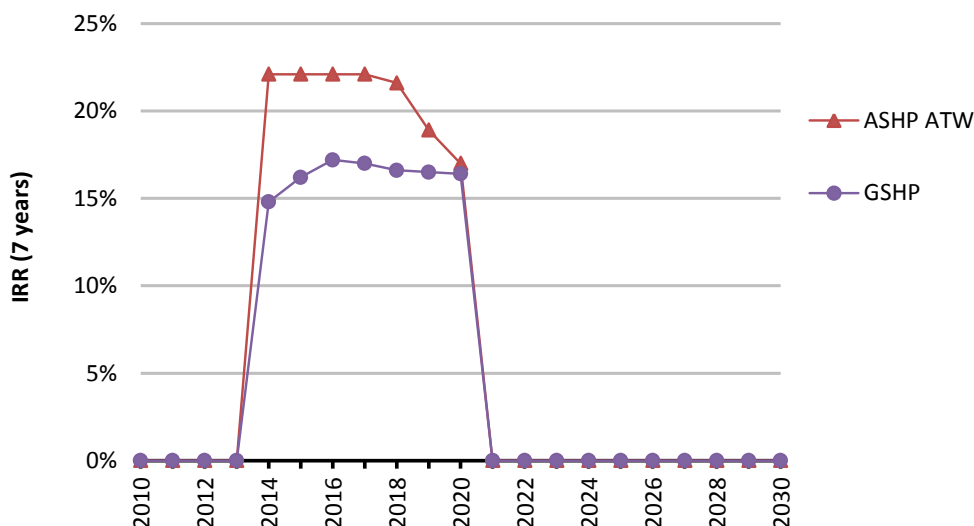
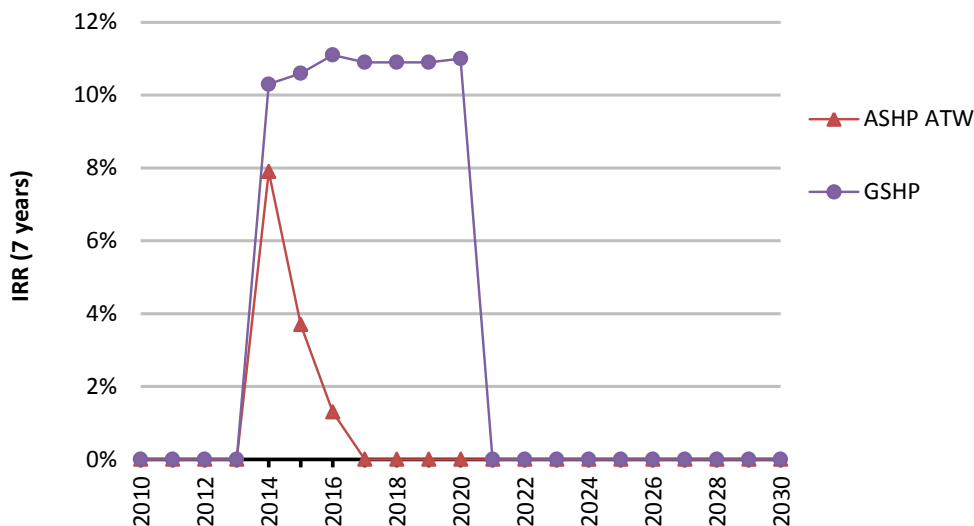


Figure 20. Comparison of the variation in rate of return (IRR) on investment in heat pumps in the off-gas, rural house (cavity-wall) segment of the market.



3.2.5 Quantifying the impact of barriers

Under the Current Policy Pathway assumptions, the uptake by 2020 is estimated at around 690,000 heat pumps, with little further uptake through the 2020s after

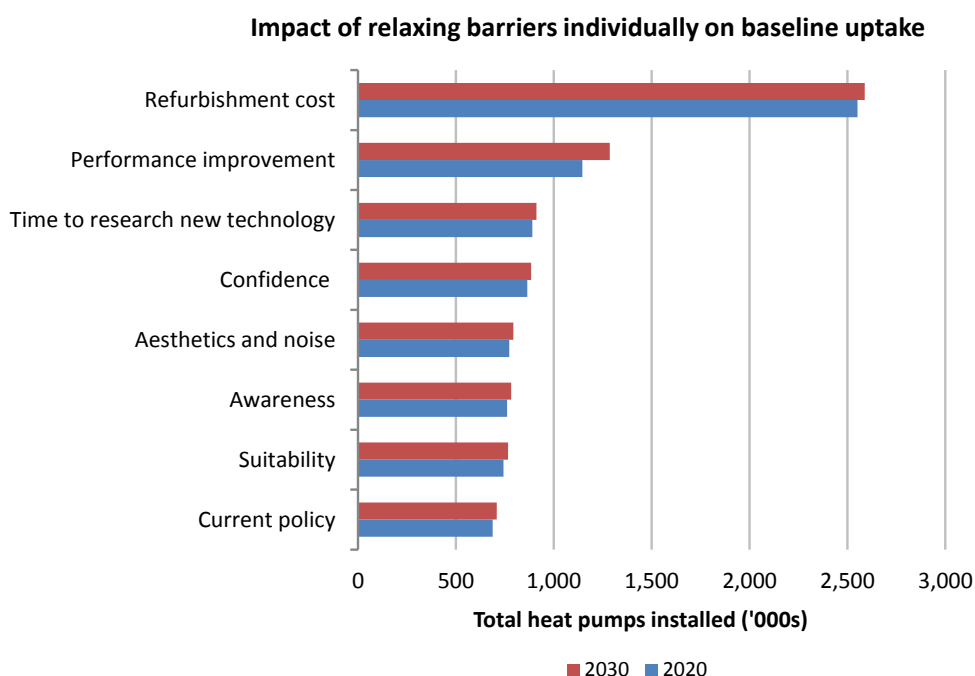
The current and critical pathways

the RHI policy elapses. The uptake is led by ASHP ATW heat pumps, which account for around 545,000 of the total in 2020.

This level of uptake has been generated under a set of base case assumptions, for factors such as capital cost, performance and the impact of certain barriers. In this section, the sensitivity of the current policy uptake to these assumptions is explored.

As described in Section 3.2.1, a range of barriers to uptake have been implemented in the model as cost uplifts, consumer hurdle rates, supply or demand-side constraints. The impact of relaxing these barriers on overall levels of uptake by 2020 and 2030 is shown in Figure 21.

Figure 21. Impact of relaxing each barrier individually on heat pump uptake, compared to uptake in the current policy path (i.e. all barriers)



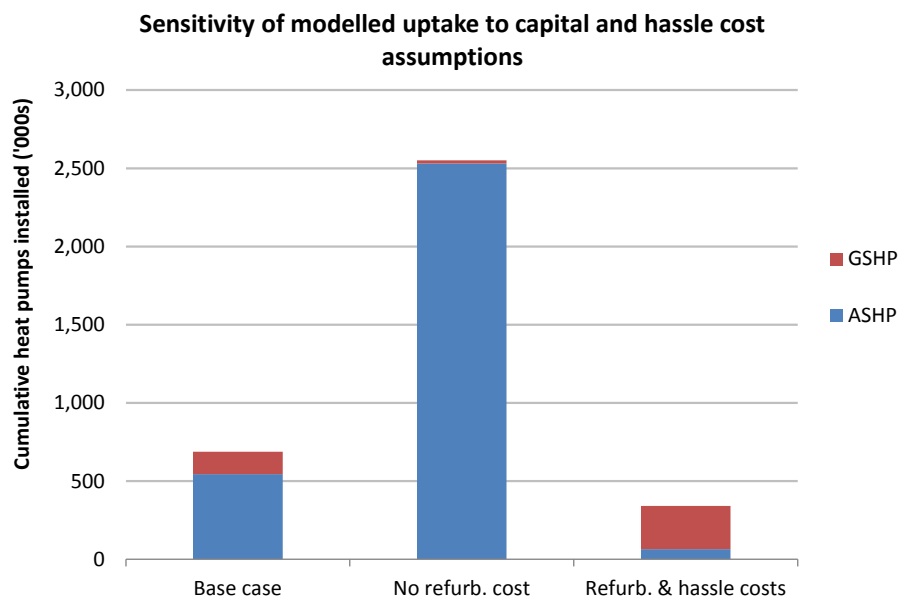
The increase in uptake resulting from relaxing each barrier individually compared to the current policy path is shown in the chart above (i.e. each set of bars represents the incremental change from relaxing a single barrier). The two barriers that have the most significant impact are the refurbishment cost and the performance improvement. The relaxation of individual barriers has very limited impact on the forecast uptake over the period from 2020 to 2030, i.e. no significant uptake over this period results from the relaxation of any individual barrier.

Refurbishment and hassle costs

Relaxing the refurbishment cost, i.e. removing the £275/kW cost uplift for replacing emitters and hot-water cylinders, has a dramatic impact on the level of uptake delivered under the RHI by 2020. Relaxation of this barrier equates to a significant reduction in the installed cost (no consequent loss in performance has been assumed in the modelling of individual relaxation of this barrier).

The impact of reducing this barrier cost has shown that the uptake is highly sensitive to the installation cost assumptions. Prior consumer survey work has indicated that householders may attach a significant 'hassle cost' when considering the purchase of a heat pump system, related to the inconvenience of having their garden dug up for a ground loop and the disruption caused by replacement of radiators. This hassle cost, which has been estimated as equivalent to a £1,600 uplift for installation of a ground loop and £600 for installation of a new hot-water cylinder, has not been included in the base case modelling. In the chart below, the impact of including an additional hassle cost on uptake by 2020 is compared against the base case and the case when the refurbishment cost barrier is relaxed. For simplicity, a hassle cost uplift of £1,000 has been applied in all cases.

Figure 22. The sensitivity of air and ground source heat pump uptake to capital and hassle cost assumptions.



The inclusion of the hassle cost reduces the modelled uptake by 2020 to approximately half of the base case level. The modelling suggests that an increase in perceived cost is more detrimental to the uptake of ASHP than to GSHP. With additional hassle costs included, the uptake of GSHP has actually increased as a result of the technology becoming the more cost-effective choice.

The current and critical pathways

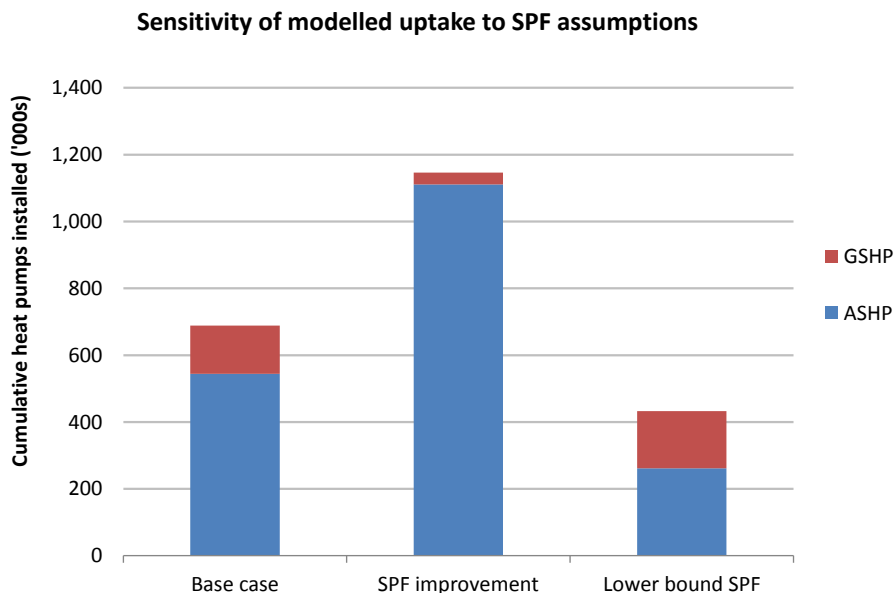
in a greater share of the overall market. By contrast, under the assumption that installed costs are lower than the base case assumptions, the uptake of ASHP has grown significantly and pushed GSHP out of the market almost completely.

Seasonal Performance Factors (SPF)

Initial SPF values are set at an average of around 2.6 for ASHP and 3.2 for GSHP under base case assumptions and are not assumed to improve over time. Relaxation of this barrier has been modelled as an incremental improvement of the SPF for both ASHP and GSHP, such that the SPF values increase to 3.1 and 3.7 respectively over a 5 year period (i.e. an uplift of 0.5 on the initial SPF for both technologies).

In the modelling, the SPF is equivalent to final demand for heat over electricity input, such that all system losses are included in the efficiency calculation. In terms of the SPF values derived for the units included in Phase 2 of the EST heat pump field trials, this is equivalent to a measure of the system efficiency (see Table 3). The average system efficiencies for units monitored in the trial were 2.11 for ASHP and 2.3 for GSHP (for space heating and hot-water provision). To further assess the sensitivity of the current policy path to SPF assumptions, the impact on uptake of using the EST monitored system efficiencies has been modelled. This is shown in the figure below, compared to the base case and the case in which SPF values are assumed to improve over time.

Figure 23. The sensitivity of air and ground source heat pump uptake to SPF assumptions



Under the lower SPF assumption, uptake by 2020 is reduced by just over one-third compared to the base case. Varying the SPF from the base case assumptions has a similar effect to changing the cost assumption, insofar as a

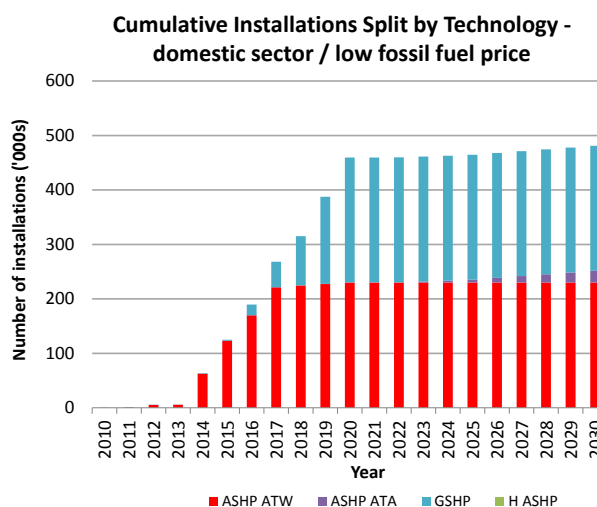
more optimistic assumption tends to further favour ASHP, whereas an increased barrier tends to reduce the dominance of ASHP and the levels of uptake overall.

Fuel price sensitivity

The sensitivity of heat pump installations to gas and oil prices is shown below (the electricity price projection has been held constant for the purpose of this analysis). A high gas price projection favours an increase of ASHP ATW installations of about 1.1 million heat pumps under current policy whereas the GSHP market remains relatively unaffected. This can be attributed to the increasing running costs of the counterfactual heating systems. The effect is more pronounced in the ASHP ATW market where the running costs represent a larger portion of the total cost of ownership compared with GSHP systems.

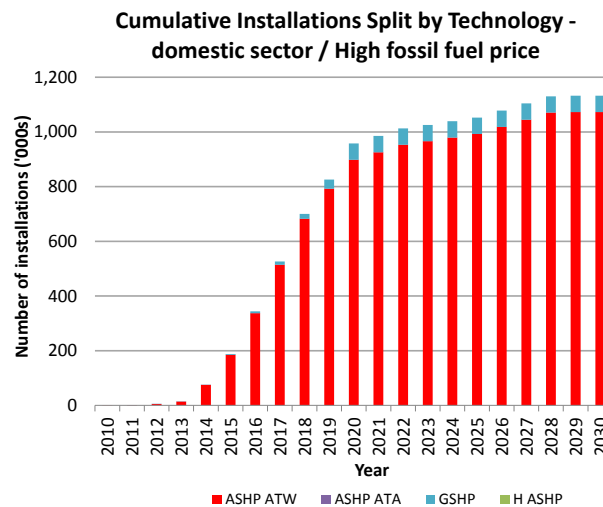
For the low price projections the counterfactual running costs are lower relative to the central scenario. This results in a significant reduction of ASHP ATW market size and a cumulative market size across all heat pump technologies of 500,000 by 2030.

Figure 24. Sensitivity of the current policy projection to gas prices. (Upper) Low fossil fuel prices. (Lower) High fossil fuel prices.³⁴



³⁴ Projections taken from 'DECC updated Energy & Emissions Projections – October 2012'

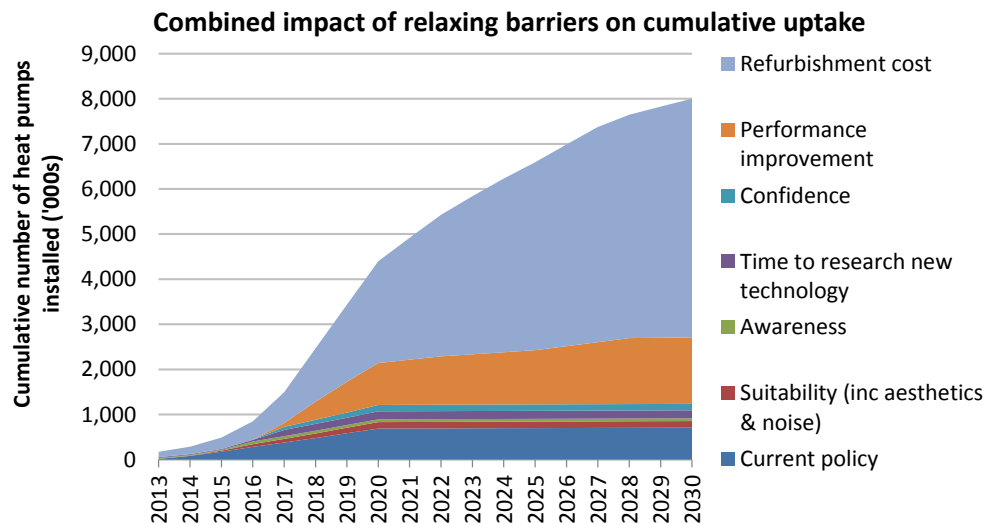
The current and critical pathways



Overall impact of barriers

The combined impact of relaxing barriers is shown in the chart below. In this case the barriers are relaxed incrementally, from the current policy path to a scenario when all barriers are relaxed.

Figure 25. Impact of relaxing barriers in combination, from the current policy path to the condition with all barriers relaxed.



The chart highlights that the impact of relaxing barriers in combination can be very large. The range of uptake from the current policy path with base case barrier assumptions to current policy but with all barriers relaxed apart from the refurbishment cost, is 680,000 to 2.1 million in 2020. This combined relaxation of barriers also results in a forecast of significant uptake of heat pumps in the 2020s, without support from the RHI (cumulative uptake increases from 2.1m to 2.7m by 2030). Policies that address these barriers might therefore be expected

The current and critical pathways

to shift heat pump uptake within this range, i.e. from around 700,000 to 2.7m in 2030.

Reducing the cost of refurbishment of the heat distribution system to zero results in very rapid heat pump uptake when all other barriers have also been relaxed – 4.4 m heat pumps in 2020 and 8m in 2030. Assuming that the heating system refurbishment costs are likely to be incurred to achieve good heat pump performance in retrofit installations, then this provides an indication of the level of financial support that might be required (in conjunction with other measures) in order to achieve levels of uptake in line with the cost-effective scenario.

3.2.6 Inclusion of hybrid heat pumps in the current policy path

A further sensitivity to the current policy pathway has been run in which hybrid air source heat pumps are included as a technology option. The assumptions regarding policy and barriers are unchanged.

For the hybrid air source heat pump (HASHP) technology option the following assumptions are made:

- The heat pump meets 75% of the annual heat load (the remainder met by gas / oil boiler)³⁵.
- The RHI is paid at the same tariff level as pure air to water heat pumps (initially at 7.3 p/kWh), but is paid only for the output of the heat pump (i.e. 75% of total heat demand)
- The payment of RHI similarly to ASHP and GSHPs is based on a calculation of the renewable heat output. For the hybrids however the calculation is based on the actual SPFs of the systems as in reality metering would be the preferred option over deeming for calculating payments
- The capital cost includes the cost of an ASHP ATW and the counterfactual boiler technology (hybrid systems are not permitted in electrically heated buildings). The heat pump technology is down-sized as a result of hybridisation (66% of the capacity of pure ASHP ATW in the same property).

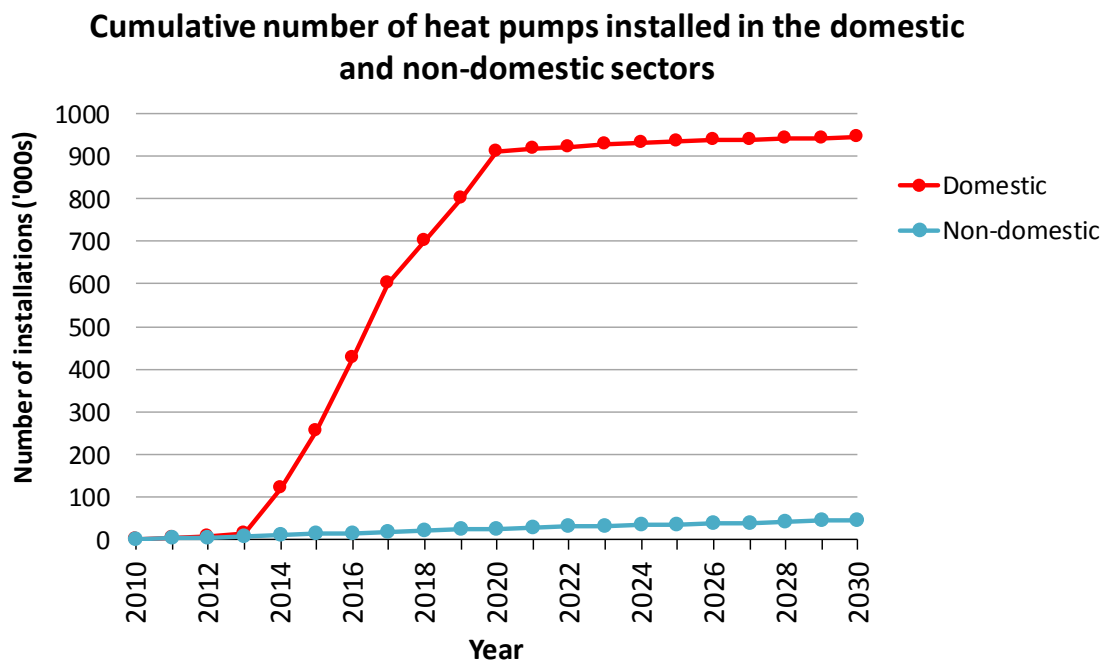
³⁵ The assumption that the heat pump unit meets 75% of the heat load when in a hybrid configuration is based on consultation discussions. Heat pump coverage in the range of 50 to 80% should be achievable with standard radiators and potentially higher coverage could be achieved with an underfloor heating system or fan-assisted radiators. The heat pump coverage could drop below 50% however with poor system sizing, requirement for high water temperatures and low ambient temperatures.

The current and critical pathways

- An improved SPF relative to equivalent ASHP ATW systems of 0.3. This is to reflect the ability to control heat pump and boiler dispatch to optimise heat pump operating conditions.
- The suitability factors for hybrid heat pumps are increased compared to ASHP due to better compatibility with existing heating distribution systems and thermal demands of higher heat loss buildings.
- Additional £1,500 capex in new build. This is to account for the need to bring a gas connection to the building (which is unlikely if a pure air to water or ground source option were taken up).
- Heating system refurbishment cost reduced to 50% of the ATW case.

The uptake forecast in the current policy pathway with hybrids included is shown in the chart below.

Figure 26. Projected heat pump uptake in the current policy path in the case that hybrid air source heat pumps are included as a technology option.



The inclusion of hybrid air source heat pumps has resulted in an increase in the overall levels of uptake by 2030 of around 300,000 heat pumps.

Figure 27. Cumulative uptake of each heat pump technology option in the domestic sector in the current policy pathway, with hybrid air source heat pumps included as an option.

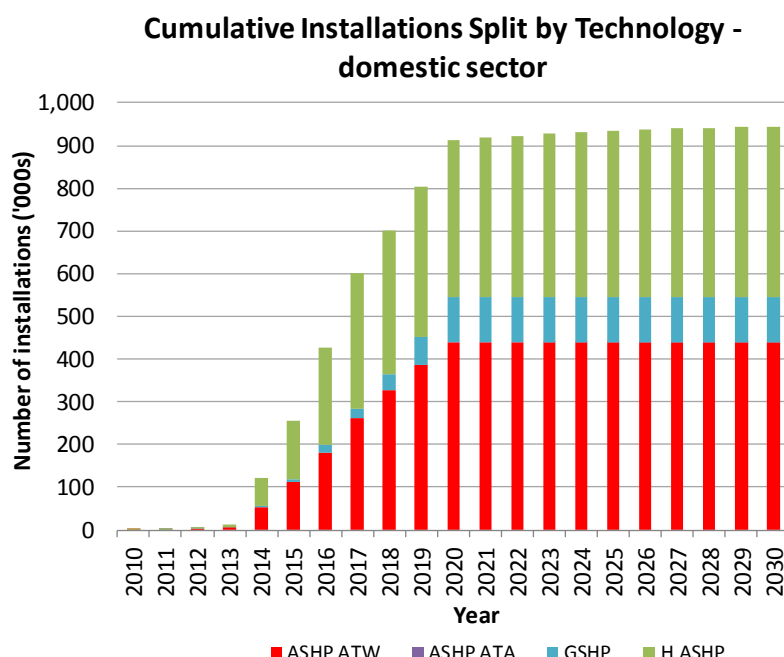
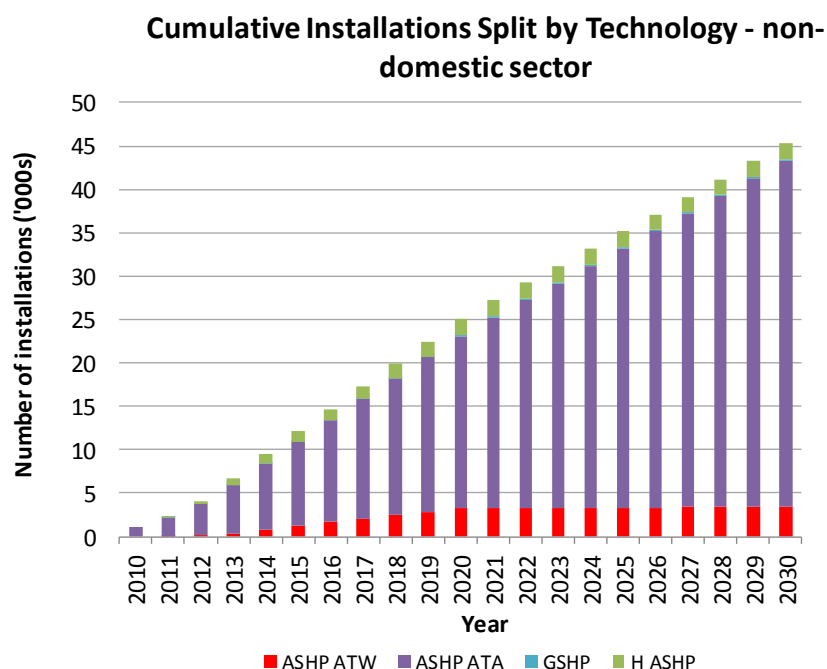


Figure 28. Cumulative uptake of each heat pump technology in the non-domestic sectors under the current policy path, with hybrid heat pumps included.



The inclusion of HASHP has resulted in some reduction of the market for ASHP and GSHP (see Figure 27 and Figure 13), but most of the HASHP uptake is

The current and critical pathways

additional. Uptake of ASHP and HASHP is mainly in the existing, on-gas segment of the stock, where the introduction of HASHP has increased the size of the addressable market (i.e. relaxed suitability constraint for hybrids). Uptake of GSHP remains in the off-gas rural and on-gas suburban homes.

Alternative heat pump systems

The modelling of hybrid heat pump systems has focussed on packaged hybrids (i.e. gas boiler and heat pump packaged together with a control system), based on air source technology. There are a number of such systems commercially available today, from manufacturers such as Daikin, Glow-worm, Bosch and Vaillant, among others. As discussed, these systems promise the potential to capture a substantial share of the UK market, based on features such as the following.

- Comparable installation costs to pure electric ASHP systems, due to the reduced heat pump capacity requirement.
- Similar operating costs and comparable CO₂ savings at current grid carbon intensity (the reduced heat pump coverage of the overall thermal demand can be compensated by the ability to run the heat pump at closer to optimum efficiency).
- Compatible with strong consumer attachment to gas boilers.
- Reduced impact on electricity grids in terms of network load growth and associated investment requirements. Hybrid heat pumps also offer flexibility to peak shave as part of a smart grid system (by switching to the gas boiler at time of network peak).

Hybrid heat pumps are also likely to require some heating system refurbishment in many retrofit installations in order to ensure high heat pump coverage (i.e. that the heat pump operates to meet a substantial proportion of the annual heat demand), although this may be lower than in the case of a pure electric system. Several of the other barriers to heat pump systems also apply to hybrid systems, such as space requirements, requirement for a hot-water cylinder (although some combi hybrids are being brought to market), noise issues (for air source hybrids) and awareness. In the longer term, hybrid systems will also fall further behind pure electric systems in terms of carbon benefits as the grid decarbonises.

Bivalent systems

A bivalent system is one in which two heat sources are available to meet the space heating demand of the property. This could be achieved by installing a heat pump alongside an existing gas (or oil) boiler, together with a control system. Bivalent systems are potentially relevant to applications with a high heat loss, as the gas boiler can be operated to meet peak demands on the coldest days

(allowing the heat pump to be reduced in size compared to the capacity of a pure electric heat pump system). A bivalent system may also make sense in applications where a relatively new boiler has been installed, which can be retained for peak heating loads. The key challenge technically is to develop an effective control system, which ensures that the heat pump and existing boiler operate together efficiently.

Bivalent systems have not been included in the modelling of technology uptake, however they are likely to be most relevant as retrofit installations in existing gas and oil boiler properties. The installation of a bivalent heat pump is not a heating system replacement but is more of a discretionary technology choice and so is less likely to be tied to distressed purchasing behaviour. This may mean that the current modelling underestimates the level of uptake of heat pumps in hybrid configurations, as it only considers consumers making a purchasing decision at the end of life of their current heating system. Given that the heat pump does not replace an existing heating system, the driver for installing the system is largely to reduce running costs (potentially also to improve environmental performance, although the evidence suggests this is not currently a strong factor in heating system purchasing decisions). At current gas, oil and electricity prices, the payback due to running cost savings on the capital investment in a bivalent system is too long to expect significant uptake. However, the RHI may drive some uptake of systems in bivalent configuration additional to that currently modelled (note that the output of these systems for RHI purposes would need to be metered, as is the case for standard hybrids, which is an additional expense).

Hybrid ground source systems

The modelling of hybrid systems has been based on air source system costs, however ground source systems can equally be installed in a hybrid configuration. Similar assumptions can be applied to hybrid ground source systems, in terms of reduced installed system capacity (compared to a pure electric system) and heat pump coverage of the overall thermal load. The capital costs of the heat pump and ground collector will also scale with the installed capacity (although there are some fixed costs associated with installation and set-up of the borehole drilling rig), such that hybrid systems are competitive with pure electric GSHP systems on installed cost.

In the current policy path modelling, ground source systems are taken up in off-gas properties and larger on-gas homes, where they compete for market share with hybrid air source systems. Hybrid ground source systems would be expected to also compete within these segments.

Gas absorption heat pumps

A gas absorption heat pump (GAHP) uses a gas burner to power the refrigeration cycle rather than an electrically driven compressor, as in an electric heat pump. The process draws energy from the surrounding air or a ground

The current and critical pathways

collector at the evaporator stage of the cycle and can achieve system efficiencies of around 140% (i.e. an SPF of 1.4). At current gas and electricity carbon intensities, the carbon benefit is similar to that of an electrically powered heat pump (based on an electric heat pump SPF of around 3). A potential advantage of the gas absorption heat pump is that it can produce high temperature hot-water, at around 70°C, so can directly replace gas condensing boilers. The GAHP can also be operated in a reverse cycle to produce chilled water for cooling demands.

GAHP have not been included in the modelling and there is little data available on costs and performance. There are a limited number of systems available in the UK at present and these are targeted at small commercial applications rather than the domestic sector. The systems are well-suited to applications with a consistent demand for hot-water, such as hotels, leisure centres, hospitals and potentially larger residential buildings.

Currently GAHP are an efficient means of providing heating and hot-water in the commercial and public on-gas segments. Increasing uptake can be expected in these markets, driven by tightening Part L standards. As products targeted at the domestic sector become more widely available, regulation may be expected to drive uptake in this sector also, although the technology is not currently eligible for the RHI. In the longer term, assuming successful decarbonisation of the grid, the carbon benefit of GAHP will be suffer in comparison to electrically driven heat pumps such that their role in a very low carbon heating sector is diminished.

3.3 The critical pathway

This section describes a critical pathway to meeting the 2050 targets under the CCC's 'Stretch' scenario. Under this scenario, the contribution of heat pumps to meeting emissions targets could be up to 31m (365 TWh) by 2050. This represents more than 80% of all properties in the UK in the domestic and commercial sectors. The breakdown of this across the domestic and non-domestic sectors is shown in Table 10.

Table 10. Estimated heat pumps installation required by 2050 to meet the decarbonisation target

	Installations	TWh
Domestic	30.6m	232
Non-domestic	0.5m	133
Total	31.2m	365

Source: CCC

To assess where, as a minimum, heat pump uptake needs to reach in 2030 to allow heat pumps to make this very large contribution to the 2050 target, we developed a critical path model. If this level of heat pump deployment cannot be reached by 2050, additional contributions would be required from other low-carbon heat options (e.g. low-grade heat from nuclear/CCS plants delivered via district heat networks).

Our modelling of the critical path is based on an assessment of ‘hard constraints’ on uptake. We define a hard constraint as one which cannot be relaxed, or is very difficult to relax, through plausible policy measures.

The hard constraints we applied are as follows:

- **Demand side constraint** (maximum installations per year). We use two factors to determine the maximum annual level of heat pump uptake per year.
 - **Suitability of housing stock.** These are differentiated depending on the type of building (e.g. only a small percentage of older, solid wall homes are deemed suitable initially). The weighted average suitability across properties rises from 46% in 2013, to 59% in 2030 and 92% in 2050³⁶.
 - **Replacement rates.** We assume heat pumps are only considered cost-effective when a property is newly built or when boilers or other heating devices are coming to the end of their life (15 years). This constraint means that only a 15th of households in existing suitable properties will

³⁶ Up to 2030 these suitability rates are based on suitability projections used in NERA/AEA (2009) *The UK Supply Curve for Renewable Heat*. Beyond 2030 we have made assumptions on suitability according to what is needed to allow the 2050 target to be met. We discuss the feasibility of this later in this section.

The current and critical pathways

consider a switch to a heat pump in a given year³⁷. We also assume a heat pump lifetime of 15 years meaning those installing before 2035 will need to re-install again before 2050.

We also apply an additional constraint to account for the fact that many purchases of heating systems are distressed purchases. The prevalence of distressed purchases means consumers may not consider installing a heat pump because a lack of time to research and get the technology installed when their previous system breaks down. We assume that for 50% of purchases of new heating systems for domestic buildings and 25% for commercial buildings consumers will not consider heat pumps in 2010³⁸. These rates decline with installations reaching 0% once half of the 2050 target number of installations has been met. This reflects the idea that, as the technology becomes more mainstream, awareness and research barriers fall away.

The growth in the housing stock is also factored in using Government projections with total buildings rising from 26.6m in 2010 to 32.5m in 2030 and 37.8m in 2050.

- **Supply side constraint.** We also look at a maximum percentage growth rate in installations per year to recognise constraints in the development of skills and systems in the installation sector. Higher growth rates are allowed in the early years on the basis that the previous year's installation base is less of a binding constraint at this stage. The growth rate assumptions are shown below in Table 11 and are the same as those applied in the uptake model.

³⁷ This is supported by current evidence on boiler sales where around 1.6m boilers are replaced per year (just over 6% of total properties).

³⁸ A survey of domestic consumers for DECC found that a large proportion of heating systems are made on a "distressed" basis where time and awareness constraints are likely to have the biggest impact: "*A system breakdown was the most common reason respondents had replaced their heating system in the past (30% gave this as the main reason). 'Non-emergency' situations where their system was still working but was coming towards the end of its life were also commonly cited as the main reason, either because they were told it would not last much longer (14%) it needed repairs too often (14%) or they were told the parts would no longer be available in the future (3%).*" Ipsos MORI and EST (2013) *Homeowners' willingness to take up more efficient heating systems* p.6

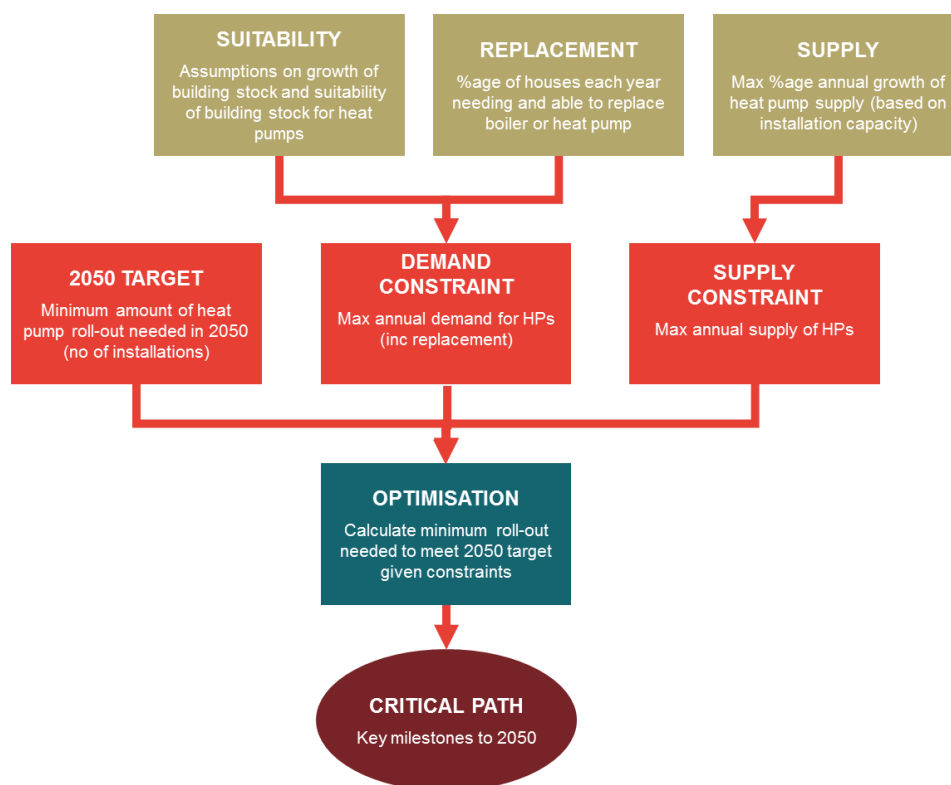
Table 11. Supply growth rate assumptions

	Maximum change on the previous year
Emerging (2010-2015)	80%
Growth (2016-2020)	60%
Mature (2020+)	30%

Source: Based on observed heat pump uptake rates in other countries with a high penetration of heat pumps.

Figure 29 summarises how these constraints are applied and the structure of the critical path tool.

Figure 29. Structure of critical path tool



Source: Frontier Economics

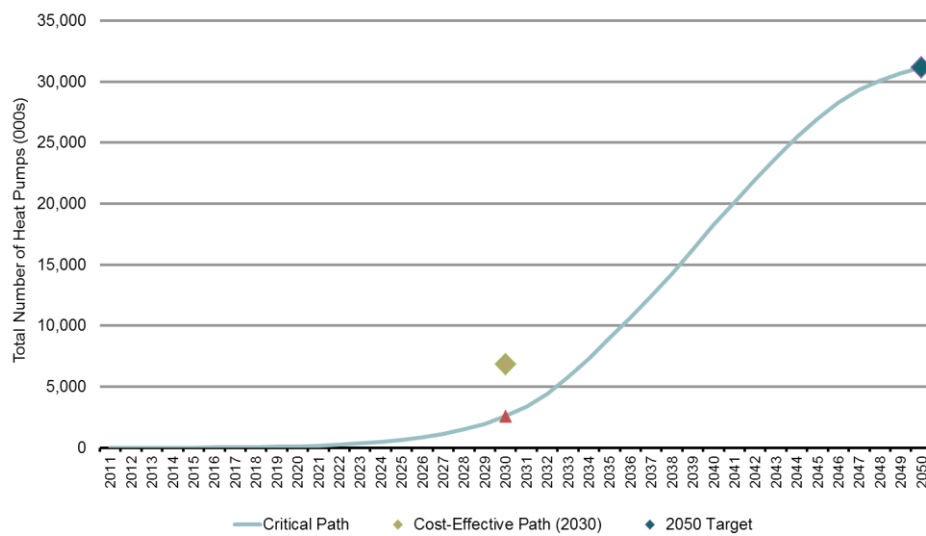
Figure 30 and Figure 31 show the results of the critical path modelling in terms of heat pump uptake and TWhs of heat. Under this critical path around 2.6m properties (producing 41 TWh of heat) must have heat pumps installed by 2030 to leave open the possibility of meeting the levels of heat pumps needed in 2050

The current and critical pathways

under central CCC projections. The critical level for just domestic heat pumps is 2.5m heat pumps and 30 TWh (see Figure 32).

For comparison, we also plot on the same graphs the level of heat-pump uptake or TWh of heat required under the CCC's "cost-effective path" in 2030³⁹. This level is higher as higher heat pump deployment is consistent with meeting interim carbon targets cost-effectively.

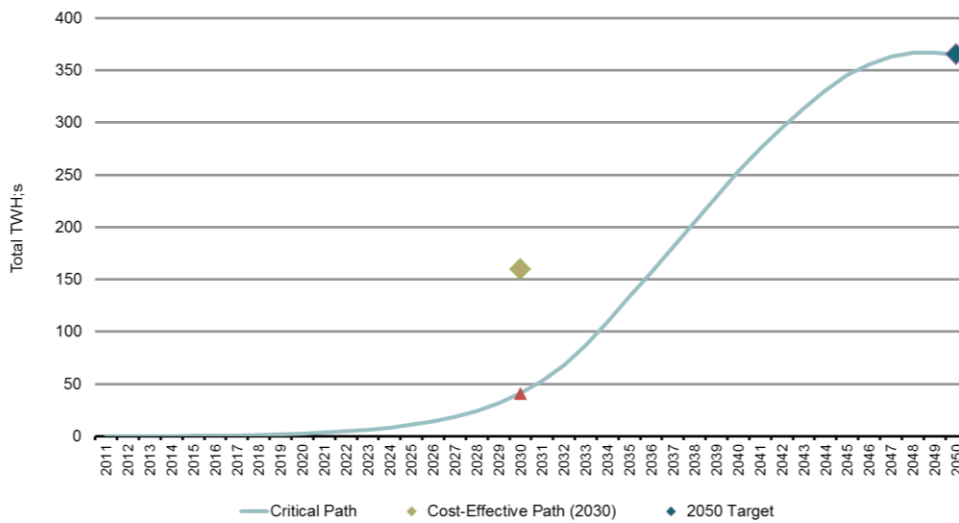
Figure 30. Critical Path: Total Installations



Source: Frontier Economics

³⁹ This is based on modelling for the 4th Carbon Budget.

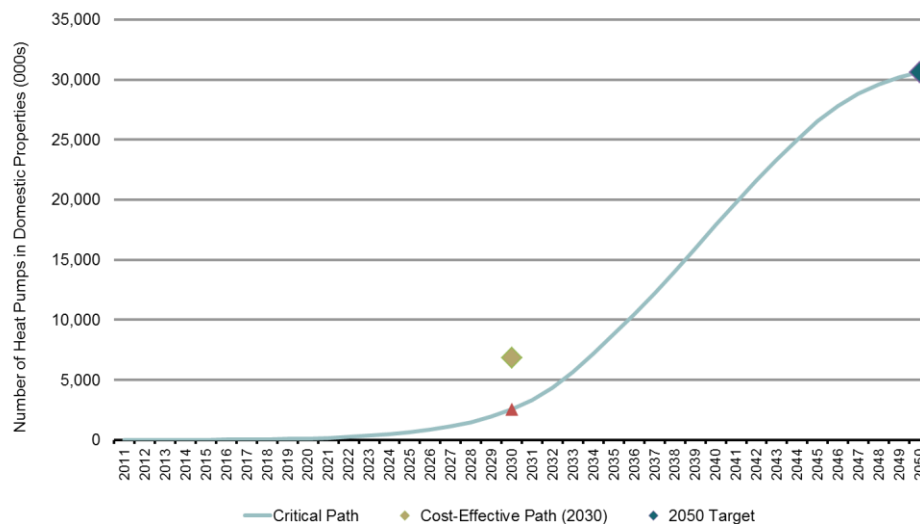
Figure 31. Critical path: Total TWhs of heat



Source: Frontier Economics.

Note: Because the critical path model is based on installations rather than TWh, TWh of heat are derived by assuming a particular TWh/installation in each year up to 2050. For domestic properties, we used the TWh/installation implied by the CCC's 2050 'Stretch' scenario up to 2030. We then assume a fall in TWh/installation to 2050, to reach the figure implied by the CCC's 2050 scenario. For commercial properties, we assume TWh/installation remains constant up to 2050, at the level implied by the 2050 targets for commercial installations and TWhs.

Figure 32. Critical Path: Domestic Sector (installations)

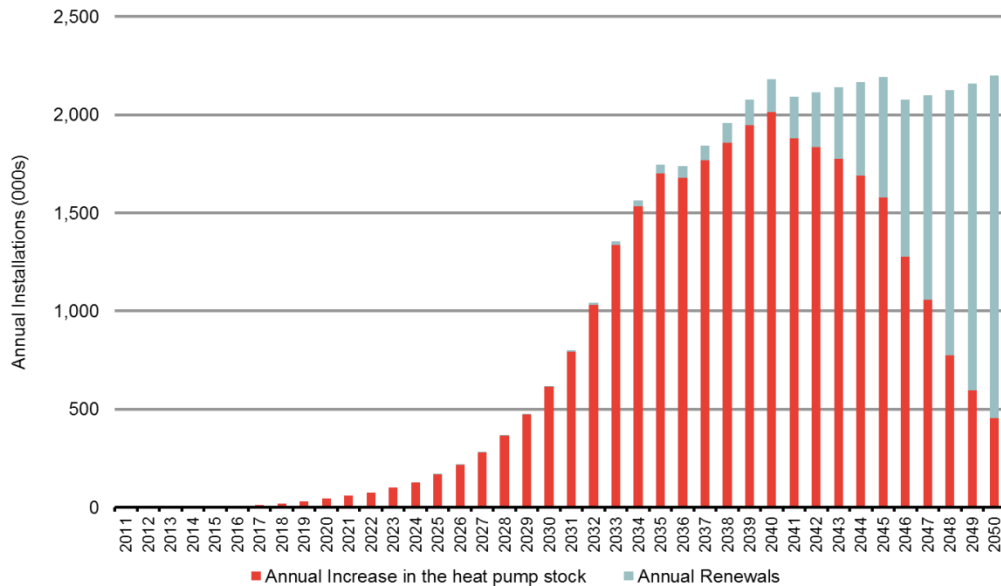


Source: Frontier Economics

The current and critical pathways

Figure 33 shows the total required annual installations under the critical path. Annual installations rise above 2m/year by 2040. By 2050, renewals of existing heat pumps represent a large portion of the market.

Figure 33. Annual Installations under the Critical Path



Source: Frontier Economics

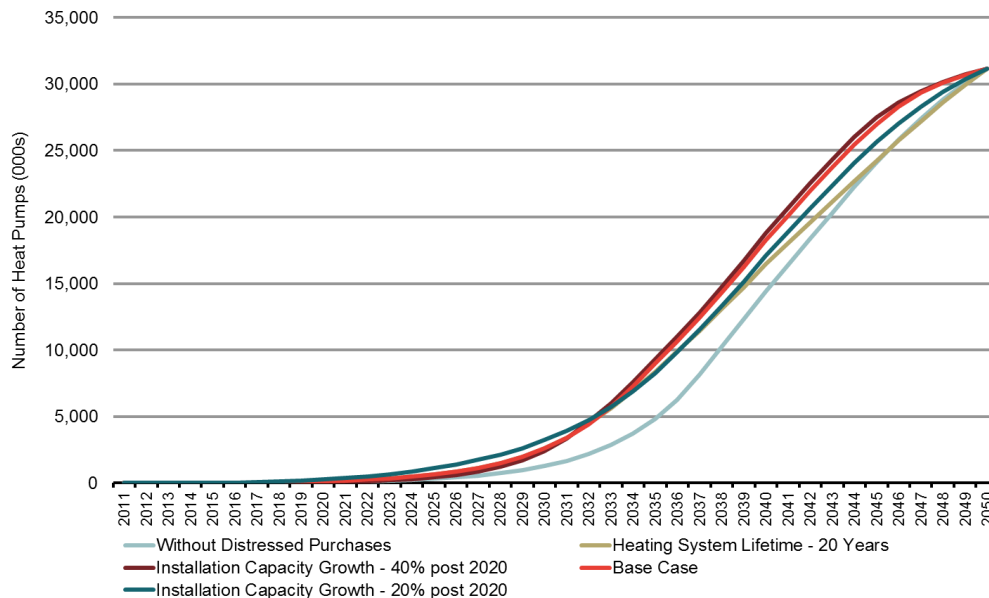
Finally we show the sensitivities of the critical path to different assumptions in Figure 34, showing how the critical level in 2030 changes from the central case of 2.6m installations.

- **Without a distressed purchase constraint.** The removal of the distressed purchase constraint decreases the number of installations required by 2030 to less than 1.3m.
- **Changing the heating system lifetime.** Increasing the assumed heating system lifetime to 20 years (from 15 years) increases the number of installations required by 2030 to over 2.6m, reflecting a slower turnover of the heating system stock⁴⁰.

⁴⁰ The critical path when a smaller 10-year heating system lifetime is assumed is not included in Figure 20. Under this assumption, neither the maximum demand nor supply constraints would bind up to 2030, meaning that running the complete critical path tool over 2010-2050 would not provide meaningful results.

- **Changing the supply growth rate.** If the maximum growth rate of supply from 2020 is increased to 40% (from 30%) then only 2.4m heat pumps are required by 2030. If the maximum supply growth rate were to fall to 20% then 3.2m heat pumps are required by 2030. If the maximum supply growth rate were to fall to 10% the critical path could not be met.

Figure 34. Sensitivity of critical path to different assumptions



Source: Frontier Economics and Element Energy

We draw out the following insights from the critical path modelling.

- **Supply capacity is the constraint on maximum growth in the early years while demand constrains in the latter years.** The capacity of the supply chain to grow is binding until just after 2035 in the critical path scenarios. After that demand, and in particular the rate at which the heating stock can be replaced, is what constrains the maximum possible growth in heat pump uptake.
- **Large increases in suitability and energy efficiency are needed from 2030 to 2050.** As stated earlier, to allow the heat pump target to be met the total level of suitability needs to reach over 92%⁴¹ in 2050 (from less than

⁴¹ Note that this is greater than the 80% figure representing the percentage of all properties in 2050 that have to have had a heat pump installed to meet the 2050 target. This is because some

The current and critical pathways

60% in 2030). Between 2030 and 2050 this implies the number of suitable existing homes needs to increase by around 16m (from a level of around 20m in 2030). Of this 16m we estimate around 4.5m will need to come from solid-wall homes.

Assuming a lack of energy efficiency is the main reason these homes are not suitable implies that an average 800,000 homes per year need to be treated with major energy efficiency measures. In 2012 (the last year of CERT and CESP) around 0.7m properties received either cavity or solid wall insulation⁴². This suggests the required improvement in suitability is achievable, although challenging. However, we note the remaining properties that are not suitable by 2030 are likely to be “harder-to-treat” and in the absence of a strong economy-wide carbon price, insulating these homes may require subsidy to be economically viable. Therefore specific policy incentives may be needed in the 2030 to 2050 period.

Noise limits on suitability should also be resolvable through improved technology or small relaxation in noise regulations, providing there is a policy case for this.

Suitability of properties due to space limits is more difficult to resolve and may therefore represent a more fundamental barrier to reaching the high levels of suitability and uptake needed to meet the 2050 target. In particular, fitting a hot water tank may be highly undesirable and challenging in smaller properties. Therefore, achieving suitability of over 92% may require significant consumer sacrifices on space in the home, with associated impacts on welfare.

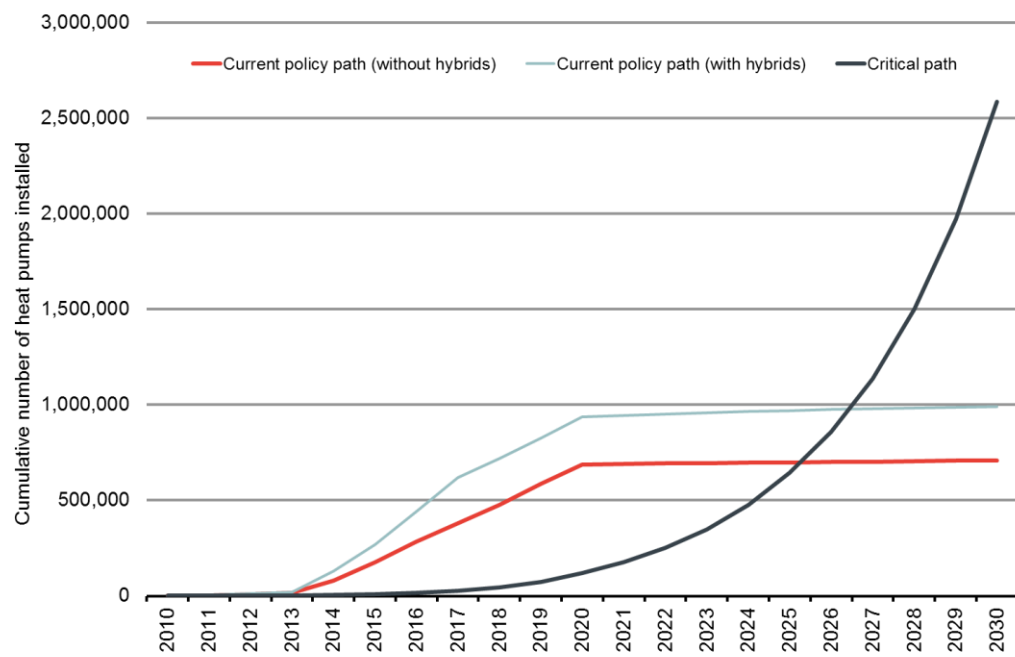
3.4 Comparing the current policy path with where we need to be

Figure 35 shows the current policy path alongside the critical path. As can be seen the current policy path is above the critical path until the early 2020s before falling below the critical path thereafter. By 2030 the current policy path is forecast to result in just under 13 TWh (0.7m installations) compared to 41 TWh (2.6m installations) required under the “critical path” and 160 TWh (~7m installations) under the “cost-effective path”.

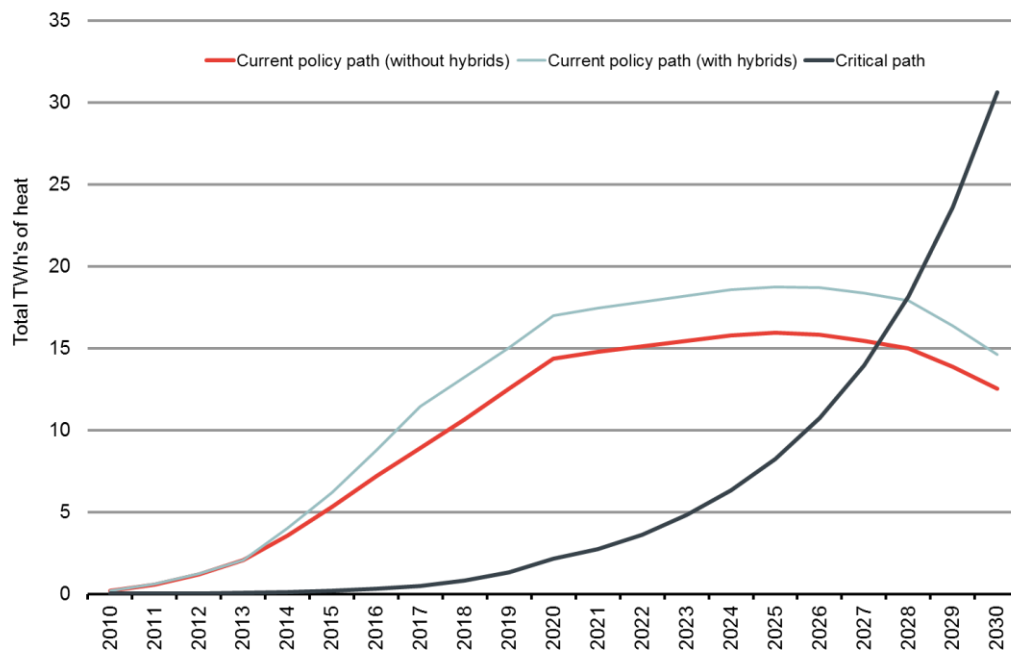
“headroom” is needed between the total number of suitable properties and the maximum level of installations.

⁴² Committee on Climate Change (2013), *Meeting Carbon Budgets – 2013 Progress Report to Parliament*

Figure 35. The current policy path versus the critical path (total installations)



Source: Element Energy and Frontier Economics.

Figure 36. The current policy path versus the critical path (TWh heat output)

Source: Element Energy and Frontier Economics.

This suggests that under business as usual the level of heat pump uptake in 2030 will not be sufficient to keep open the possibility of meeting the required 2050 uptake. Moreover, the level of uptake under the base case is well below the socially “cost-effective” path. Therefore, additional measures are needed, particularly in the 2020s. This is the subject of the next section.

It should be noted that the critical path does not include the option for hybrid heat pumps. With hybrids as an option the stock replacement constraint would not bind as hard (as consumer could, in some cases install a heat pump in addition to an existing boiler). This implies that with hybrid heat pumps as an option only a very small volume of heat pumps would be needed in 2030 to allow the 2050 installation levels to be met. However, we note that widespread use of hybrids would not be consistent with a decarbonised heat sector by 2050.

4 Achieving the required uptake by 2030

This section describes and assesses policy packages that would allow the CCC’s “cost-effective pathway” for uptake of heat pumps to be met. 160 TWh of heat pump output annually by 2030. This includes 81 TWh from the domestic sector, coming from 6.8m heat pumps.

4.1 Costs of heat pumps and alternative heating technologies to 2030

Before analysing and assessing the policies needed to drive greater uptake of heat pumps, it is useful to compare the costs of heat pumps with their alternatives. Over time, heat pumps will become an increasingly cost-effective option, from a social perspective, as the cost of carbon saving from heat pumps falls and the value of the carbon saved rises.

A levelised cost of energy (LCOE) comparison between heat pumps and the counterfactual heating appliance is shown in Figure 37. In the case shown, the counterfactual is a gas boiler. The LCOE is shown under Base Case assumptions, including the impact of the carbon price. Comparisons are shown for 2020 and 2030 snapshot years.

Figure 37. LCOE in 2020 for gas boilers and heat pump technologies in an on-gas, suburban house with cavity walls.

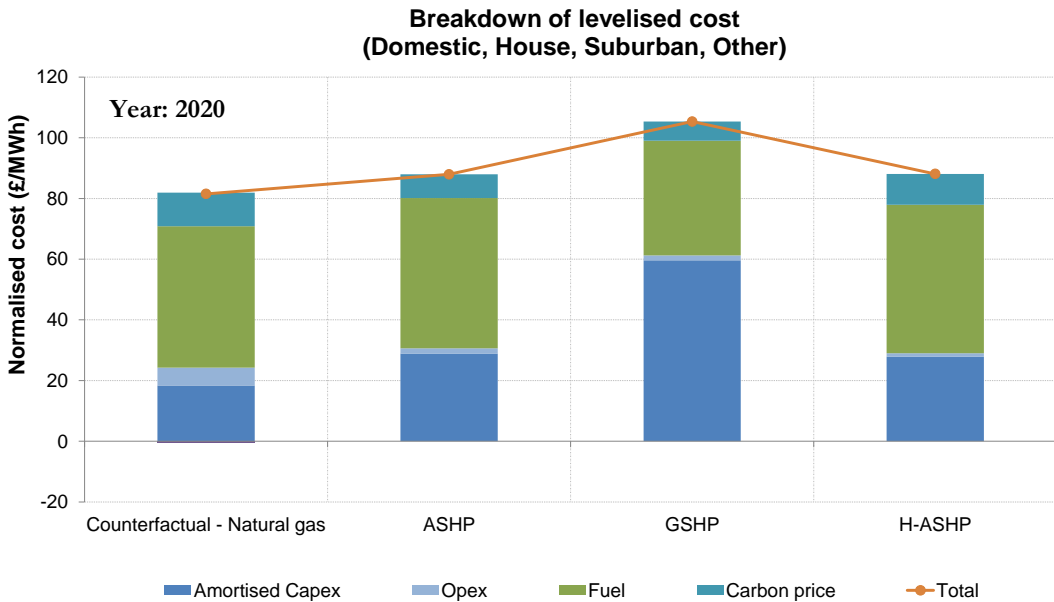
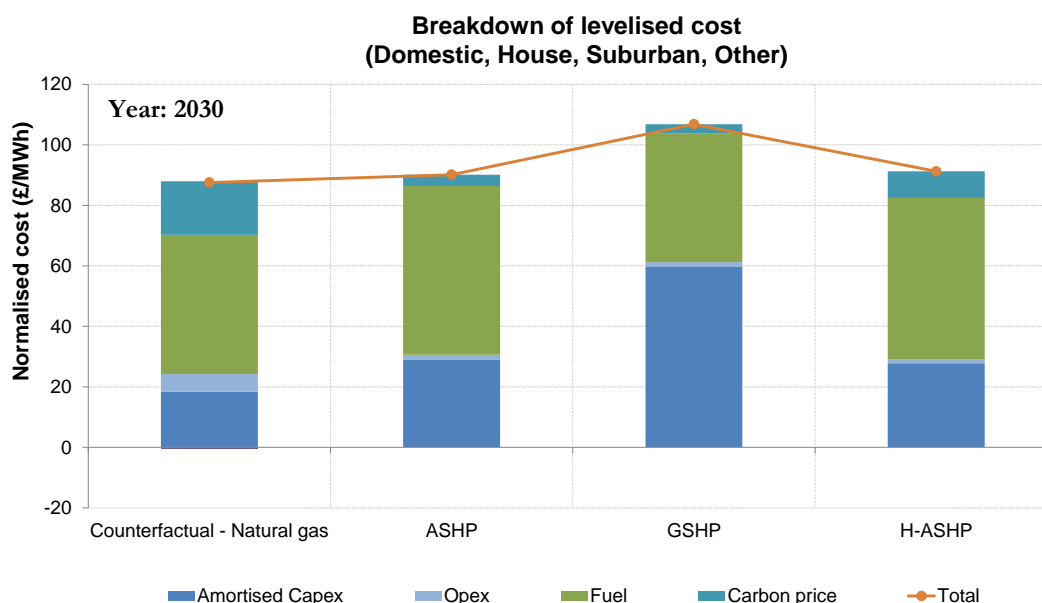


Figure 38. LCOE in 2030 for gas boilers and heat pump technologies in an on-gas, suburban house with cavity walls.

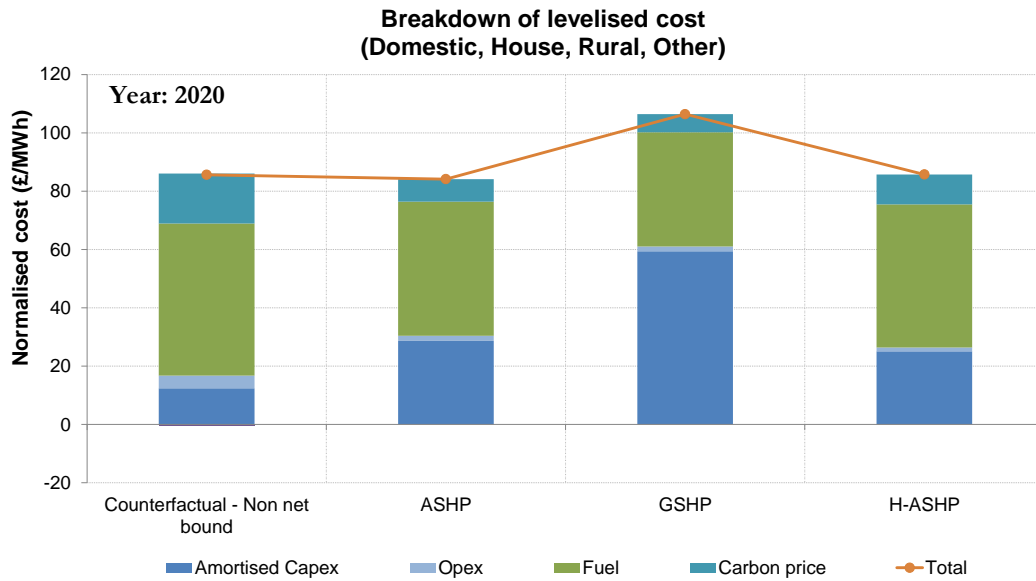


As expected given the lack of uptake of heat pumps in the current policy scenario (i.e. no subsidies for heat pumps through the 2020s), the LCOE for each heat pump option exceeds that of the counterfactual throughout the period. The LCOE of heat pump technologies change only marginally between 2020 and 2030, as reductions in capital costs are offset by rising electricity prices and increasing carbon price. The LCOE of the counterfactual, in this case gas boilers, changes more significantly due to the increasing contribution of the carbon price to the overall cost.

We note that the fuel costs of gas boilers remain below those of ASHPs in 2030. Therefore without a carbon price or RHI these consumers could not make any running costs savings by installing ASHPs.

The LCOE comparison for an off-gas, rural house type is shown in Figure 39 for the 2020 installation year. In this case, the LCOE of ASHPs is comparable to the counterfactual, largely due to the higher fuel prices and carbon costs associated with heating oil (based on Central case fuel price projections).

Figure 39. LCOE in 2020 for gas boilers and heat pump technologies in an off-gas, rural house with cavity walls.



While the LCOE for ASHP and counterfactual are close in the off-gas house type, we predict very limited uptake of heat pumps in this sector during the 2020s in the current policy path (see Section 3.2.3). The LCOEs shown here are calculated at a social discount rate of 3.5%, which is well below the hurdle rate required by the majority of consumers. At a higher discount rate, the LCOE of the counterfactual drops below the LCOE of all heat pump technologies (furthermore the cost of carbon is not factored into the consumer decision-making).

As shown by the LCOE comparison in 2020 and 2030 snapshot years, LCOE varies over time. This is due to changing fuel / electricity prices, changing carbon price and grid intensity, as well as assumptions regarding technology cost reduction and performance improvements. The net impact of these factors is that heat pumps tend to become more cost-effective in comparison to the counterfactual over time. This change in the relative cost-effectiveness of heat pump technology compared to the counterfactuals is explored in more detail in the figures below, which plot the relationship between LCOE and installation year for an on-gas (Figure 40) and off-gas (Figure 41) house type. Note that in these plots the year is the year of installation of the technology and the levelised cost is calculated on a whole life basis (NPV over lifetime heat output, using a 3.5% discount rate).

Figure 40. Change in LCOE⁴³ with year of installation for heat pump and gas boilers in an on-gas, suburban house type

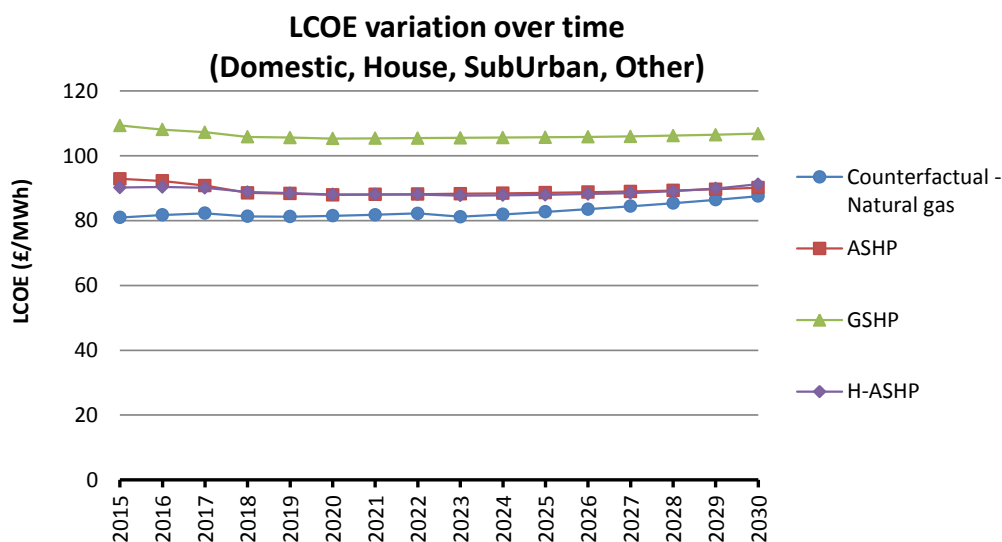
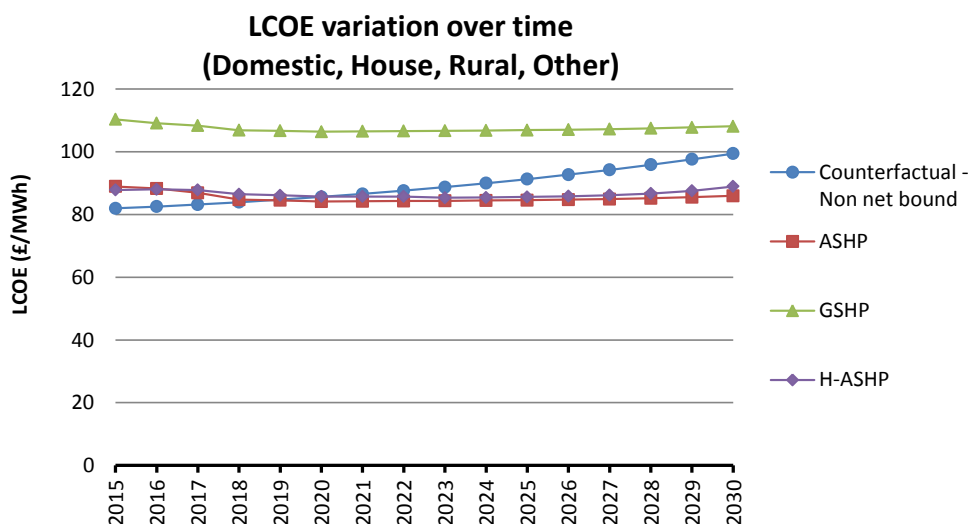


Figure 41. Change in LCOE with year of installation for heat pump and counterfactual technology in an off-gas, rural house.



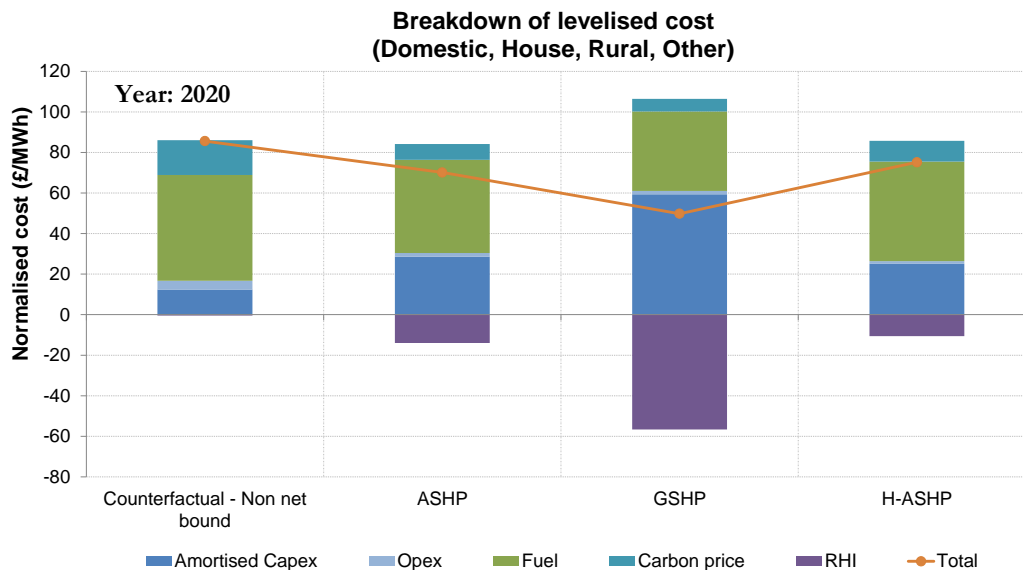
As expected, under the current assumptions heat pumps do not achieving parity in terms of LCOE with gas boilers over the period to 2030, although the LCOEs are converging toward the end of this period. However, ASHP and HASHP technologies are projected to become cost-effective relative to oil boilers, from around 2020. Note that cost-effectiveness on this basis does not imply that

⁴³ Levelised cost of energy calculated as NPV (3.5% discount rate) over lifetime heat output

substantial uptake should be expected, as the discount used in calculating the lifetime costs is low compared to consumer hurdle rates.

The current policy path does predict uptake of heat pumps over the period to 2020, due to the support of the RHI. The impact of the RHI on LCOE is shown in Figure 42 for 2020 in an off-gas, rural house type. In this case, the total LCOE for ground and air source technologies is less than that of the counterfactual.

Figure 42. LCOE in 2020 for gas boilers and heat pump technologies in a 'Domestic, House, Rural, consumer type (with insulated cavity wall construction).



The competitive LCOE of heat pump technology when the RHI is included in the lifetime cost calculation is consistent with the levels of uptake modelled in the current policy pathway. Again these LCOEs are calculated at a social discount rate. If a higher discount rate is used, more typical of the hurdle rates of domestic consumers, the LCOE benefit compared to the counterfactual diminishes. This is consistent with rates of uptake shown in the current policy path modelling (around 600 – 700k in the period to 2020), which suggest that the hurdle rates typical of significant proportions of the consumer population are not being met.

4.2 Barriers to uptake

To identify policies to increase uptake of heat pumps, and assess their impact, we identified the following key barriers to heat pump uptake based on the literature review and the industry interviews described in Section 2.

Economic barriers

- **Cost.** At present the lifetime costs of heat pumps are typically higher than conventional alternatives such as boilers.
- **Access to finance.** Heat pumps have high upfront costs and consumers may have difficulties financing these.

Behavioural barriers

- **Awareness and confidence.** Heat pumps are not currently a mainstream technology and therefore awareness of them and the process for installing them as a heating option is limited. Similarly, due to uncertainties around performance, consumers may not have the confidence to invest.
- **Space and aesthetics.** Heat pumps and associated heat emitters can take up more space than conventional heating systems and some consumers may have a negative perception of the aesthetics of having a unit on the exterior of their home.
- **Hidden costs (e.g. time).** Non-monetary costs such as time taken to research the technology and hassle associated with installation can limit uptake.
- **Landlord-tenant split.** Heat pumps are a long-term investment. The beneficiaries of heating services are often tenants who many only have short tenures whereas the investor is the landlord. This can lead to a mismatch of incentives to invest in beneficial technologies.

Technical barriers

- **Suitability of building (including noise).** Properties must be relatively energy efficient and have a sufficient surface area of heat emitters and, in many cases, hot water storage for heat pumps to be effective. Permitted development limits on noise from heat pumps and objections from local residents can limit uptake.
- **Regulatory barriers.** Some regulations may create barriers to uptake. For example the standard value for the carbon intensity of electricity used in

SAP assessment does not allow for a falling intensity over time and thus penalises heat pumps⁴⁴.

- **Installation / operational.** There are technical challenges in installing and operating heat pumps so that they deliver heating comfort efficiently (e.g. getting the sizing of the heat pump and the [heat emitters] optimised).

Supply-side

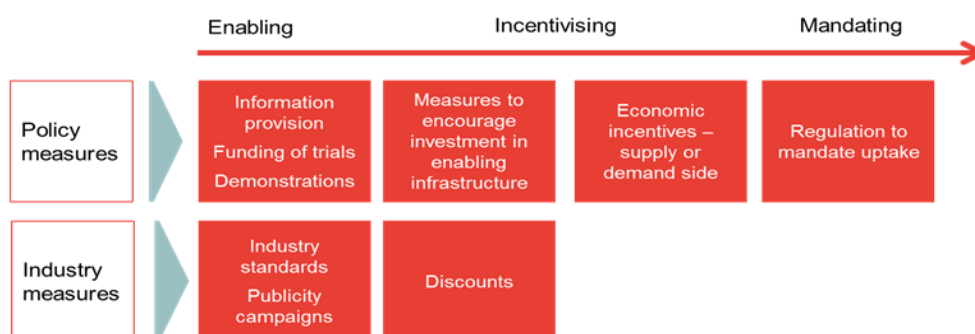
- **Supply chain capacity.** The capacity of the supply chain may not grow fast enough to match demand (e.g. number of trained installers).
- **Supply chain coordination.** The effectiveness of the heat pump industry to grow may be determined by interdependences along the supply chain (e.g. the development of a spare parts network which matches the needs of installers).

4.3 Policy measures to address barriers

There are a wide range of policy measures that could be used to address the barriers shown above. These range from “enabling” measures (which tackle behavioural barriers to uptake such as awareness and confidence) “incentivising” measures (which provide financial inducement to take-up of heat pumps or related infrastructure such as energy efficiency) and “mandating” measures (which make regulatory requirements on heat pump uptake or carbon performance of heating systems). These categories are shown in Figure 43.

⁴⁴ The default SPF values for heat pumps in the current version of SAP (2009) are also low. This has the result that heat pumps are rarely selected as a means of achieving compliance with Part L.

Figure 43. Categorisation of policy measure to encourage heat pump uptake



Source: Frontier Economics

We have identified the following principal policy measures that can be effective in tackling these barriers. These are based on a mapping of policies onto barriers, (see Annexe 1) filtering of these policies based on a set of criteria and the review of international and UK policies covered in Section 2.

A description of these policies is listed below including the barriers they address and some of the key benefits/drawbacks of each policy measure.

Enabling measures

- **Enhanced heat pump certification (requiring installer and consumer training) with sustained information campaigns.** This bundle of measures would be aimed at enabling greater take-up of heat pumps through:
 - a standard requirement for all heating system installers to be given basic training (in addition to existing MCS requirements for training for installers of heat pumps)⁴⁵;
 - a standard requirement that installers train consumers in using their heat pump efficiently (via a requirement that installers deliver a standard level of training and performance monitoring). This also would include a requirement that installations are metered to allow this performance monitoring⁴⁶; and

⁴⁵http://www.microgenerationcertification.org/images/MIS_3005_Issue_3.1a_Heat_Pump_Systems_2012_02_20.pdf (see Page 24 for competencies required of installers)

⁴⁶ Note, DECC have proposed that under the domestic RHI that consumers are given an incentive for 'metering and monitoring' packages. Under this scheme, householders installing heat pumps are given an optional additional payment of £230 per year for purchasing a Metering and Monitoring Service Package from their installer that meets DECC's requirements. Under these packages an

- marketing/information campaigns on the benefits of, and process for, installing heat pumps.

These measures are aimed at reducing the behavioural barriers to heat pump uptake. In particular, improving awareness and confidence in the technology, reducing hidden costs and improving the operational performance of heat pumps. There is evidence that these schemes have been effective in other countries. Moreover the costs of this bundle could be relatively low. We estimate additional costs of around £10m/year plus £60/installation for this measure. Annexe 4 describes this bundle of measures in more detail and summarises how we estimated the costs.

Incentivising measures

- **Extension of the Renewable Heat Incentive (RHI) operating subsidy beyond 2020** (for all renewable heat technologies). The RHI is a subsidy paid for each kWh of renewable heat produced based on deemed heat usage⁴⁷. It directly addresses the costs barrier and, to the extent it stimulates mass uptake, the awareness and confidence barrier could be reduced.

In the base case, the RHI is in place to 2020. This policy measure extends the RHI beyond 2020. For the policy packages, we test a range of different tariff levels. While the RHI could be very effective in tackling cost barriers and encouraging uptake it also implies high costs to government which in turn can create some uncertainty for consumers and the heat pump industry over future tariff levels and funding availability.

A further option - which we do not explicitly model - is to pay the RHI directly to installers based on renewable heat output. This may encourage installers to offer consumers their own financing packages. It would also necessitate a long-term relationship between installers which, if well-designed, could help encourage installers to optimise heat pump performance (e.g. by improving the SPF through better installation and providing training).

- **Capital grants.** This is a one-off upfront payment to consumers to offset the capital cost of heat pumps. As an upfront subsidy it addresses both the cost and access to finance barriers to uptake. From a government

installer will fit an advanced set of meters to the new heating system so that the householder and installer will be able to view measured data from their system over the internet. This training measure would be additional to this by making it a standard requirement on installers (as opposed to an incentive for consumers) and by requiring additional training.

⁴⁷ For non-domestic consumers the maximum payment period is 20 years. For domestic consumer the payment is made over 7 years.

perspective a drawback of the policy is that subsidy payments must be frontloaded. However, at the same time this may improve consumer confidence as they are not dependent on future subsidy payments as is the case under the RHI. We note that in other European countries to date, capital subsidies have been more commonly used than RHI-style operating subsidies. It is also notable that subsidies arising from the Renewable Heat Premium Payment Scheme (RHPP) and those arising under energy supplier obligations (CERT, CESP and now ECO) manifest themselves as upfront capital subsidies.

- **Loan guarantees and social finance.** The Green Deal provides loans for energy efficiency and low-carbon measures (including heat pumps) to be secured against the consumers' property and repaid through the energy bills of the property⁴⁸. In this way, the Green Deal helps to overcome the financing barrier to heat pumps uptake. The Green Deal may also help focus heat pump installations in homes where they are most cost-effective. In order to receive a Green Deal loan an assessment must be undertaken to ensure measures are cost-effective. Homes with high suitability, where refurbishment costs are low, are more likely to be recommended heat pumps under these assessments.

In the base case we assume the Green Deal is in place to 2020, whereas with this policy measure we assume it continues through to 2030 and is available for heat pumps. We assume a 7% interest rate for Green Deal loans.

We also considered an idealised form of 'social finance' where consumers are able to access loans at the social discount rate (3.5%) and always invest if the return on investment exceeds this. This would ensure all social efficient investments take place (providing other policy incentives are well-designed). However, in practice 'social finance' may be difficult to achieve. It may require explicit government guarantees of loans and consumers may not always take-up the offer.

We also considered a carbon tax on gas and oil used for heating. This encourages heat pumps by making gas and oil heating relatively more expensive. This advantage of this policy is that it explicitly targets carbon saving and should encourage uptake where it is most cost-effective. However, it would entail large transfers from consumers to government in tax.

⁴⁸ Note: the treatment of heat pumps under SAP would need to be amended to allow heat pumps to be used on a widespread basis under the Green Deal.

Mandating measures

- **Tightened carbon emissions standards on new build.** This policy measure would first reduce the carbon standard in Part L of the Building Regulations to 10-14kgCO₂/m²/year from 2016 in line with the current government ambition. In addition, in some packages we impose a further tightening of the carbon standard to 6kgCO₂/m²/year from 2020 (this equates to approximately 70gCO₂/kWh consumed in the average new house, and 80gCO₂/kWh in the average new flat⁴⁹ although higher levels of energy efficiency would allow both these rates to rise).

This tightening of carbon standards in buildings would have the advantage of allowing housebuilders to have flexibility to choose the most cost-effective solutions to meet the low carbon standards.

By removing consumer choice on new home standards, the policy effectively removes behavioural barriers to uptake for new homes. The policy has the advantage of limited direct cost to government (which may make it more robust to change). Consumers will face higher home purchase costs but generally lower ongoing energy costs as a result of the increased energy efficiency of the building.

- **Carbon emissions standard on heating system replacement.** This is a minimum standard on new heating systems based on CO₂ performance, subject to suitability requirements for alternatives to the existing system being met.

This standard would replace the current energy efficiency requirement for boilers with a requirement that the average lifetime carbon intensity of new heating systems is less than 180gCO₂/kWh⁵⁰ (based on average consumption levels this translates to approximately 15.5 kgCO₂/m²/year in the average new house, and 13.5 kgCO₂/m²/year in the average new flat).

In effect, this rules out gas condensing boilers⁵¹ as an option for heating systems and makes heat pumps the most cost-effective option in many cases. In our policy packages, this policy is sometimes applied to specific property types (e.g. off-gas grid) and phased in at different times.

⁴⁹ This is based on average house and flat sizes of 81m² and 63m² respectively (RIBA (2011), Case for Space), and implied average annual energy consumption figures for the average house and flat of 7,150KWh and 4,550KWh respectively (Energy Savings Trust (2008), Domestic Heating by Gas: Boiler Systems).

⁵⁰ Even if a gas condensing boiler were 100% efficient it could only achieve around 184 gCO₂/kWh based on standard values from the Carbon Trust. Carbon Trust (2011), *Conversion Factors*

⁵¹ Including those with flue gas heat recovery.

The policy has the advantage of limited direct cost to government (which may make it more robust to change). However, consumers will face higher heating system replacement costs which could be a major issue for lower income households with limited access to finance (in particular given that many purchases will be unplanned, distressed purchases).

Related to this, there may be perverse incentives associated with the policy. For example, consumers may seek to maintain old boilers for as long as possible to avoid high replacement costs. There is also potential for gaming around suitability criteria (e.g. consumers may seek to avoid meeting the criteria).

Combining a carbon standard at point of replacement with capital grants and/or the option to use the Green Deal loans could help mitigate these distributional and perverse incentive problems.

In Annex 2 we describe how these policy measures were applied in the uptake modelling

Table 12 below summarises how the policy measures were modelled in the uptake model.

Table 12. Inputs to the uptake model for each policy measure

Policy measure	Input(s) to uptake model
Installer and consumer training with information campaigns	<ul style="list-style-type: none"> Time to research new technology reduced from 8h to 4h. Reduced awareness barrier (more rapid diffusion). Incremental improvement in SPF of 0.1 per year for five years.
Extension of the RHI beyond 2020	<ul style="list-style-type: none"> RHI extended to 2030 No further degression of tariff over 2020 to 2030 period. Actual tariff depends on amount of degression from start of RHI to 2020 (varies between policies according to rate of uptake).
Capital grants	<ul style="list-style-type: none"> Reduction in heat pump capital cost of 50%.
Loan guarantees via the Green Deal	<ul style="list-style-type: none"> Loans are modelled at an interest rate of 7% and up to 50% of installed cost⁵². RHI receipts are included in the Golden Rule calculation. 'Social finance' is modelled by assuming all consumers invest based on a 3.5% hurdle rate.
Tightened carbon emissions standard on new build	<ul style="list-style-type: none"> For the 2016 standard (10-14kgCO₂/m²/year) we uplift the capital cost of each technology to reflect the energy efficiency costs associated with achieving the target. We use a rate of £2/kg/CO₂/year to calculate these capital costs. For the stronger standard (6 kgCO₂/m²/year from 2020) it would be extremely expensive to achieve this whilst retaining a gas boiler given reductions in the carbon intensity of electricity. Therefore we model this more stringent standard by ruling out gas boilers as an option for new homes.
Carbon emissions standard on heating system replacement	<ul style="list-style-type: none"> Boilers ruled out as an option for replacement in existing homes.

Source: Frontier Economics

⁵² This is implemented under as a loan covering 50% of the loan because of the requirement, under the Golden Rule calculation, that RHI receipts and energy savings are sufficient to cover loan repayments. Under higher loan percentages than 50%, this requirement is not generally met, resulting in low uptake.

4.4 Impacts and assessment of individual policies measures

In choosing and assessing these policy measures we used the following criteria.

- **Effectiveness in tackling barriers.** Policies must be effective in reducing the main barriers associated with heat pump uptake.
- **Flexibility in the face of change.** There is uncertainty around which technologies will prove to be most appropriate for low-carbon heating. Therefore policies should ideally be flexible to changing circumstances.
- **Investor and consumer certainty.** Effective policies need to be robust over time and give long-term confidence for manufacturers, builders, installers and consumers investing.
- **Risks and unintended consequences of policy measure.** Policies involve risks around their effectiveness, unintended consequences and potential negative public reaction.
- **Impact on cost over time.** There is some scope for cost-reduction for heat pumps (particularly with regard to installation costs) and some policies may help encourage this.
- **Distributional impacts.** Heating is a basic need and represents a high proportion of spending for low income households. Therefore it is important to consider the impacts of policy measures on low-income households.

A qualitative assessment of these policy measures individually is shown below in Table 13. We provide a quantitative assessment of the costs and impacts on uptake of these measures as part of our assessment of the policy packages.

Table 13. Qualitative assessment of individual policy measures

	Overall assessment	Effectiveness in tackling barriers	Flexibility in face of change	Investor and consumer certainty	Risks and unintended consequences	Impact on cost over time	Distributional impacts
Installer/consumer training with information campaigns	An effective, low-cost method of improving confidence in heat pumps	Effective in reducing behavioural barriers but cannot overcome cost barriers	Certification and information can be adjusted over time	Standards and information give consumer greater confidence to invest	Limited risks so long as information is accurate and standards are appropriate		
Extension of the RHI beyond 2020	Directly tackles cost barriers but high cost to government	Directly addresses cost barrier to uptake	Subsidy can be adjusted if costs change	High subsidy costs can make scheme vulnerable to change by government		Mass deployment may generate some cost savings via learning	Low-income groups with limited access to finance less able to invest and benefit from subsidy
Capital grants	Directly tackles cost and finance barriers but high cost to government	Directly addresses cost and access to finance barriers to uptake	Subsidy can be adjusted if costs change	High subsidy costs can make scheme vulnerable to change by government		Mass deployment may generate some cost savings via learning	Capital subsidy helps address limited access to finance for lower-income groups
Loan guarantees	May have limited impact on its own but a low-cost way of reducing financing barriers	Addresses access to finance barrier but, on its own, may not have a major impact	Highly flexible as consumer are free to choose technology/measure		Risk heating cost savings may not justify loan costs if heat pump underperforms		Loan guarantee helps address limited access to finance for lower-income groups
Tightened carbon emissions standards on new build	Highly effective in removing behavioural barriers and ensuring suitability of new housing stock for heat pumps	By mandating, cost and behavioural barriers are effectively removed for new homes	By mandating on the basis of CO ₂ , heat pumps will not be taken up if they not the most cost-effective option	Creation of a market would improve investor confidence		Mass deployment may generate some cost savings via learning	
Carbon emissions standard on heating system replacement	Highly effective in removing behavioural barriers and increasing uptake but may create financial difficulties for households	By mandating cost and behavioural barriers are effectively removed across existing homes	A CO ₂ standard on the heating system may rule out boiler/electric heat solutions with energy efficiency	Creation of a large guaranteed market would improve investor confidence	May encourage efforts to avoid replacement (e.g. maintaining old boilers)	Mass deployment may generate some cost savings via learning	Mandate could result in high unavoidable replacement costs for consumers with limited funds

Achieving the required uptake by 2030

4.5 Policy packages to deliver the required uptake

Having established individual policy measures to address barriers, we selected distinct packages of measures to increase heat pump uptake to 2030.

Two measures are included in all packages:

- **Installer/consumer training with information campaigns.** Due to the relatively low cost of these measures and the importance of awareness barriers (including time to research) in the early years we include this bundle of measures in all policy packages⁵³.
- **New home carbon standard in 2016.** We include the 10-14kgCO₂/m²/year standard from 2016 in all scenarios on the basis that new homes are typically the most cost-effective place to install heat pumps. Moreover, focusing on new homes first is a highly effective means to tackle behavioural and suitability barriers to heat pump uptake.

These two measures are included in all of the packages because of their relative cost-effectiveness in tackling barriers.

We then developed policy packages by first looking at additional measures individually and then looking at combinations of measures. We present the following policy packages (which are summarised in Table 14).

- **Package 1: RHI-driven uptake.** In this package the RHI extended to 2030 (it stops at 2020 in the current policy path). The tariff levels are kept at 2020 levels through to 2030 (i.e. no further degression).
- **Package 2: Capital grant-driven uptake.** In this package the RHI is replaced by a system of capital subsidies (covering 50% of the capital cost) from 2020.
- **Package 3: Green Deal.** In this package we assume the Green Deal loans are available for installation of heat pumps through to 2030.
- **Package 4: Tightened new home standard.** In this package the new home carbon standard is tightened to <6kgCO₂/m²/year from 2020.

⁵³ If only this measure is added to the base case uptake increase from 0.7m to 1.5m by 2030. The policy has a positive NPV (relative to the base case) of £446m.

- **Package 5: Off-gas grid standard.** In this package a carbon standard on heating system replacement is applied to off-gas grid homes only from 2020. The rationale for targeting these homes is that these are likely to be using higher-carbon sources of heating such as oil or resistive electric heating, and therefore the potential for carbon savings is higher. This also includes the tightened new homes standard.
- **Package 6: All homes standard.** In this package a carbon standard on heating system replacement is applied to all homes only from 2020. This package also includes the tightened new homes standard.
- **Package 7: All homes standard with Green Deal.** This package is the same as Package 6 with the addition of the Green Deal on the basis that this can help mitigate the negative financial impact of the replacement standard on consumers.
- **Package 8: RHI and Green Deal.** This package combines extension of the RHI with the Green Deal.
- **Package 9: Capital subsidy and off-gas grid homes standard.** This package combines capital subsidies in the 2020s with a carbon standard on heating system replacement for off-gas grid homes only from 2025. The rationale is that the capital subsidy can help mitigate the negative financial impact of the replacement standard on consumers.
- **Package 10: Social finance and an 'optimised' RHI.** In this package we aim to illustrate the impact of finance provided at a social discount rate, rather than at commercial rates. This allows consumers to finance via a loan at a social rate of 3.5%. In this package we also include an 'optimised' RHI which caps the RHI tariff at a level that will only deliver uptake in the more cost-effective segments and then optimises the tariff level within that cap to avoid large rents being paid and limit subsidy costs⁵⁴.

Another option to reduce subsidy requirements, which we do not model, would be to exempt some heat pump customers from transmission and distribution charges. For example, for heat pumps which use storage and run at night an

⁵⁴ The RHI tariff is capped at £ 30/MWh for ASHP and £ 60/MWh for GSHP. Within the cap, the RHI tariff is then optimised to provide a simple payback of five years for each property type. This avoids large rents being paid to cost-effective market segments and reduces the overall subsidy cost.

exemption could be justified on the basis that they do not add substantially to network costs (which are heavily linked to peak demands)⁵⁵.

Table 14. Policy packages

	P1: RHI- driven uptake	P2: Capital subsidy	P3: Green deal	P4: New home standard	P5: Off-gas standard	P6: All homes standard	P7: Mandate combo	P8: RHI and Green Deal	P9: Capital subsidy and off- gas standard	P10: Social finance and RHI
Installer/consumer training & info campaigns	2015-2030	2015-2030	2015-2030	2015-2030	2015-2030	2015-2030	2015-2030	2015-2030	2015-2030	2015-2030
Extension of the RHI beyond 2020	to 2030							to 2030		to 2030 (optimised)
Capital grants		2020-2030							2020-2030	
Loan guarantees and social finance			Green Deal to 2030				Green Deal to 2030	Green Deal to 2030		Hurdle rates set to social discount rate
Tightened carbon emissions standards on new build	2016-2030 (<10-14kg)	2016-2030 (<10-14kg)	2016-2030 (<10-14kg)	2016-2020 (<10-14kg)	2016-2020 (<10-14kg)	2016-2020 (<10-14kg)	2016-2020 (<10-14kg)	2016-2020 (<10-14kg)	2016-2020 (<10-14kg)	
				2020-2030 (<6kg)	2020-2030 (<6kg)	2020-2030 (<6kg)	2020-2030 (<6kg)		2020-2030 (<6kg)	
Carbon emissions standard on heating system replacement					2020-2030 (off-gas grid)	2020-2030 (all homes)	2025-2030 (all homes)		2025-2030 (off-gas grid)	

We summarise the uptake achieved and cost-effectiveness of packages in Figure 44, Figure 45 and Figure 46. We use three key metrics:

- **Total uptake.** This is the total number of heat pumps installed and associated heat output (in TWh) by 2030.
- **Total net present value (NPV).** This is the present value of the change in capital and operating costs plus the present value of the carbon savings⁵⁶ for

⁵⁵ Transmission and distribution charges are estimated to represent around 3.6p/kWh in 2020. An exemption would reduce heat pump operating costs facing consumers by around one quarter, substantially reducing the subsidy required to stimulate uptake.

each package versus the base case. We use standard DECC ‘non-traded’ carbon values in this assessment to value carbon savings⁵⁷.

All costs and benefits are discounted to 2010 using a discount rate of 3.5% (with costs and benefits assumed to accrue at the end of each year). Costs and carbon savings are assessed over the lifetime of all heat pumps installed before 2030⁵⁸.

- **Cost per tonne CO₂ saved.** This is the cost, in present value terms, per tonne CO₂ of saved for each package versus the base case.

The uptake levels and costs needed to calculate these metrics were taken from the outputs of Element Energy’s uptake model (described in Section 3). In the following we assume hybrid heat pumps are not an option and have also excluded large-scale heat pumps linked to district heating systems. The impact of inclusion of hybrid heat pumps is described in Box 1. The potential of larger scale heat pumps serving district heating networks is discussed in Annex 4.

⁵⁷ We use the central, ‘non-traded’ carbon value published by DECC in January 2013. <https://www.gov.uk/government/policies/using-evidence-and-analysis-to-inform-energy-and-climate-change-policies/supporting-pages/policy-appraisal>

⁵⁸ This means that for heat pumps installed in 2030 we assess their carbon savings up to 2045.

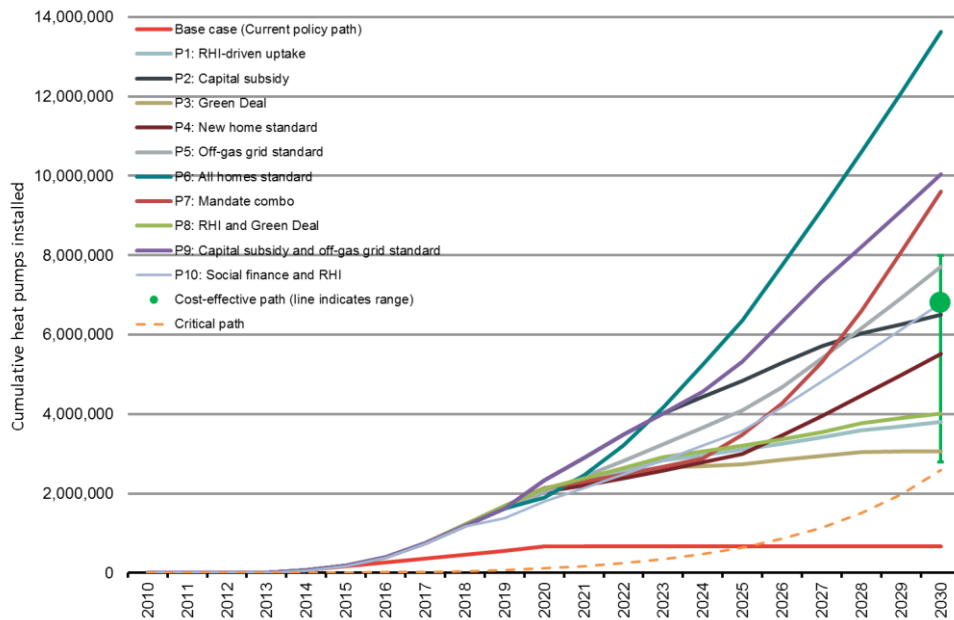
Figure 44. Uptake and present value of policy packages

	Base case	P 1: RHI- driven uptake	P 2: Capital subsidy	P 3: Green deal	P 4: New home standard	P 5: Off- gas standard	P 6: All homes standard	P 7: Mandate combo	P 8: RHI and Green Deal	P 9: Capital subsidy and off-gas standard	P 10: Social finance and RHI
UPTAKE											
Heat pumps installed by 2030 (cumulative)	0.7	3.8	6.5	3.1	5.5	7.7	13.6	9.6	4.0	10.0	6.2
Heat pump output in 2030 (TWh)	5	29	57	23	40	75	147	100	32	99	45
BENEFITS/COSTS											
Total NPV, £m (A+B+C)	-	-391	-1,957	42	1,048	6,078	3,110	3,093	-1,026	3,145	944
Government, £m (A)	-	-3,194	-6,902	-521	-186	-265	-19	-521	-4,394	-848	347
Consumers, £m (B)	-	-476	-955	-1,029	-3,045	-9,921	-23,696	-13,310	-191	-12,490	-5,658
Carbon, £m (C)	-	3,482	5,693	1,802	4,402	10,009	19,411	13,379	3,798	12,499	5772
COST-EFFECTIVENESS											
£cost/tonne CO₂ saved	-	98	120	80	73	38	85	81	113	73	77

Note: All costs/benefits are measured relative to the base case. To determine uptake we used retail gas and electricity prices. We then calculated overall NPVs using long-run variable costs (LRVCs) of gas and electricity in accordance with DECC appraisal guidance. Government costs are subsidy costs/savings and £81m arising from an information campaign in all packages. There are other distributional impacts on margins for retail firms, network firms as well as tax revenues not included in the distributional analysis (hence impacts on consumers, government and carbon do not sum to the NPV).

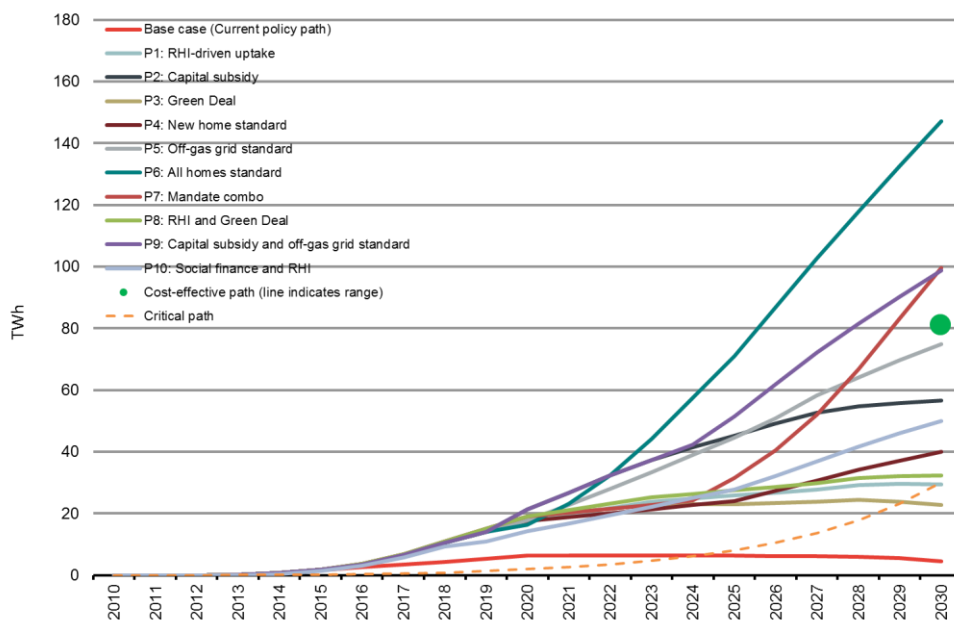
Achieving the required uptake by 2030

Figure 45. Uptake of heat pumps in the domestic sector under different policy packages (total installations)



Source: Element Energy and Frontier Economics.

Figure 46. Uptake of heat pumps in the domestic sector under different policy packages (TWh heat output)



Source: Element Energy and Frontier Economics.

Achieving the required uptake by 2030

Further detail on how these policies impact the uptake of heat pumps, in terms of the split of uptake between technology types and between different segments of the building stock, is provided in Annexe 6.

The following provides a brief description of the effectiveness and notable features of this assessment.

- **Uptake achieved.**

- All packages comfortably exceed the **“critical path”** level of 2.6m heat pumps installed. Most packages also exceed the critical path level 30 TWh in homes by 2030, with the exception of Package 1 (RHI) and Package 3 (Green Deal).
- Five packages exceed the **“cost-effective path”** level of heat pump uptake in terms of number of installations and/or TWh (6.8m heat pumps, 81 TWh). Four of these are all packages that involve carbon standards on heating system replacement in existing homes: Package 5 (Off-gas standard), Package 6 (All homes standard), Package 7 (Mandate combo) and Package 9 (Capital subsidy and off-gas standard). The fifth combines social financing of heat pumps with an ‘optimised’ RHI.

- **Overall NPV and cost-effectiveness of packages.** Seven policy packages have a positive net present value (NPV) and an average cost per tonne of carbon saved that is below the value of carbon. The uptakes in these packages are in line with those suggested by the “cost effective” path suggesting that this is desirable and achievable.

- The highest NPV comes from Package 5 (off-gas grid standard). This results from the higher costs of heating alternatives (e.g. oil and resistive electric heating) in these homes and the higher carbon savings that can be achieved from switching to heat pumps.
- Other mandating policies (Package 6 and Package 7) have lower NPVs as, although they include off-gas grid homes, they result in some installations in home types where heat pumps are not cost-effective in saving carbon. Package 4 (new homes standard) delivers a positive NPV, reflecting the cost-effectiveness of heat pumps in new homes. But the NPV is lower than other mandating policies because it does not include installation in off-gas grid homes.
- Package 10 (social finance and RHI) delivers a higher NPV than Package 1 (RHI). In this package the RHI tariff has been ‘optimised’ so as to deliver uptake in the most cost-effective property types and to limit the overall subsidy cost. This package suggests that there is scope to improve the efficiency of the RHI and that measures to improve

consumers' access to finance and lower their required hurdle rates could be important.

- Package 2 (capital subsidy) has a large negative NPV which partly reflects that capital subsidies do not always encourage uptake in properties, or heat pump types, which are most cost-effective in saving carbon.

The average cost per tonne of carbon saved ranges from £38 to £120/tonneCO₂. To put this in context, the DECC carbon price ('non-traded') rises from £59/tonneCO₂ in 2013 to £76/tonneCO₂ in 2030 and £182/tonneCO₂ by 2045.

These packages were modelled without the option of hybrid heat pumps. NPVs are generally higher when modelled with hybrids included (see Section 4.5) suggesting these should be included in policy incentives.

- **Distribution of costs.** In general policy packages which focus on subsidies have a high cost to government (e.g. Packages 1, 2 and 8).

Package 10 also focuses on subsidy. However, because consumers invest on the basis of social discount rates in this package, much lower subsidies are required to induce investment with, subsidy costs only slightly higher than the base case. On top of this, tariffs are set such that uptake is focused on cost-effective property and heat pump types and towards the late 2020s when heat pumps are most cost-effective. These factors greatly reduce subsidy costs and result in savings to government compared to the base case.

Packages that are heavily reliant on standards (e.g. Packages 6 and 7) result in high direct costs for consumers. In these cases consumers could incur sudden and high capital costs when they replace their heating system, potentially including extra financing costs not captured in this cost assessment⁵⁹.

The negative effects of this could be reduced by Green Deal (or similar) financing which allows spreading of payments over time. Finally, it is notable that, under the assumptions used for modelling uptake, subsidy-based policies (Packages 1, 2, 8 and 10) also result in some costs to consumers over the lifetime of the heat pump.

⁵⁹ For example, say consumers needed to finance these capital costs with a 10-year loan at a 7% interest rate the present value of the capital costs facing consumers would increase by around 20% for each installation. This would increase the costs to consumers by £3bn in Package 6 and £2bn in Package 7.

Finally, it is notable that, under the assumptions used for modelling uptake, subsidy-based policies (Packages 1, 2, 8 and 10) also result in some costs to consumers over the lifetime of the heat pump⁶⁰.

Box 2: Impact of including transitional technologies

In the modelling of the policy packages above we exclude the option for hybrid solutions (where air-source heat pumps are used in combination with gas boilers) on the basis that these were not included in modelling of the “cost-effective” pathway for the CCC.

Hybrids are potentially attractive to consumers as they retain an element of gas boiler technology that consumers are comfortable with and may require less adaptation of existing heat distribution systems. They also have potential technical advantages, such as the ability to optimise heat pump efficiency by controlled dispatch. However, in the long-term the use of hybrid solutions may not be fully consistent with meeting carbon targets and may become less cost-effective as volumes of gas supplied for domestic heating drop.

Figure 47 shows the uptake and NPVs under policy packages with and with hybrid option. The uptake and NPVs are generally higher with the hybrids included, in particular for the packages which include a capital subsidy.

Levels of carbon savings are generally slightly higher when allowing for hybrid solutions - suggesting that up to 2030 hybrid solutions could be consistent with meeting carbon targets. The average cost-effectiveness of carbon abatement is somewhat lower than in the scenarios which exclude hybrids, ranging from £11 to £122/tonneCO₂.

⁶⁰ Under the uptake model consumers choose to install based on the payback period whereas operating costs are assessed over the full lifetime of the heat pump (15 years) using a social discount rate (3.5%). In the later years, as result of rising electricity prices and the expiry of subsidies, there are higher operating costs relative to the counterfactual for many heat pump installation which results in costs to consumers over the lifetime of the heat pump (net of subsidy received) even though the achieve payback in the early years. This highlights the issue that unless the carbon cost associated with gas heating is corrected for with a tax or subsidy measure over the life of the heat pump, consumers may not realise savings compared to gas heating in later years.

Figure 47. Uptake and present value of policy packages (with hybrids option)

	Base case	P 1: RHI- driven uptake	P 2: Capital subsidy	P 3: Green deal	P 4: New home standard	P 5: Off- gas standard	P 6: All homes standard	P 7: Mandate combo	P 8: RHI and Green Deal	P 9: Capital subsidy and off-gas standard	P 10: Social finance and RHI
UPTAKE											
Heat pumps installed	0.9	4.5	11.5	3.8	6.0	8.0	14.9	11.4	4.9	12.8	10.3
Heat pump output in 2030 (TWh)	6	34	84	26	42	70	148	111	34	114	79
BENEFITS/COSTS											
Total NPV, £m (A+B+C)	-	303	953	1,030	2,198	8,953	8,395	6,820	-71	7,552	-4,308
Government, £m (A)	-	-4,274	-992	-1,598	-757	-887	-598	-1,598	-5,578	-992	-1,503
Consumers, £m (B)	-	-281	-13,499	-750	-2,694	-8,317	-23,325	-14,164	-118	-15,465	-6,546
Carbon, £m (C)	-	4,018	12,683	2,474	4,563	10,151	20,922	15,609	4,407	16,864	9,215
COST-EFFECTIVENESS											
£cost/tonne CO₂ saved	-	81	91	47	49	11	60	58	88	55	122

Note: All costs/benefits are measured relative to the base case. To determine uptake we used retail gas and electricity prices. We then calculated overall NPVs using long-run variable costs (LRVCs) of gas and electricity in accordance with DECC appraisal guidance. Government costs are subsidy costs/savings and £81m arising from an information campaign in all packages. There are other distributional impacts on margins for retail firms, network firms as well as tax revenues not included in the distributional analysis (hence impacts on consumers, government and carbon do not sum to the NPV).

Achieving the required uptake by 2030

4.7 Recommendations on policies needed to meet the CCC's "cost-effective pathway"

Our modelling suggests that the CCC's "cost-effective pathway" is achievable with strong policy measures.

Based on the qualitative and quantitative assessment of the policy packages in this section we make the following policy recommendations.

- **Enhanced heat pump certification (requiring installer and consumer training) with sustained information campaigns should be implemented in the next few years.** Given the low costs of this measure and the current importance of awareness barriers (including time to research) we recommend that these measures are implemented in the next few years.
- **Heat pump uptake should be stimulated by the end of this decade in new homes through tightening carbon standards for new homes.** Regulation of new homes first is a highly effective means to tackle behavioural and suitability barriers to heat pump uptake. By targeting the standard based on carbon (in Part L of the Building Regulations) the policy retains the flexibility to allow other options to reduce emissions that may be more cost-effective in certain circumstance or different scenarios.
- **Policies should encourage uptake of heat pumps in off-gas homes in the 2020s.** Off-gas grid homes are one of the most cost-effective home types to target as the heat pumps are replacing high carbon heating options such as oil in the homes. Policies such as an extended and optimised RHI or an off-gas grid carbon standard could be used to encourage this. However, we note that many off-gas grid homes are poorly insulated and therefore suitability criteria and/or complementary energy efficiency measures may be needed to ensure heat pumps are not installed in unsuitable homes.
- **Green Deal or similar financing arrangements for heat pumps may be important in the 2020s.** Heat pumps have high capital costs relative to gas boilers (and other conventional alternatives). To reduce financial barriers and reduce hurdle rates required by consumers to invest, the Green Deal or a similar loan guarantee arrangement for heat pumps could be important. Moreover, if any carbon standard on heating system replacement were implemented such financing arrangements could help mitigate the potential negative impacts of consumer facing sudden upfront costs when replacing their heating system.

In addition, Renewable Heat Zones should be considered as a way of stimulating local supply chains and network operators as well as providing important learning for other areas.

5 Conclusions and timeline

The analysis in this report suggests that heat pump uptake consistent with the CCC “cost-effective path” could be achievable with strong policy measures in the 2020s.

Under the current policy path the level of heat pump uptake would be well below the “cost-effective path” and also below the “critical path” needed to leave open the possibility of meeting 2050 heat pump uptake scenarios.

To achieve this level of uptake major step-changes in policies will be needed over the next decade to overcome barriers to uptake. In particular:

- **Cost and access to finance.** Up to 2030 the higher capital cost of heat pumps relative to conventional boiler alternatives will be a major barrier to uptake. In the near term the RHI will play a major role in addressing this barrier. Up to 2030, the Green Deal or similar loan guarantee arrangements could be important in making heat pumps easier to finance for consumers and reducing the subsidies required to encourage uptake.
- **Awareness, confidence and hidden costs (e.g. time).** Consumer awareness and confidence in heat pumps is currently limited. This can be addressed, at a relatively low cost, by mandating training of installers and heat pump customers as well as through large-scale information campaigns. Policies which encourage mass uptake, such as subsidies and carbon standards, can also indirectly improve awareness and confidence.
- **Suitability.** Up to 2030 there are a sufficient number of suitable homes needed to allow well over 6.8m heat pumps to be installed - although even in these homes there are refurbishment requirements that raise capital costs by around £1,000/installation. Beyond 2030 major increases in suitability will be needed such that almost all homes are suitable for heat pumps by 2050. Therefore continued and new policies to improve energy efficiency (particularly in “hard-to treat” homes with solid walls) will be needed, potentially beyond 2030.

To bring heat pump uptake close to the “cost-effective” level in 2030 would entail the introduction of major policy changes. We have identified a number of policy packages that offer value for money once the benefit of carbon saved is factored in.

The most cost-effective policy packages are those which focus installations on new build properties and suitable off-gas properties.

5.1 Timeline of actions to meet the “cost-effective pathway”

Table 15 shows our recommended timeline of actions to achieve heat pump uptake which is consistent with the CCC’s central “cost-effective pathway” by 2030.

Table 15. Timeline of actions to meet 2030 uptake pathways

Date	Action
Present-2020	RHI support
2015-2030	Regulate for enhanced installer and consumer training
2015-2030	Information campaigns
2016-2020	New home carbon standard of < 10-14 kgCO ₂ /m ² /year
2020-2030	New home carbon standard of < 6 kgCO ₂ /m ² /year
2020-2030	Green Deal or other loan guarantees made widely available for heat pump installations
2020-2030	An ‘optimised’ RHI or off-gas grid carbon standard to focus installations on suitable off-gas grid properties.

Annex 1: Identification of policy measures

In Section 4, we presented a short-list of policy measures that we use in the policy packages. This annexe sets out how we identified a longer list of policies and how we selected a short list from these.

We first identified a long-list of policies based on a mapping of policies to uptake barriers and a review of the literature on uptake policies. This mapping is shown in Figure 48, Figure 49 and Figure 50. We then assessed these policies based on the criteria set out in Section 4 giving us the short-list of six policy measures.

Figure 48. Barriers addressed under "enabling" policy measures

		ECONOMIC		BEHAVIOURAL					TECHNICAL				SUPPLY-SIDE	
		Cost	Access to finance	Attitudes / unfamiliarity	Space and aesthetics	Hidden costs (e.g. time)	Landlord-tenant split	Suitability of building	Noise	Regulatory barriers	Installation / Operational	Supply chain capacity	Supply-chain coordination	
Trials and test facility	Larger-scale and ongoing trials of heat pumps in different building types			X							X		X	
Consumer/installer training with information campaign(s)	Funding of information campaigns on the benefits/process of installing heat pumps.			X		X		X			X	X		
Standards, certification and labelling	Enhanced standards and labelling on the performance of and installation of heat pumps (industry- or govt-led)			X									X	
Supply-chain development initiatives	Industry development of repair and maintenance networks (e.g. via trade associations)										X	X	X	

Figure 49. Barriers addressed under "incentivising" policy measures

		ECONOMIC		BEHAVIOURAL					TECHNICAL				SUPPLY-SIDE	
		Cost	Access to finance	Attitudes/ unfamiliarity	Space and aesthetics	Hidden costs (e.g. time)	Landlord-tenant split	Suitability of building	Noise	Regulatory barriers	Installation / Operational	Supply chain capacity	Supply-chain coordination	
Operating subsidies for HPs	Extension of RHI-style subsidy beyond 2020	X												
Capital subsidy for HPs	Upfront payment of subsidy via a capital grant or allowance	X	X											
Loan guarantees for HP installation	Measures to improve access to finance such as allowing consumers finance HPs via their energy bill (e.g. Green Deal)		X				X							
Energy service business models	Industry offering heating services contracts which finance upfront costs and take operational risk		X	X		X					X			

Figure 50. Barriers addressed under "mandating" policy measures

		ECONOMIC		BEHAVIOURAL					TECHNICAL				SUPPLY-SIDE	
		Cost	Access to finance	Attitudes/ unfamiliarity	Space and aesthetics	Hidden costs (e.g. time)	Landlord-tenant split	Suitability of building	Noise	Regulatory barriers	Installation / Operational	Supply chain capacity	Supply-chain coordination	
Mandation of HPs in new homes	This could be achieved via new build standards either directly or through a carbon (inc. SAP) or 'renewable' heat requirement.	X	X	X	X	X			X	X				
Mandation of HPs in existing homes	Requirements that existing homes have a HP installed (potentially on basis of house type)	X	X	X	X	X	X		X	X				
Mandation of HPs at point of boiler replacement	Requirement that boilers are replaced with HPs (subject to suitability). This could be implemented via emissions standard. Softer version that HPs must be "offered".	X	X	X	X	X			X	X				
Public procurement	Govt could conduct mass public procurement of heat pumps (e.g. for schools, social housing) to stimulate the mkt and increase visibility.			X								X	X	
Relax permitted development rules	Relax noise thresholds in permitted development								X					

Annex 2: Training and information policy measure design features and costs

This annex provides details on how the training and information policy measure presented in the main report could be designed and our estimates of the costs of this. The measure consists of a bundle of three measures aimed at enabling greater take-up of heat pumps:

- Installer training and certification;
- Consumer training; and
- Marketing/information campaigns.

Installer training

Under the base case we assume all heat pump installers are trained and certified to the MCS standard before they perform any installations. Such training schemes have been a popular policy tool in other countries, particularly in countries such as Sweden, the Netherlands, and Switzerland, where the market for heat pumps is much further developed than in the UK and is viewed as important to avoid periods of bad repute through a lack of qualified installers (EHPA, 2005)⁶¹. The cost of installer training is likely to be very low, equating to around £5 per installation up to 2030 based on our estimations. This is captured in the assumed cost of heat pumps.

The additional training measure which we include provides basic training on heat pumps to *all* heating engineers. This aims to ensure that the repairers of heating systems have the basic knowledge to provide sound advice on heat pumps, so consumers can assess their merits relative to other heating options at the point their heating system breaks down/ is due to be replaced.⁶²

This training would be regulated, to ensure such advice is not biased towards more conventional heating systems. For example the scheme could provide a ‘checklist’ for repairers outlining the key points that should be covered when giving advice to consumers (e.g. expected system lifetime, process of installation, energy efficiency requirements, potential cost savings and available financing options), and key information/sources of information that should be made available to the consumer

⁶¹ EHPA (2005) *Heat Pumps Technology and Environmental Impact*

⁶² As highlighted in Section 2, the information that a consumer receives at the point of replacement has a significant influence on their subsequent heating system choices.

This basic training would act to improve awareness at the point of replacement, and also addresses the “hidden cost” barrier by reducing necessary research time. Our estimates suggest that the total cost of training all heating engineers across the UK could be around £2m per year.

Consumer training

This part of the measure involves the heat pump installer providing 2-hour training sessions to consumers at the point of installation, showing them how the heat pump works, and how to operate it. It would also include a follow-up visit after 6 months for 2 hours, where the installer would monitor the heat pumps performance and check if it is being used correctly (e.g. use of heating controls). As part of this, data would be collected on heat pump usage and performance (subject to the consumers’ consent) such to help installers provide better advice on how to improve performance.

The impact of the measure would be to improve consumer confidence in the technology and improve the operational performance of the heat pump. There is evidence to suggest that there is a strong need for additional consumer advice in relation to the operation of heat pumps. For example, findings from heat pump trials conducted by the Energy Savings Trust in the UK suggest that consumers have difficulty understanding instructions for operating their heat pumps (Energy Savings Trust, 2010)⁶³.

The cost of consumer training is likely to be around £60 per installation⁶⁴.

Marketing/Information campaigns

This part of the measure provides consumers with information on heat pumps via marketing campaigns. This would be targeted at consumers before the point of purchase, primarily to build awareness of heat pumps and their advantages over other heating systems.⁶⁵ Given this, at least part of the campaign would be put in place from 2015 onwards.

The campaign is aimed primarily at reducing the behavioural barriers to heat pump uptake. In particular, they address the “awareness and confidence” in the

⁶³ Energy Savings Trust (2010) *Getting warmer: a field trial of heat pumps*

⁶⁴ This cost is relatively high because the training is ‘one-to-one’ with the consumer, meaning the cost of a given hour of training cannot be spread across a number of installations.

⁶⁵ Currently, awareness of heat pumps as an alternative heating option is low across the UK. In a survey conducted by Ipsos Mori and the Energy Saving Trust, 68% (53%) of respondents had never heard of Air Source (Ground Source) Heat Pumps. See P59 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/191541/More_efficient_heating_report_2204.pdf

technology, and reduce the “hidden costs” (such as research costs) associated with heat pumps.

There is evidence that marketing campaigns have been effective in addressing these barriers and stimulating heat pump markets in other countries. For example, a procurement programme including a test and certification programme for new installations, and marketing activities consisting of information campaigns, brochures and articles, was successful in boosting demand for heat pumps in Sweden, leading to a doubling of sales between 1995 and 1996⁶⁶. In Switzerland, the Swiss Heat Pump Promotions Group (FWS), including a professional marketing company, also supported a range of marketing activities and heat pump exhibitions in the mid-1990s⁶⁷.

We estimate the cost of the information campaign to be relatively low at around £8m/year up to 2030.

To sum up we estimate the overall costs of the “training and information” policy measure to be a fixed cost of £10m/year (£2m/year for installer training and £8m/year for the information campaign) plus £60/installation for the consumer training.

The assumptions and method for these estimates are summarised below in Table 16.

⁶⁶ Marketing activities represented a significant part of the programme, being allocated 50% of the total programme budget.

⁶⁷ Kiss, B., Neij, L. & M. Jakob (2012). *Heat Pumps: A comparative Assessment of Innovation and Diffusion Policies in Sweden and Switzerland*. Historical Case Studies of Energy Technology Innovation in: Chapter 24, The Global Energy Assessment. Grubler A., Aguayo, F., Gallagher, K.S., Hekkert, M., Jiang, K., Mytelka, L., Neij, L., Nemet, G. & C. Wilson, Cambridge University Press: Cambridge, UK.

Annex 2: Training and information policy measure design features and costs

Table 16. Measuring the cost of the training and information policy measure

Basic Installer Training – All Heating Engineers	
Cost: £2m/year	
Method: Annual costs are estimated by multiplying the number of heating engineers needing basic training each year, with the cost of basic training per engineer. Training is needed every 5 years.	
Input	Value
Unit cost of a training scheme	£200 ⁶⁸
Total Number of heating engineers in the UK	50,000 ⁶⁹
Time before re-training (years)	5
Consumer Training	
Cost: £60/installation	
Method: The cost for each installation is calculated by multiplying the installer's hourly rate by the number of hours spent training the consumer post-installation.	
Inputs	Value
Installer hourly rate	£15
Number of hours to train a consumer	4
Marketing/Information Campaign	
Cost: £8m/year	
Inputs	Value
Campaign planning/design costs	£1m/year
Leaflet costs	£2m/year (10m leaflets per year @20p per leaflet)
TV and Radio Advertising	£2m/year
Online advertising costs	£1m/year (20m impressions/year @5p/impression)
Exhibition costs	£2m/year (20 exhibitions @£100,000/exhibition)
Source: Frontier Economics	

⁶⁸ Based on a third of the cost of the 3-day heat pump training course provided by NICEIC.⁶⁹ Based on a range of 11,000 – 115,000 (lower bound based on annual boiler installations; upper bound based on ONS employment figures).

Annex 3: Communal ground collectors for GSHP systems

The costs used to model ground source heat pump economics in this analysis are based on the assumption that each property has an individual ground collector (based on borehole collector costs). If ground source heating were to be installed in a cluster of neighbouring buildings, a cost reduction could potentially be achieved by connecting each property to a single, communal ground collector. This arrangement has a number of benefits that can provide cost reduction, as follows:

- Due to diversity in the heat loads across the buildings connected (i.e. all buildings do not demand peak load simultaneously), the required collector length per unit of installed capacity can be reduced.
- There can be a benefit from drilling fewer, deeper boreholes to meet the combined heat load, rather than individual boreholes for each property. This derives from reduced drilling time (e.g. fewer movements of the rig) and in certain areas because drilling conditions become easier once the near surface layer has been penetrated (note that this is very dependent on the local geology and, in certain areas the reverse may be true).
- Reduction in site set-up time and other fixed costs.

Of these potential sources of cost reduction the reduced requirement for ground collector is perhaps the most significant. A high-level approximation of the scale of cost reduction that could be achieved as a result of diversity can be made based on typical drilling costs and figures for the collector length required per unit of heating capacity.

The Microgeneration Certification Scheme (Work Stream 6) has produced a Standard for the area of ground collectors⁷⁰, which sets out the maximum heat that can be extracted per unit of borehole length under different ground conditions and under different assumptions for the Full Load Equivalent (FLEQ) hours of operation (FLEQ). Due to the impact of diversity across multiple systems connected to the same ground collector, the collector area can be designed to a lower FLEQ run hours than would be the case for an individual system.

An estimate of the scale of cost reduction is tabulated below.

⁷⁰ MCS 022: Ground heat exchanger look-up tables, Supplementary material to MIS3005,2008

	3-bed semi with individual borehole	Group of 10 3-bed semis with communal borehole
Design FLEQ (run hours)	3,600	1,200
Maximum heat extraction rate (W/m) ⁷¹	39	51
Typical borehole drilling price (including ground loop installation) (£/m ²)	£40	£40
Heat pump capacity per property (kW)	8	8
Ground collector cost (£)	£8,205.13	£6,274.51
% reduction on borehole cost	24%	

Assuming an overall installed system cost of around £12k for 3b semi, the substantial reduction in borehole cost translates to around a 16% reduction of the overall installed cost per property (i.e. including the heat pump and ancillaries). Further cost reductions could be achieved as the number of properties connected to a communal ground collector is increased, although the impact of adding additional properties diminishes as the number of properties connected increases.

The opportunity for connection to a communal ground collector is likely to be particularly relevant to the new build sector, where the issues of coordinating the actions of multiple property owners are avoided. A further benefit of the communal ground collector providing a connection between multiple properties is that it has been accepted as a district heating system under the non-domestic RHI and is therefore eligible to receive a tariff. Ground source systems with communal collectors could therefore compete strongly in the new build sector, where heat pump technologies are not eligible for the domestic RHI.

⁷¹ Based on a mean ground temperature of 10°C and average ground thermal conductivity of 2.5 W/k/m.

Annex 3: Communal ground collectors for GSHP systems

Annex 4: Heat pumps and district heating

Penetration of district heating in the UK is currently very limited. A small number of city-centre schemes have been established, for example in Sheffield, Birmingham and Southampton. In London there has been a concerted effort to stimulate increase connection to district heating systems through the London Plan, which strongly encourages developers to consider district heating for new build sites (for example the Olympic Park), and through the action of individual boroughs, such as Southwark and Islington. The existing uptake of heat pumps with district heating systems (outside of blocks of flats served by a communal ground or air heat exchangers) is negligible, with the majority of systems served by gas CHP or utilisation of waste heat.

There is significant interest in coupling heat pumps to district heating systems in the future. There are a number of potential configurations, as follows:

- Heat pumps serving low temperature district heating networks
- High temperature heat pumps and conventional Low Temperature Hot Water (LTHW) systems
- Multiple buildings coupled to a communal ground-coupling system
- Heat pumps to utilise waste heat

These system configurations are discussed in more detail below.

Low temperature district heating networks

In this case, the heat distribution system is matched to the low temperature output of the heat pump, i.e. a flow temperature of no more than 50 to 55 °C and a return temperature of 20 to 25 °C. There are a number of potential advantages associated with operating a district heating network as these lower temperatures:

- Reduced heat loss
- Reduces operational and possible capital costs
- Increases potential for integration of low temperature / waste heat sources

Clearly the implication of a low temperature district heating network is that the buildings connected also require internal low temperature distribution and emitter systems. These systems may therefore be better suited to new build projects, where the buildings connected can be designed for the low circulation temperatures and will also be constructed to high standards of energy efficiency. Retrofit of low temperature district heating networks to the existing building stock in the UK is likely to be more problematic, due to the need for each of the customers to adapt their existing heating systems in order to connect.

Retrofitting to social housing or clusters of council-owned properties may be a better opportunity, owing to the presence of a single landlord.

High temperature systems

The alternative to a low temperature heat distribution system is to use a high temperature output heat pump that can be matched to a district heating network operating at conventional flow temperatures.

- There are various designs for heat pumps that are capable of providing a high outlet temperature, for example using multi-stage compression or injection compression.
- High COPs seem to be possible in these systems. The main challenge is cost reduction.

The use of high temperature heat pumps alleviates problems regarding the compatibility of the district heating network circulation temperature with the heat distribution systems likely to be found in the bulk of existing dwellings. There is a potential trade-off here between capital and operating costs of high temperature systems versus the costs of upgrading existing buildings to utilise a lower temperature heat source and the barrier associated with convincing multiple potential customers to make the necessary adaptations.

Communal ground loop systems

A potentially more cost-effective form of heat pump district heating is the connection of multiple dwellings to a single ground array.

- Multiple buildings connected to a single ground array is recognised as a district heating system under the RHI policy and is eligible for the applicable tariff under the non-domestic scheme (even where the buildings connected are domestic)
- The configuration can have advantages over individual boreholes per building, as the diversity of heat load across multiple buildings means that total capacity of boreholes can be reduced and also gives the option of drilling fewer, deeper boreholes.

If a ground source system with a communal ground array receives the RHI under the non-domestic tariff, then the incentive will be paid to the owner of the communal system. This might assist the project developer, which might be a housing developer, local authority, social landlord etc., to raise finance for the installation. This is distinct from the case under the domestic RHI, where homeowners with an individual ground-source system will usually be the beneficiaries of the incentive.

Annex 4: Heat pumps and district heating

Using the waste heat

Under future scenarios involving high penetration of district heating, it is anticipated that a significant utilisation of waste heat sources will be required in order to supply sufficient low carbon heat. A further role that heat pumps could play is to assist in the utilisation of low grade waste heat sources (i.e. low temperature heat), where they can be used to upgrade the temperature of the heat source to make it compatible with neighbouring space and hot-water heating demands (i.e. upgrade to typical low temperature hot-water temperatures).

Ground source heat pumps offer a particular advantage in cases where there is a waste heat source, as they provide the opportunity for heat to be stored in the ground. This can improve the utilisation of the waste heat source and also increase the efficiency of the ground source heat pump. In certain cases, this can also improve the efficiency of the particular industrial process, for example in the case of large-scale refrigeration where the relatively constant ground temperature can improve the operating efficiency of the chillers.

Barriers to district heating

The economics of district heating systems improve with the density of heat demand. A large proportion of the cost of a district heating system is in the pipework and, in simple terms, at higher heat density less pipe is required to serve a given heat load. The number of connections will also be important, with fewer larger heat users being preferable to a large number of small connections. Various rules of thumb have been developed to provide a guide to the minimum heat density needed for district heating to be viable, although in practice this will depend on a large number of site specific factors.

Even in areas where the heat density and demand profile are ostensibly well-suited to district heating, penetration to date has been low. It is widely recognised that there are a host of other barriers operating that have hindered uptake of district heating. A recent DECC study⁷² has attempted to draw together the key barriers for both retrofit systems, which have typically been led by local authorities, and in the new build sector, where private developers are typically leading the project. The barriers identified are tabulated below.

⁷² Research into barriers to deployment of district heating networks, DECC, March 2013

Table 17. Summary of main barriers to district heating deployment in the retrofit and new build sector

Barrier
<i>Retrofit to existing buildings (LA led)</i>
Paying the upfront capital cost
Allocating financial resources to initiate projects (including feasibility work, legal advice)
Identifying internal resources to instigate the scheme and overcome lack of knowledge
Lack of accepted contract mechanisms
Inconsistent pricing of heat
Uncertainty regarding longevity and reliability of heat demand
Uncertainty regarding reliability of heat sources
<i>New build (property developer led)</i>
Lack of contract mechanisms
Inconsistent pricing of heat
Concluding agreements with energy service providers, including obtaining a contribution toward capital cost
Uncertainty regarding longevity and reliability of heat demand e.g. lack of heat demand in new buildings
Uncertainty regarding reliability of heat sources
Persuading building occupants to accept communal heat (mandated by the planning authority)

Each of the barriers identified above is equally applicable in the case of a district heating system served by a heat pump system. Indeed, the use of a heat pump as the heat source may bring additional barriers, for example related to the low temperature of heat distribution.

Annex 4: Heat pumps and district heating

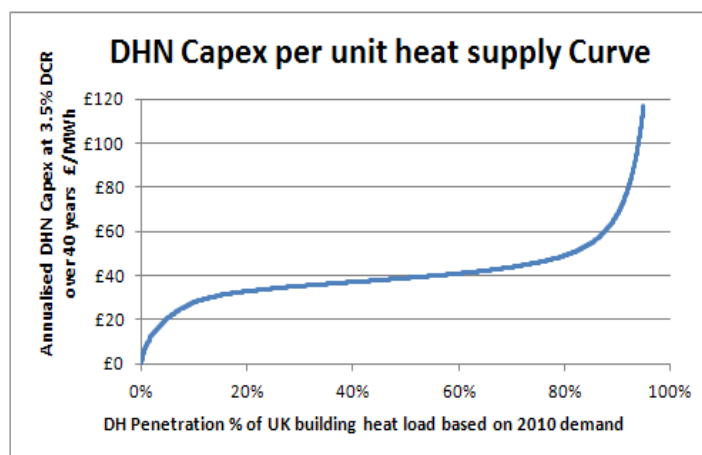
Total potential for district heating

Developing realistic trajectories for the uptake of district heating at a national level is extremely difficult. A number of attempts have been made on the basis of mapping of heat density and analysis of how the economics vary between areas of differing heat density. While these analyses provide an economic potential, they do not fully take account of the barriers identified above, many of which relate to factors such as project risk, market arrangements and lack of knowledge.

The DECC 2050 Pathways report provides a number of scenarios for the decarbonisation of heat to 2050. In the upper bound scenarios for district heating deployment, it is assumed that up to 68% of the housing stock could be connected to district heating networks – approx. 27 million households by 2050. This includes all households in city centres and other urban centres plus semidetached houses, terraced houses, and flats in higher density suburban areas.

This upper bound on technical potential is borne out by analysis provided in the Element Energy / AEA Decarbonising Heat to 2050 report, which provided the following district heating heat supply curve based on AEA's network growth model.

Figure 51. District heating supply curve



The plot above suggests that the capital costs associated with network deployment escalate sharply above around 70 to 80% penetration of the UK's building heat load. The Element / AEA report went on to note that in terms of providing a low carbon heat supply, the contribution of biomass and heat pumps is limited to around 12% (note that this was based on the assumption that water source heat pumps would be required and hence that heat pumps would only be applicable with access to water). The remaining low carbon heat supply would be provided by utilisation of waste heat, leading to an upper bound potential of 40% penetration of low carbon heat (based on viability of extracting heat from current

power stations) or a more realistic level of 20%, assuming that the least cost path of heat network development may not be optimal for linking to power stations.

A further study into the potential for district heat by Poyry / Aecom concluded that under appropriate conditions, district heating could provide up to 14% of the UK's building heat demand and that to achieve this, economic barriers facing new projects – high risks and upfront capital costs would need to be addressed.

Penetration of heat pumps into district heating systems deployment

As discussed in the section above, while the technical potential for deployment of district heating in the UK is potentially high, the barriers to deployment are such that most studies have concluded with more modest estimates. The 14% of UK's building heat demand determined by the Poyry study, for example, could be considered as a reasonable upper bound for 2030 deployment (7.9 million households and 26.3 million square metres of non-domestic floor space).

The extent to which heat pumps could penetrate into this potential for district heating deployment is subject to further uncertainty. The following factors should be taken into account:

- Heat pumps are likely to be most suited to new build projects, where the barriers to deployment of low temperature systems are lower.
- Based on the new build rate assumed in this work, approximately 5 million new dwellings will be constructed between 2016 (when zero carbon homes is expected to come into force) and 2030.
- Based on NHBC housing statistics and government policy for more brownfield, higher density housing, it is likely that a high percentage of these dwellings (perhaps 50%) will be built on sites where the density is sufficient for district heating to be potentially feasible.
- Heat pumps will compete in this sector against gas CHP, biomass boilers and biomass CHP. Gas CHP is likely to provide a lower cost solution and is better known to developers. Biomass systems can also be economic on the basis of incentives such as the RHI, but brings a number of complications in terms of fuel supply, space requirements and air quality issues.
- An upper bound estimate for the potential penetration of heat pumps into new build projects with high suitability for district heating is around 30%, which corresponds to 750,000 to 1million households by 2030.
- The penetration of heat pumps into retrofit district heating is subject to greater barriers. However, the benefits offered by heat pumps linked to district heating systems and thermal storage, such as facilitating the integration of large quantities of intermittent renewables on the grid, will provide a driver for this. These benefits are likely to become monetised

Annex 4: Heat pumps and district heating

over time as the requirement for balancing services increases [Further analysis to be provided in the final version of the report].

Policy mechanisms and enablers to support heat pumps in district heating

To increase the deployment of large-scale heat pumps linked to district heating a number of policy interventions could be used. These are likely to include policies that support the deployment of district heating generally and policies that specifically support the use of heat pumps.

- Local planning policy requiring consideration of district heating in new developments
- Requirement for local authorities to provide assessment of district heating potential in the existing stock
- Building Regulations / Zero carbon policy that is sufficiently stringent to drive consideration of heating networks fed by a low carbon source.
- RHI or similar financial incentive support for renewable heat technologies with consideration of an uplift for district heating

Annex 5: Policy package analysis on the split of installations by consumer type

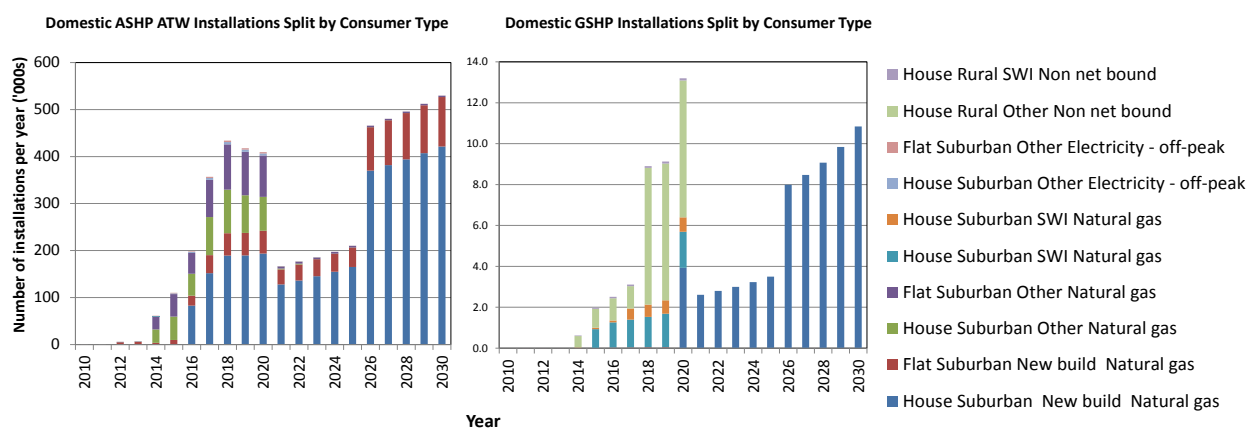
This annex provides details on which consumer types are favoured by the policy measures presented in the main report. The policy measures included are those which result in a significant uptake of heat pumps by 2030 i.e. greater than [4m] installations.

Policy Package 4: New Homes Standard

As expected the ‘New Homes Standard’ policy package drives up installations in the new build property types, particularly houses. The policy has been modelled by attaching a price to carbon emissions that is sufficiently stringent to make gas boilers a very uneconomic choice (over the period from 2016 to 2020 a price is associated to carbon emissions that is in line with ‘Allowable Solutions’ prices under consideration as part of zero carbon homes policy).

The model predicts high uptake of heat pumps in the 2020s, dominated by air source technology (on the basis of lower total cost of ownership). The levels of uptake are expected to be an overestimate of the impact of the policy in reality, due to the lack of alternative technology options within the current uptake model⁷³.

Figure 52. Installations of GSHPs and ASHP ATWs under policy package 4

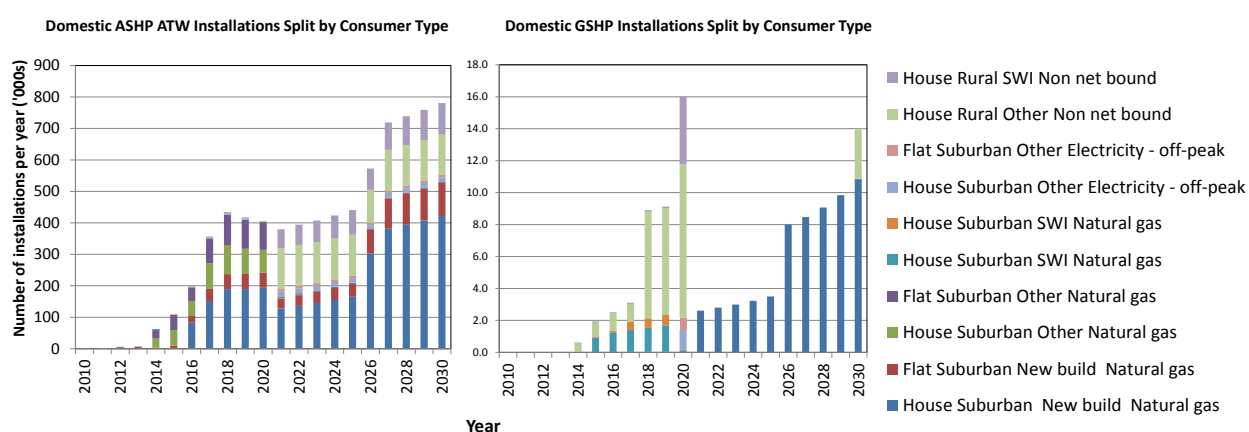


Policy Package 5: Off Gas Standard

⁷³ Biomass boilers are also included as a technology option in the model, but other technologies that will compete in the new build sector, such as site-wide energy systems or microCHP are not modelled.

Policy package 5 mandates low carbon heating systems in the off-gas properties (incumbent non-net bound and off-peak electrical heating systems) after 2020 as well as the new build market. The resulting uptake of heat pumps in the off-gas and new build segments through the 2020s is dominated by air source systems. In the absence of the RHI, air source technology offers the lower cost of energy. Limited uptake of ground source systems is projected to occur in the new build segment (as seen under Policy Package 4).

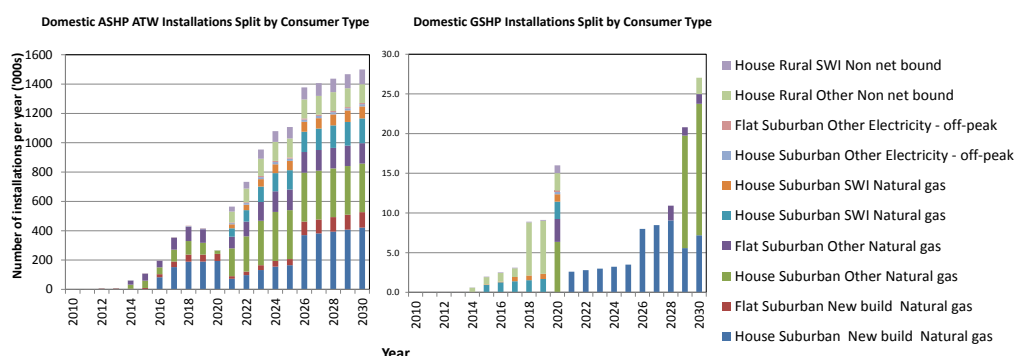
Figure 53. Installations of GSHPs and ASHP ATWs under policy package 5



Policy Package 6: All Homes Standard

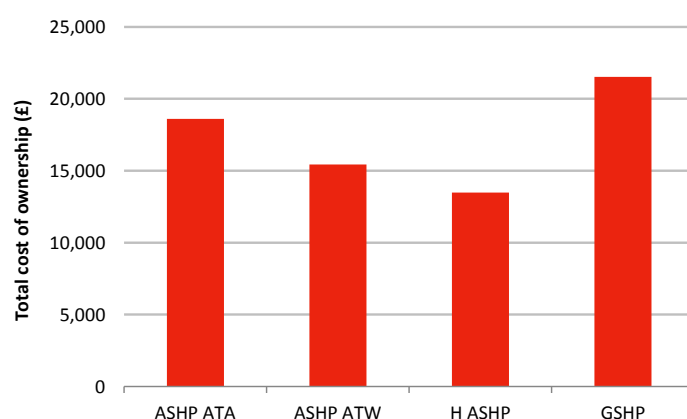
Under policy package 6, which mandates low carbon heating systems in all property types, a broad mix of consumer types take up ASHP ATWs in the domestic sector.

Figure 54. Installations of GSHPs and ASHP ATWs under policy package 6



As shown in the other mandating based policy packages, air source heat pumps are favoured over ground source on the basis of lower cost of energy, as shown in the chart below.

Figure 55. Comparison of total cost of ownership of heat pump options in an off-gas, rural (cavity-wall) house (based on 2025 price data)



GSHP remain substantially higher cost without subsidy support, hence the uptake is very limited compared to ASHP.

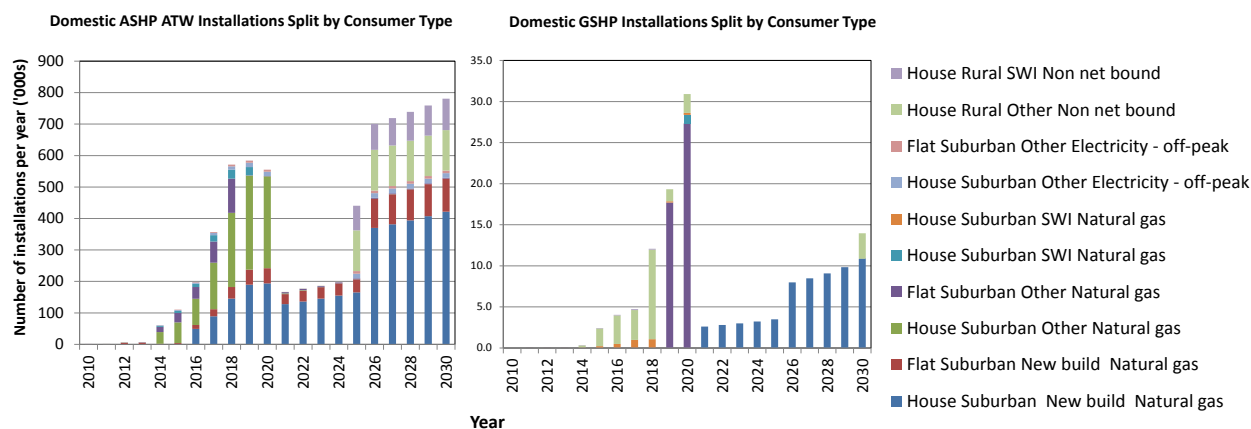
Policy Package 7: Mandate Combo

Under policy package 7, the Green Deal or other low cost finance loans are modelled as an option to reduce the upfront capital costs associated with installing a heat pump. This is in combination with mandating low carbon heating appliances in the new build property types from 2020, and all other property types from 2025.

The model suggests that the loan guarantee financing measures provide favourable overall economics for consumers installing ASHP ATWs compared to GSHP systems.

Annex 5: Policy package analysis on the split of installations by consumer type

Figure 56. Installations of GSHPs and ASHP ATWs under policy package 7

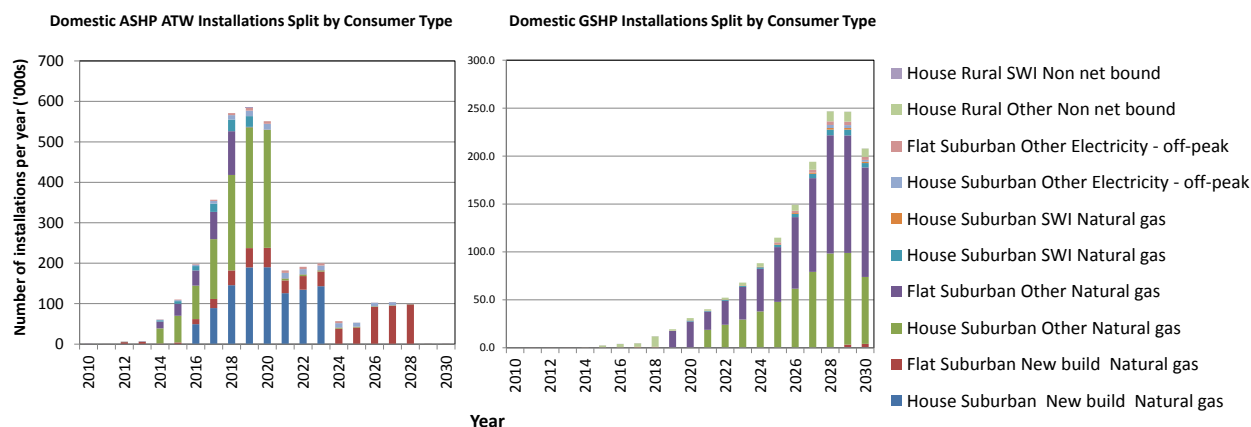


Policy Package 8: RHI and Green Deal

Policy package 8 models an incentive scenario by extending the RHI to 2030 in parallel with a low cost loan scheme (e.g. Green Deal).

This policy package highlights the importance of costs as a barrier to the uptake of ground source in non-new build property types, as the number of installations in the gas grid segment increases significantly. This is a result of consumers being able to exploit the Green Deal by meeting repayments with their RHI subsidy.

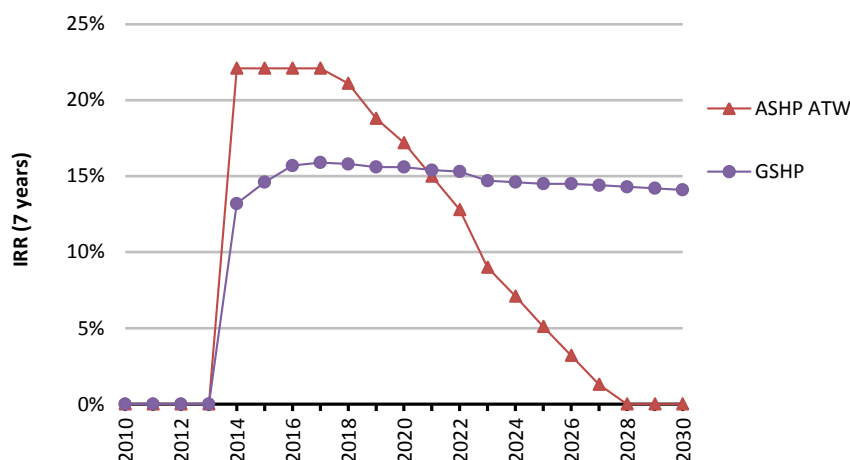
Figure 57. Installations of GSHPs and ASHP ATWs under policy package 8



ASHP ATW heat pumps are favoured in the new build market and retrofit gas-grid market only up to 2020, after which the ASHP market share declines. This highlights the importance of a mandating policy to drive uptake in the new build segment post-2020.

The shift in uptake from air to ground source in the on-gas house types during the extended period of the RHI (i.e. during the 2020s) can be understood by analysing how the rates of return of the two technologies varies over the period, as shown in the plot below.

Figure 58. Comparison of the rate of return on investment in heat pumps



The drop in the rate of return on investment in ASHP during the 2020s is partly a result of the degression of the tariff (mainly in the period prior to 2020) and also the rise in electricity costs during the 2020s.

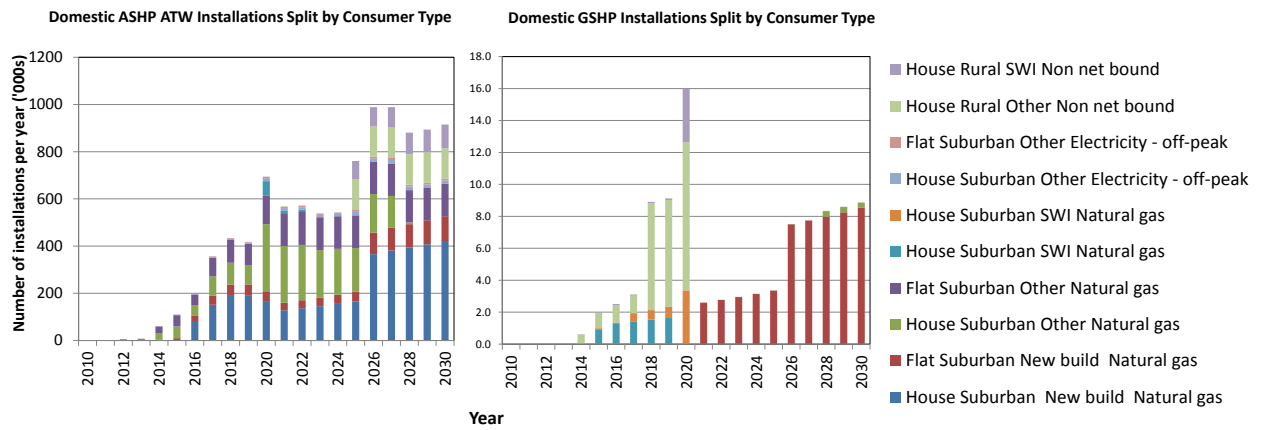
Policy Package 9: Capital Subsidy and Off-Gas Standard

Policy package 9 models a scenario where a combination of incentives (capital grants) and mandating policies in the off gas, and new build segment are introduced.

A relatively large uptake of air source heat pumps is seen in the on-gas period in the absence of a mandating policy. This is a result of the capital grant overcoming the cost-effectiveness gap compared to the counterfactual.

The ground source market installations between 2014 and 2020 are focussed in the retrofit market with a strong preference for rural house types. After the introduction of capital grants in 2020, the ground source market shifts to new build flats as the cost barrier of the small size systems required is addressed.

Figure 59. Installations of GSHPs and ASHP ATWs under policy package 9



In summary the model suggest a stronger dependence of ground source on incentive based policy measures relative to the ASHP ATW market. This can be attributed the overall higher capital costs associated with GSHPs.

FRONTIER ECONOMICS EUROPE

BRUSSELS | COLOGNE | LONDON | MADRID

Frontier Economics Ltd 71 High Holborn London WC1V 6DA

Tel. +44 (0)20 7031 7000 Fax. +44 (0)20 7031 7001 www.frontier-economics.com