Decarbonising Home Heating: An Evidence Review of Domestic Heat Pump Installed Costs

Technology and Policy Assessment

Research Report

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Contents

Highlights

- The UK's net zero pathway requires a rapid rise in the use of heat pumps for home heating. Alongside a much higher installation rate, the UK Government has set highly ambitious targets for reductions in total installed costs, including both equipment and non-equipment costs.

- In this report, we review UK and international data on the total installed costs for domestic scale heat pumps, both historic and forecast, across a wide range of technology types and building contexts.

- Heat pump cost data is relatively scarce and is often inconsistent across different studies. Given the importance of heat pump costs for energy transitions, there is a vital need for improved data, and greater data access, in the UK and internationally.

- In the UK, there has been little or no reduction in the average total installed cost of heat pumps over the past decade. Over the same period, some cost reductions have been achieved internationally, and over time, particular countries have successfully aligned market growth with reduced installed costs.

- There are real prospects for reduced installed costs, particularly non-equipment costs, over the next decade. Most UK forecasts suggest a reduction in total installed costs by 2030 of around 20-25%. Expected savings are higher for non-equipment installation costs, including labour costs, than for equipment costs.

- However, almost all cost reduction forecasts are significantly less than UK policy targets, and in the short term, given rising international demand and supply side challenges, heat pump installed costs face inflationary pressures.

- Substantially increasing heat pump deployment in UK homes is a critical part of the net zero transition – but meeting the UK's heat pump deployment and cost reduction targets would require a radical change in less than a decade, from international laggard to leader.

- Heat pumps also offer energy security and efficiency benefits, and jobs and local economy opportunities. Over time, they can also offer households lower and more stable heating costs. This suggests a wider framing of the heat pump proposition in the UK, going beyond possibly unrealistic goals for installed cost reduction.

1. Introduction and Background

1.1. Policy context

The UK government is committed to achieving net zero levels of carbon dioxide and other climate-changing emissions by 2050, with an interim target of a 78% reduction by 2035, relative to a 1990 baseline (BEIS, 2020a). The Scottish Government has set an earlier target of 2045 for achieving net zero emissions, with an ambitious interim target of 75% reductions by 2030 (Scottish Government, 2020).

These targets imply a rapid transition in home heating. The CCC's 'Balanced Net Zero Pathway' requires that 100% of UK domestic heating system sales are low-carbon from 2033 (CCC, 2020b). In Scotland, around half of all homes (over one million households) will need to convert to a low carbon heating system by 2030 to ensure the interim statutory target of 75% reductions by 2030 is met (Scottish Government, 2020).

Domestic heating and hot water provision account for around a quarter of total UK energy demand (CCC, 2019) and 17% of carbon dioxide equivalent emissions (BEIS, 2021d). UK domestic heating is dominated by natural gas boilers which, together with the inherent flexibility of the gas supply network, are well suited to meeting the very large daily and seasonal fluctuations that are a feature of UK domestic heat demand (Carmichael et al., 2020).

Deployment of low carbon heating in the UK is currently very low, accounting for only 5% of total heating demand, meaning that the overwhelming majority of UK homes will need upgrading to a decarbonised heat solution by 2050 (Carmichael et al., 2020; Rosenow et al., 2020).

Low-carbon domestic heat may be supplied by a range of technologies, including electric resistive heating, district heating (provided the heat source is low carbon) and by decarbonising the gas grid using hydrogen or biomethane. Improving the thermal efficiency of existing and new homes can also contribute very significantly to emissions reductions from buildings. However, it is clear from multiple studies that heat pumps will need to play a major role. CCC Sixth Carbon Budget analysis suggests that heat pumps are likely to dominate provision of low carbon domestic heat, making up around three quarters of new installations in 2030 (CCC, 2020b).

In its *Net Zero Strategy* and *Heat and Buildings Strategy* (BEIS, 2021b; BEIS, 2021a) the UK Government set out a range of measures to support the decarbonisation of domestic heat. These include an ambition that by 2035 no new gas boilers will be sold, a Boiler Upgrade Scheme offering households grants of up to £5,000 for Air Source Heat Pumps (ASHPs) and £6000 for Ground Source Heat Pumps (GSHPs), and funding for innovative heat pump technologies (BEIS, 2021b).

The Heat and Buildings Strategy also confirmed a target for at least 600,000 'hydronic' (Air-to-Water) heat pump installations per year by 2028 (BEIS, 2021a), including around 400,000 retrofit installations, with up to 1.9 million installations per year by 2035 under a ‘high electrification’ scenario (BEIS, 2021b). The CCC’s own assessment is that the heat pump installed rate should reach more than one million by 2030, with a cumulative total of 5.5 million by that date (CCC, 2021). All of these figures represent a dramatic increase: just 54,000 residential heat pumps were installed in the UK in 2021 (CCC, 2022).

The anticipated growth in the UK market for heat pumps is accompanied by expectations of very significant cost reductions, and a rapid growth in domestic manufacturing capacity. The UK Government has noted that meeting its target for at least 600,000 heat pump installations per year by 2028 is contingent on reduced upfront costs. The *Heat and Buildings Strategy* sets a ‘clear ambition’ for industry to reduce the costs of installing a heat pump by at least 25-50% by 2025, and to ensure heat pumps are no more expensive to buy and run than gas boilers by 2030 (BEIS, 2021a, p.15).[1]

1.2. Project scope

Given its importance for the feasibility and affordability of the UK’s buildings heating transition, our review has focussed on the total installed costs for domestic scale heat pumps, including capital equipment (the heat pump unit and ancillary equipment), non-equipment installed costs (including labour costs, sales, design and any follow-up activity post-installed), and any associated changes made to the building fabric and/or heating system.[2]

We have systematically searched for UK and international data related to total installed costs, both as reported (based on actual experience) and also forecast (studies anticipating future cost trends). An international scope is valuable because the UK has had relatively little experience of heat pump installations.

Our focus is on total installed costs, and we have not analysed data or evidence related to lifetime or running costs, or wider energy system costs or benefits. Extending the analysis to cover these issues would offer a fuller picture, but it also introduces many context-specific factors, including national policy and regulatory design, wider energy system characteristics, and the changing international market price of fuels.

By limiting our project scope to total installed costs[3] we have been able to include a large proportion of the available data on heat pump costs. Even on this restricted basis, comparing costs and identifying cost trends is challenging. Heat pump

[1] A key policy tool in achieving these cost reductions will be a new ‘market-based mechanism’, designed to set a rising standard for the number of heat pump sales to end-consumers as a proportion of heating equipment firms’ fossil fuel boiler sales (BEIS, 2022).
[2] The operating characteristics of heat pumps compared to gas boilers mean that improvements to building fabric and the home heat distribution system may be necessary in order to maximise overall efficiency.
[3] Other studies have examined running costs of heat pumps e.g. (Rosenow, 2022).

installed costs are made up of a range of equipment and non-equipment costs, in varying proportions, depending on technology design and building context.

On average, equipment costs make up around 60% of total installed costs, and non-equipment costs around 40% (Hardy, Sugden and Dale, 2016; Cooper, 2021; Sissons, Wiley and Williamson, 2022). Equipment costs are typically approximately evenly shared between the heat pump unit itself and 'ancillary equipment' (including the buffer tank, hot water tank, emitters (radiators), piping and valves), although again this varies by design and context (Sissons, Wiley and Williamson, 2022). On average, labour costs make up around 60% of non-equipment installed costs, alongside other costs such as design, commissioning, distribution and overheads (Hardy, Sugden and Dale, 2016).

All heat pump costs vary greatly with technology type (e.g. air source or ground source; air-to-air or air-to-water, high or low temperature heat output, with or without hot water provision, monobloc or split unit design, etc.), and with ancillary equipment costs, labour costs and wider installed costs, including any upgrades to the building fabric or heating system.[4]

Average installed costs for new build and existing homes are often broadly similar, although the balance between equipment and non-equipment costs varies: new build installs typically incur lower non-equipment costs, but higher ancillary equipment costs (Hardy, Sugden and Dale, 2016).[5] In many heat pump cost studies, detailed aspects of cost assumptions may not be fully stated or made sufficiently clear, so that the overall dataset cannot be 'normalised' for different assumptions. Another recognised problem is the limited amount of data available internationally (Jakob et al., 2020; Renaldi et al., 2021).

We have included UK and international data on the installed costs of domestic heat pumps across a wide variety of technology designs and building contexts. This means that caution is needed when comparing data from different studies, or attempting to identify cost trends over time. For example, improvements in heat pump performance – perhaps driven by tightening regulatory standards – may lead to *increased* equipment costs, at least in the short term. Another issue is that as heat pumps are deployed more widely across a given housing stock, they are likely to incur additional costs in improving the building fabric or heat distribution system.

Although our main focus has been on reviewing data on reported and forecast heat pump installed costs, we have also sought to understand the drivers and causal factors involved, including policy influence, by analysing selected individual studies in more detail. The causes of changing heat pump costs are often omitted from quantitative assessments, and there are relatively few studies which relate changing cost to causal factors in particular contexts. We also briefly consider the relevance of changing costs for some other energy technologies.

[4] For more detail on heat pump technologies and operation see Trask, Hanna and Rhodes (2022) and Hepbasli (2018).
[5] Also informed by analysis carried out by Eunomia on behalf of the Department for Business, Energy and Industrial Strategy (BEIS).

1.3. Research questions

Reflecting the key issues related to project context and scope discussed above, the main and subsidiary research questions for this project are:

- How have the reported installed costs of domestic scale heat pumps changed over time, internationally and in the UK?
    - Which factors have driven any changes in reported costs?
- What are the forecast installed costs of domestic scale heat pumps, internationally and in the UK?
    - Which factors explain any expectations of future cost reduction?

1.4. Research method

This review uses an approach developed over many years by UKERC TPA that draws on the practice of systematic review (Speirs, Gross and Heptonstall, 2015). This aims to provide a stronger evidence base for policymakers and practitioners, avoid duplication of research, encourage higher research standards, and identify research gaps. This approach is common in areas such as education, criminal justice, and healthcare (ibid).

Full details of our research method, including the search criteria and search strings, and the expert advisors we consulted, will be made available on the project page on the UKERC website, together with links to the datasets collected and analysed by the project team.

1.5. Data availability and metrics

Quantitative data on domestic heat pump installed costs were extracted from the reports, papers and other sources of evidence identified. In total, over 550 individual data points were extracted, across three main categories of cost metric.

The first of these categories, *single year cost*, was the most commonly found metric, with 402 data points drawn from 57 sources. Almost two-thirds (63%) of single year cost data points refer to UK installations.

The second category is *experience rate* data.[6] These data were drawn from historical analyses of heat pump costs in a country or region to determine the experience or learning rate between two points in time. A total of 39 data points from 13 sources were found for this metric. Almost two-thirds of experience rate data points (62%) are from non-UK studies, mostly other European countries.

[6] The experience rate in this context is the cost reduction associated with a doubling of heat pump deployment. A positive rate means that costs are reducing; a negative rate means that costs are rising.

The third data category, *% cost reduction*, is where data is presented as a percentage reduction in heat pump costs between two points in time, presented as an absolute cost reduction percentage. These data may be based on historical analysis of actual cost data or, more typically, forecasts of some future cost reduction. A total of 122 data points from 31 sources were found for this metric. Almost three-quarters (72%) of % cost reduction data points are for UK studies.

The heat pump cost data that we have collated is also differentiated within each of our three metrics (to varying degrees, according to availability) by three main subcategories: (i) technology type, either air-source heat pumps (ASHPs) or ground-source heat pumps (GSHPs); (ii) whether costs were reported as total installed costs, equipment costs only, or non-equipment costs; (iii) whether costs were reported as a total value or on a cost per rated unit of capacity (per kW) basis.[7]

[7] Sources which report costs as a total value rather than per kW generally show 'typical' costs and/or a range of costs to reflect installations in differing home sizes and types.

2. Results

2.1. Single year costs

The most common way to report heat pump installed costs – over three quarters of data points in our review – is as a single occurrence figure for a single year. Figure 1 below shows all of the single year costs data that we have collated for years up to and including 2020. Reflecting the way most single year costs are reported in the original source documents, the chart shows total installed costs, including the costs of the heat pump unit, ancillary equipment, labour costs and any associated changes in building fabric and domestic heating system. The figure does not show cost data for the heat pump unit alone, as this was a small proportion of the overall data collected for this category, under 13%.

The data shown in the figure cover a wide range of contexts and assumptions, including existing and new build houses, and differing levels of building fabric retrofit and heating system upgrades. In cases where single studies offer multiple cost figures according to different assumptions, or sensitivities, we included all values as separate data points.

The data shown in Figure 1 distinguish between installed costs according to the two main domestic heat pump technology types: air source heat pumps (ASHPs), shown as solid green circles, and ground source heat pumps (GSHPs), shown as solid blue circles. In general, GSHPs incur considerably higher installed costs than ASHPs because of the additional costs of trench excavation, borehole drilling and pipework. Figure 1 also shows data sources which present data on a per kW basis, shown as outline green and blue circles.

The total installed costs of domestic heat pumps varies widely, spanning different designs and contexts, from over €30,000 to just over €5000 – a six-fold range. Higher values typically refer to larger GSHP installations, perhaps involving significant building fabric and heating system upgrades. Lower values typically refer to ASHPs for new build housing, or retrofit installs which avoid building fabric or heating system upgrades.

Figure 1 also suggests that, on an aggregated basis across all data (UK and Rest-of-the-World, or RoW), total installed costs have been roughly stable over time: the trend lines show only very modest declines in average total installed costs between 2010 and 2020 for both ASHPs and GSHPs.[8] There also appears to be no convergence of installed costs over time, perhaps reflecting a continuing variety of installation contexts.

There is less data available for total installed cost per kW, but this shows a trend toward slight increases in costs over time. Although there are limited reported costs for equipment costs alone, these show a similar pattern: a broad data range,

[8] For ASHPs, the trend line suggests a cost reduction between 2010 and 2020 of around 5%.

reflecting different technology types and installed contexts, with no observed cost reduction trend over time.

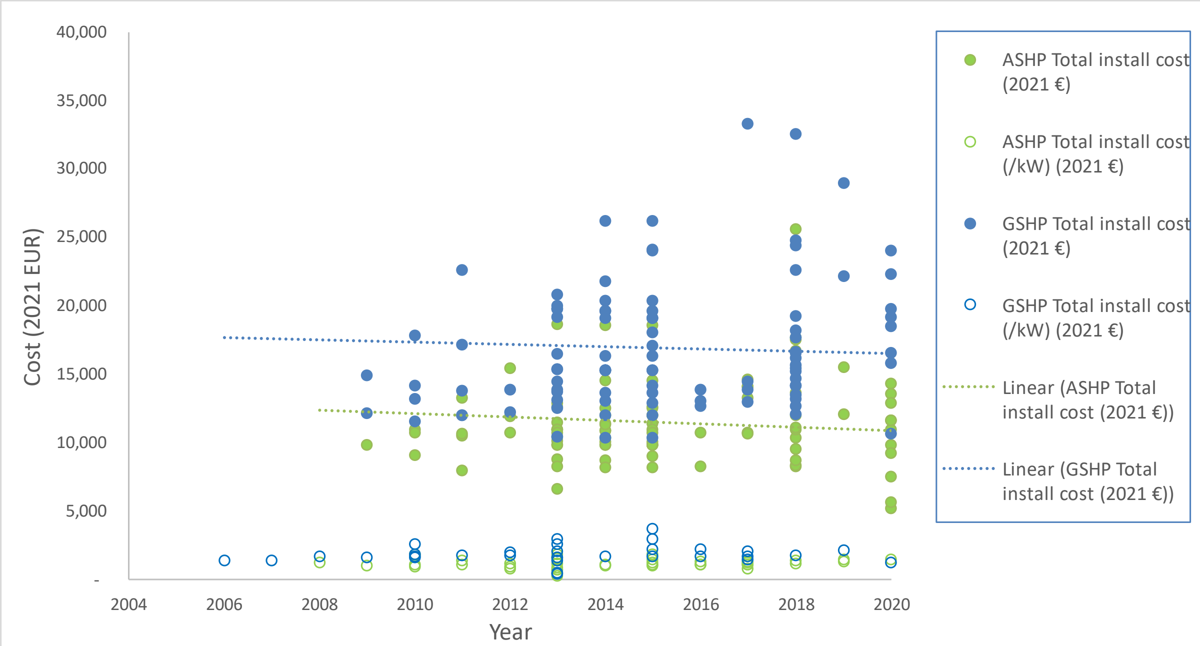

Figure 1: Single year total install costs, up to 2020 (UK and RoW)

Although most single year costs data are historical, there are also a number of studies forecasting future installed costs. Figure 2 below combines data from Figure 1 above with forecast costs data. Most forecasts suggest that average total installed costs are expected to modestly decline in the future: the trend lines shown on Figure 2 suggest cost reduction between 2020 and 2030 of approximately 9% for ASHPs and 6% for GSHPs.

While this suggests only modest cost reductions, the trend line is weighted toward historic data as there are relatively few forecast data points, and so it may underestimate forecasted cost reductions.

Figure 2: Single year costs up to 2020 and forecast costs for beyond 2020

Total installed costs per kW, historic and forecast, show a similar pattern as total installed costs: for ASHPs, average reported total installed costs per kW have increased slightly since 2009, and average costs per KW are not forecast to fall.

To display single year cost data in a more consolidated way, and help distinguish between historic and forecast costs, Figure 3 below uses the same underlying total installed costs single year dataset as Figure 2 above, but grouped into multi-year intervals.

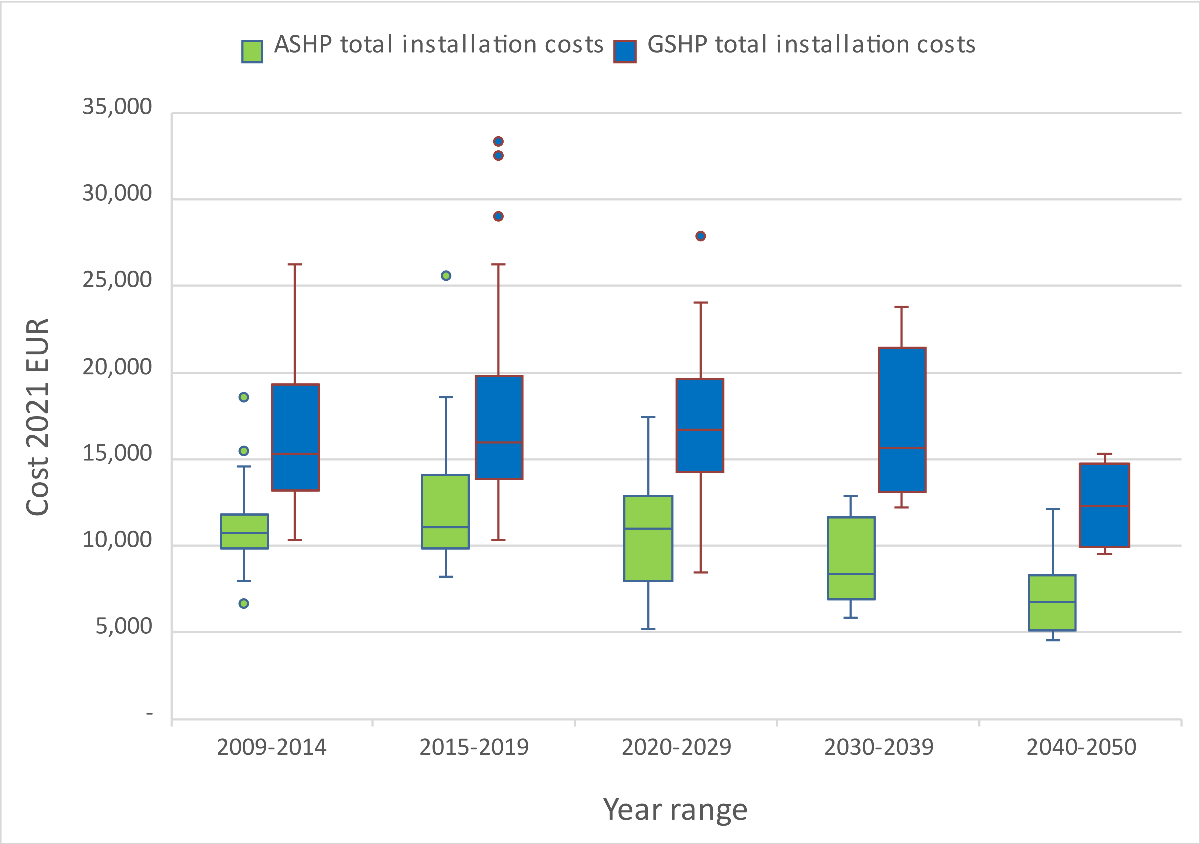

Figure 3: Single year costs up to 2020 and forecast costs for beyond 2020, grouped by year ranges

Median value cost reduction from the early 2020s to the early 2030s for ASHPs is c.24% (around €11,000 to €8,400, c.£9,500 to c.£7,200). For GSHPs the suggested reduction over the same period is more modest, c.6%, from c.€16,700 to €15,700 (c.£14,300 to c.£13,500). Based on very limited data, a greater cost reduction is anticipated for GSHPs after 2040.

Disaggregating UK-only and RoW data suggests that there has been a greater reduction in average installed costs internationally than in the UK, particularly for ASHPs. Median costs in the year ranges 2015-19 and 2020-29 reduce by 22% in the RoW dataset, compared to only 6% in UK-only.[9] For GSHPs, there is no equivalent difference between UK-only and RoW data, although this is based on very limited data points.

[9] RoW cost datapoints for 2020-29 are all for the year 2021, so they reflect reported historic costs rather than cost forecasts.

2.2. Experience rates

Experience rates are a widely used metric for benchmarking energy technology costs (Junginger, van Sark and Faaij, 2010). Unlike single year costs, experience rates allow analysis of cost trends, and in some studies the causes of cost reduction. At the same time, there are a number of methodological challenges involved in constructing experience rates for heat pumps, and comparing calculated rates between different studies.[10]

Confirming other analyses (Renaldi et al., 2021; Jakob et al., 2020), we found relatively few heat pump experience rate studies of any kind, with just 13 distinct sources internationally. Although it offers a more robust way to assess installed cost trends, heat pump experience rate analysis is scarce. Figure 4 below shows 32 reported heat pump experience rates, for both equipment costs and total installed costs.

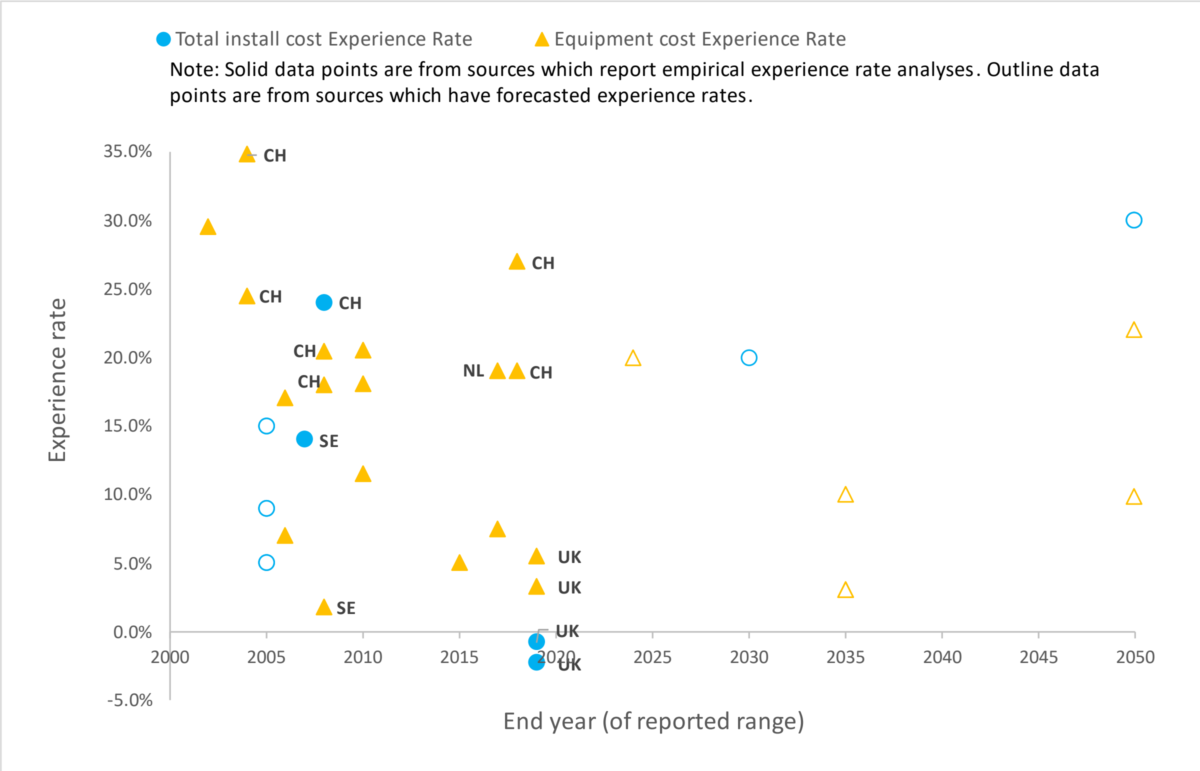

Figure 4: Experience rate, by end year of reported range (highlighting selected country specific studies)[11]

The solid triangles and circles in Figure 4 show actual reported experience rates i.e. those drawn from empirical studies of historical heat pump costs and deployment. The hollow markers denote that the source document presented forecasted data, which we have included for completeness – although strictly, such an indicative or forecasted value cannot constitute a real experience rate.

[10] Jakob *et al.* (2020) summarise these methodological challenges.
[11] Country abbreviations: NL (Netherlands), SE (Sweden), CH (Switzerland), UK (United Kingdom).

In contrast with single year cost data, most heat pump experience rate data relates to equipment-only costs, with just one-third of available data points based on total installed costs. This equipment-only focus reflects the conventional approach to experience rate assessment. Although this makes costs easier to compare across multiple studies, it omits a high proportion of the total costs of a typical heat pump installation made up of non-equipment costs (Cooper, 2021). Different studies may also be inconsistent in terms of whether ancillary equipment costs, as well as heat pump unit costs, are included or excluded.

Figure 4 shows a wide variation in reported heat pumps experience rates internationally, ranging from +35% to -2.3%.[12] Of the 32 data points shown, the majority (19) have an experience rate greater than 10%, showing clear evidence of positive learning effects and a cost reduction trend, and six data points have high rates, of over 25%. However, there are several cases of much lower rates, with two instances of negative rates – both for the UK.

There is an apparent inconsistency between most experience rates being significantly positive, and the absence of a significant cost reduction trend in historic single year installed costs, as discussed in the previous subsection. This may be because most experience studies focus only on equipment costs and exclude non-equipment costs. In addition, there is much less experience rate data than single year cost data, and experience rate studies may over-represent country cases where cost reductions have been more pronounced.

To analyse the causal factors behind reported experience rates, Table 1 summarises published analysis for four countries: Switzerland, Sweden, the Netherlands and the UK. Each country has a distinctive pattern of heat pump deployment trends, costs and suggested causal effects:

- *Switzerland* has longstanding experience of heat pump deployment, from the 1980s. Since the mid-1990s, Switzerland has seen market growth combined with substantial reductions in installed costs, and high experience rates – of around 20% for GSHPs. As well as technical improvements, savings have been enabled by supply chain competition and component importing.

- Heat pump deployment in *Sweden* also has a long history, with a gradual building-up of manufacturing and installer expertise, and technical advances. Sweden is one of the largest markets for heat pumps in Europe.[13] Cost reduction has been modest, with recent increases in GSHP costs. Evidence suggests that this reflects an emphasis on domestic manufacturing and local supply chains.[14]

[12] The wide variation here is perhaps surprising, given that most data refers to equipment costs. It suggests that heat pump equipment costs are influenced by national context to a greater extent than is often assumed.
[13] Sweden has the largest market for GSHPs in Europe. Total heat pump units sold per 1000 households in 2018: Sweden: 22.7; Switzerland: 8.8; UK: 0.8 (EHPA, 2020).
[14] There is some inconsistency in reported experience rates for Sweden, with one study suggesting a significantly positive learning rate, although no details are given (Munuera, 2014). A recent study of single year costs in Sweden also claims that costs have reduced in the 2010s (IRENA, 2022).

- The *Netherlands* has had much less experience of heat pump deployment, historically, but in a supportive policy context, it has seen rapid recent growth in installations, particularly for ASHPs (both air-to-air and air-to-water), and heat pumps now dominate domestic heating sales for new homes in the Netherlands. While evidence is limited, this appears to be associated with significant cost reductions, driven by supply chain competition.

- The *UK* has little experience in heat pump deployment, and has seen only modest recent market growth. In a context of weak policy support, there has been little evidence of cost reduction or learning in technology development or installation practices. Recent increases in costs, especially for non-equipment costs, are reflected in negative experience rates.[15]

One overall insight that emerges from experience rate studies is that neither market growth nor technology innovation necessarily drive reductions in installed costs. Indeed, installed cost reduction may not be a primary factor in deployment programmes and policy intent, as the Swedish case illustrates; Renaldi et al., (2021, p.8) concluded “not all progress is translated into cost reduction”.

Another insight is that although high experience rates tend to be associated with countries in which heat pumps have a long history of deployment and the gradual building-up manufacturing capacities and supply chains, such as Switzerland, sizeable cost reductions and experience rates have also been reported for countries with much less involvement historically or only recent domestic market deployment, such as the Netherlands.[16]

As shown on Figure 4, there are relatively few forecasts of future heat pump experience rates. The available forecasts span a wide range of scales and contexts, from relatively modest rates, in the range 3-10% for equipment costs in the UK to 2035 (Sissons, Wiley and Williamson, 2022), to much higher global experience rates of 30% to 2050 for total installed costs (Knobloch et al., 2019). All forecasted rates fall within historically reported rates: despite expectations of significant growth in global deployment (IEA, 2021) there is little indication that future rates will exceed those reported historically, particularly for equipment costs.

[15] In contrast with the studies reported in Table 1 for the UK, a recent study by IRENA has suggested cost reductions in UK installed costs, for both ASHPs and GSHPs in the 2010s (IRENA, 2022). IRENA’s findings are based on a relatively limited sample of UK installations, and exclude costs associated with changes to heat distribution systems. The UK MCS Installer Database, the largest available dataset on domestic HP installation costs in the UK, suggests continued increases in average installed costs for ASHPs between 2019 and 2022. See https://certificate.microgenerationcertification.org/

[16] It should be noted that this is based on a single study of the Netherlands (Jakob *et al.*, 2020).

Reported ER (%) or Cost Trends	Deployment Trends	Causal Factors
Switzerland		
• 20% (GSHP, 1982-2008) (Kiss, Neij and Jakob, 2013), in (Renaldi *et al.*, 2021) • 18% (GSHP single dwelling, 1980-2008); • 27% (GSHP, multi dwelling, 2012-2018); • 19% (GSHP, combined long term rate); (all Jakob et al, 2020) • 25-42%, varying with unit of analysis; 28%, combined cost and COP (Weiss et al., 2008) • 24%, 1991- 2008; (Munuera, 2014) no details)	Total sales of ASHP and GSHP grew from c.4,000 in 1995 to c.26,000 p.a. in 2017, mostly ASHPs (Kiss, Neij and Jakob, 2013; Jakob *et al.*, 2020). Average growth of 3.3% p.a., 2010-18 (EHPA, 2019).	Market growth has encouraged learning in design, manufacture and installation for HP units and wider system components, including smaller and cheaper heat exchangers, improved assembly methods and system integration. Importing of cheaper components from Asia (especially compressors) has also been important. For GSHPs, cost reduction reflects advances in borehole drilling technology, higher equipment use rates and increasing competition from market entrants (Weiss, Junginger and Patel, 2008; Kiss, Neij and Jakob, 2013; Jakob *et al.*, 2020).
Sweden		
• 1.8% (GSHP, 1994-2008) (Kiss, Neij and Jakob, 2013), in (Renaldi et al., 2021)) • 29% increase in price of GSHPs, 2008-2020 (Gidén Hember, 2020) • 14% (1987-2007) (Munuera, 2014); no details)	Total annual sales grew from c.10,000 to c.135,000, 1994-2008; GSHP sales rose from c.2,000 to 40,000 1994-2008; (Kiss, Neij and Jakob, 2013). Slower sales growth in 2010s.	Priority on performance improvements (such as the introduction of inverters and advanced controls) rather than cost reduction, in-part driven by regulation (e.g. EU Ecodesign Directive). Limited supply chain competition and importing, with close links between domestic manufacturers and local sellers and installers). A subsidy scheme in the mid-2000s led to price increases because of limited supply capacity (Kiss, Neij and Jakob, 2013; Gidén Hember, 2020)
Netherlands		
• 19% (ASHP, air-to-water) (2012-18) • 18% ASHP (2011-16) (both (Jakob *et al.*, 2020)	Rapid market growth since mid-2010s, from 51,000 total annual sales in 2015 to 118,000 in 2018, and 250,000 in 2020, almost all ASHPs (Jakob *et al.*, 2020; EHPA, 2019); (Statista, 2022b)	Learning in manufacturing and installation of both HPs and wider system components, including smaller and cheaper heat exchangers, cheaper assembly methods, system integration and importing of components from Asia. Policy support has also been key, particularly a capital subsidy support scheme introduced in 2016 (Jakob et al., 2020).
UK		
• ASHP: 5% (equipment); -2.3% (total install) • GSHP: 3.3% (equipment); -0.8% (total install), 2010-2019 (Renaldi *et al.*, 2021) • ASHP install cost has increased by 15%, from c.£9k to £10.5k (2015-2021); GSHP install costs roughly stable, c.£20k (Sissons, Wiley and Williamson, 2022).	Annual installations rose from 18,500 in 2011 to 31,200 in 2019 and 55,000 in 2021); over 90% are ASHP, air-to-water (EurObserv'ER, 2013; EurObserv'ER, 2020; CCC, 2022).	Policy instability, and taxes and policy costs imposed on electricity (and not on gas) have restricted market growth. Upward cost pressures from increasing demand in a historically small market with few qualified installers (Renaldi et al., 2021). Increased ASHP costs are due mostly to non-equipment costs, such as more demanding installation requirements, labour, overheads, commissioning and distribution costs (Sissons, Wiley and Williamson, 2022).

Table 1: Reported Experience Rates (ER), Deployment Trends and Causal Factors, selected countries

2.3. Percentage cost reduction data

Rather than experience rates, a simpler and more widely used way to assess the changing cost of heat pumps is a percentage change (typically a reduction) between two specified dates.[17] This '% cost reduction' category is the third category of heat pumps cost metric identified in our review.

There are three main ways in which % cost reduction data is presented: for heat pump equipment (37% of all data points in this category), total installed costs (41%) and 'non-equipment costs' (22%). The last subcategory is rarely reported as a distinct value in the other two metrics in our review; it typically refers to labour costs, sales process and installation design costs.

Figures 5, 6 and 7 show available % cost reduction data for these three subcategories. Lines on these figures connect initial and final year points in a single study. Most % cost reduction data are forecasts of anticipated changes in future cost. This contrasts with single year and experience rate data, which mostly refer to historic, observed changes. Mean average values of expected % cost reductions are shown on Figures 5, 6 and 7, for those data points with end dates of 2030 and 2050.

% cost reduction data includes a wide range of values, from -19% to +90%.[18] This reflects diverse deployment contexts, and varied assumptions and uncertainties affecting future costs. However, almost three-quarters (72%) of the % cost reduction dataset is drawn from UK based studies, and the dataset includes multiple data points from single studies, across different installation assumptions and archetypes.

The lowest value, a 19% increase in cost, is for a historic, observed increase in GSHP total install costs in the UK between 2006 and 2010 for installations supported by the Low Carbon Buildings Programme (Ipsos MORI and CAG consultants, 2011). This is the only increase in observed or forecast costs for this metric.[19] The highest value, a 90% reduction in costs, is also an observed, historic study, for GSHP equipment costs in Switzerland between 1985 and 2008 (Kiss, Neij and Jakob, 2013).

Most forecasts anticipate some level of future cost reduction, with mean average reduction values for 2030 of 16% (for equipment costs alone), 31% (for non-equipment costs) and 23% (for total installed costs); equivalent median values are 17%, 30% and 20%.[20] This suggests significant prospects for cost reduction to 2030, particularly for non-equipment costs.

[17] In almost all studies, the '% change' metric refers to a cost reduction, so we use the term '% cost reduction' here. On this basis, a cost increase is represented as a negative cost reduction, in a similar way to negative experience rates.

[18] To reduce the 'y axis' range on the Figures in this section, neither of these lowest and highest values are shown on the figures; these are the only two data points omitted from the figures for this reason. To reduce the 'x axis' range, a small number of pre 2010 and one 2070 data point are also omitted.

[19] The same study reported a 22% decrease in ASHP total installed costs over a similar period.

[20] Calculating an average using the median rather than the mean is recommended when the data distribution is either skewed (a non-normal distribution) or when there are outliers present.

This is illustrated by two relatively high forecasts for UK non-equipment cost reductions by 2030 of 55% for 2014-2030 (Hardy, Sugden and Dale, 2016) and 50% for 2021-2030 (Cooper, 2021)). Both are based on ‘optimistic scenarios’ of UK market deployment for ASHPs, and both reflect a perception of the potential for significant non-equipment installed cost savings in the UK heat pump sector over the next decade. For total installed costs, the highest cost reduction figure is 38% for 2021 to 2030 (Cooper, 2021).

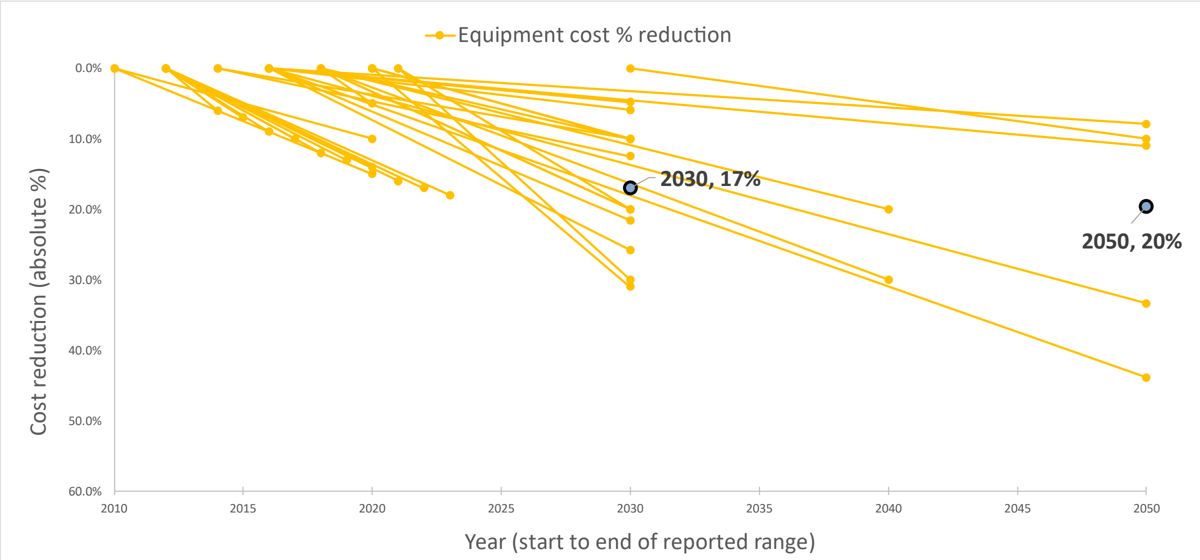

Figure 5: Heat pump equipment cost reduction forecasts

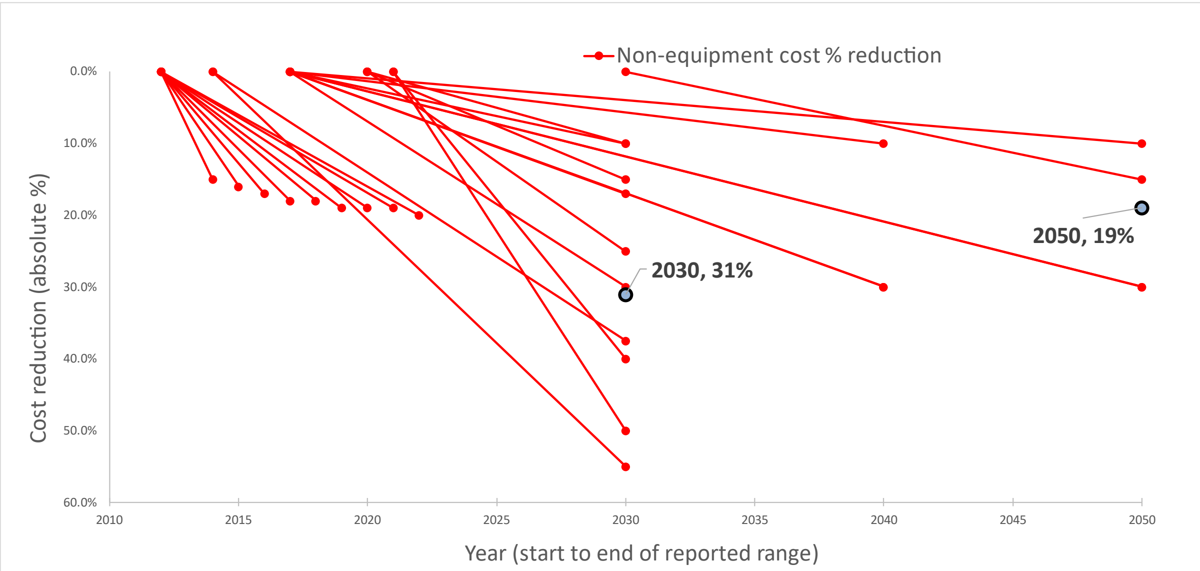

Figure 6: Non-equipment cost reduction forecasts

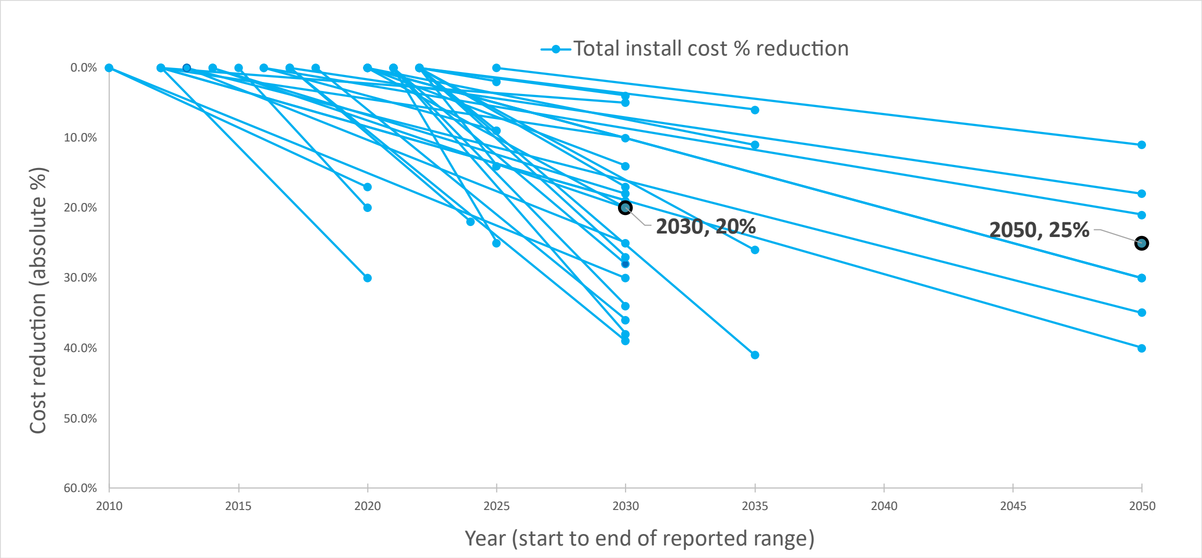

Figure 7: Total installed costs reduction forecasts

3. Summary and Discussion

3.1. Comparing cost metrics

Heat pump cost data is relatively scarce and is often inconsistent across different studies. Given the importance of heat pump costs for energy transitions, there is a vital need for improved data on heat pump costs, in the UK and internationally, in terms of both quantity and quality. There is also a need for improved public access to installed cost data, given that public funding is subsidising costs in many countries.

Across available data, heat pump costs are reported in many different ways, according to unit of assessment boundaries, technology types, building contexts, and whether costs are assessed on an installed or lifetime basis. Our review has focussed on total installed costs, reported as single year costs, experience rates and/or % cost reduction. Most historic (actual) cost assessments are reported as single year costs, while most cost forecasts are stated as % cost reductions.

Our review adopted a broadly inclusive approach to data gathering, to widen the data sample and allow trends to emerge, while noting the varied assumptions and contexts included within it. Table 2 below collates average figures for the three cost metrics.

Single Year	**%**
Median forecast single year cost reduction, 2020 to 2030, ASHP (total installed costs)	24
Median forecast single year cost reduction, 2020 to 2030, GSHP (total installed costs)	6
% Cost Reduction	
Median forecast % cost reduction, 2030 end point (equipment costs only)	17
Median forecast % cost reduction, 2030 end point (non-equipment costs only)	30
Median forecast % cost reduction, 2030 end point (total installed costs)	20
Experience Rates [21]	
Median experience rate, historic and forecast (equipment costs only)	18
Median experience rate, historic and forecast (total installed costs)	14
Experience rate data range, all data	-2.3 to +35

Table 2: Collated heat pump installed cost data averages and trends

[21] Experience rate percentages represent % cost changes for each doubling in cumulative installed capacity; the figures are not directly comparable to % changes in single year or multi-year cost metrics, which may be calculated independently of deployment forecasts.

Collating data across the three metrics highlights a number of points:

- Total installed costs have been roughly stable historically, for both ASHPs and GSHPs, with most studies finding little or no reduction in domestic heat pump installed costs in the UK over the past decade. Over the same period, some cost reductions have been achieved internationally, and over time, particular countries have successfully aligned market growth with reduced installed costs.

- Average forecasts for both single year and % cost reduction data, mostly based on UK based studies for ASHPs, suggest total installed cost reductions of around 20-25% by 2030. Average % cost reduction forecasts are notably higher for non-equipment costs than equipment costs.

- Reported heat pump experience rates vary widely, internationally, from over 30% to less than 0%. Average rates are significantly positive, at 18% for equipment costs alone, and 14% for total installed costs. The UK has the lowest internationally reported heat pump experience rates.

Explaining these findings is not straightforward, and many studies report costs without causal explanation. However, the averages and trends may relate to differences in country scope between different metrics. Aggregated single year and % cost reduction datasets refer mostly to UK studies – a country with a poor track record of heat pump deployment and cost reduction. In contrast, almost two-thirds of experience rate studies are for RoW studies, including countries which have successfully combined deployment growth and cost reduction.

There are also temporal differences between the metrics: single year and experience rate data are based mainly on historic costs, whereas % cost reduction data are based mainly on forecasts. HP units and ancillary equipment are often seen as mature technologies, with relatively little scope for future cost reduction (Hardy, Sugden and Dale, 2016; Renaldi et al., 2021). By contrast, non-equipment costs, which are mostly locally or nationally determined, may offer significant scope for future cost reduction, particularly in countries such as the UK with relatively small and immature supply chains (Cooper, 2021; Sissons, Wiley and Williamson, 2022).

3.2. UK policy targets in context

The cost of installing heat pumps in UK homes is a key challenge for delivering net zero, and achieving significant cost reductions over the next decade is a UK policy priority. In this context, the UK Government’s policy ambitions can be benchmarked against historic and forecast cost data.

In its *Heat and Buildings Strategy*, the UK Government sets a “clear ambition for industry to reduce the costs of installing a heat pump by at least 25-50% by 2025 and to ensure heat pumps are no more expensive to buy and run than gas boilers by

2030" (BEIS, 2021a, p.15). Here, we have assumed that, as part of the Government's ambitions, installed cost parity with gas boilers should be achieved by 2030.

From a starting point in 2020 of 36,000 heat pump installations in the UK (CCC, 2021), and total cumulative installations of approximately 275,000 (Statista, 2022a), it is possible to estimate the annual and cumulative installations required to achieve the UK Government's 2028 deployment target of at least 600,000 annual installations. Assuming an exponential growth trend between 2020 and 2030[22], cumulative heat pump installations in the UK are projected to be over 2m by 2028, and over 4m by 2030. This represents just under four market doublings between 2020 and 2030.

Installed costs for domestic gas boilers and heat pumps vary considerably, according to technology design and building context, but typical estimates are of c.£3,000 for a gas boiler and c.£10,000 for an air-to-water ASHP (Cooper, 2021). Achieving cost parity in ASHP installed costs would therefore require a 70% reduction. For this to be achieved by 2030, over approximately four doublings in cumulative capacity, implies an experience rate of around 26%.[23]

This is well above the international median average experience rate for total installed costs of 14%, and above the highest reported rate internationally of 24%, for Switzerland, over the period 1991-2008 (Munuera, 2014). There are few published forecasted heat pump experience rates, but the indicative UK rate is less than the highest forecast rate for total installed costs, a global forecast of 30% for the 35 year period 2015-2050 (Knobloch et al., 2019).

This indicative target rate is set against the UK's poor recent track record of installed costs trends. It is also distinct given the short timescale involved – under a decade – although a 19% experience rate has been reported for the Netherlands for the seven year period 2012-18 (Jakob *et al.*, 2020). In effect, realising the UK policy ambitions for heat pump deployment and cost reduction implies a radical change, from international laggard to leader, in less than a decade.

A reduction in total installed costs of 70% by 2030 is over three times greater than the median average % cost reduction forecast in our review of 20%, and almost double the highest single figure of 38%. By comparison, the Climate Change Committee's 'balanced pathway' assumes a 20% installed cost reduction by 2030, and up to 30% under more optimistic assumptions (CCC, 2020a).[24] The UK innovation agency Nesta has concluded that even under optimistic assumptions,

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[22] The UK Government has not published projected annual installation figures. For our indicative analysis, the number of annual installations in the period 2021-2030 were generated using an exponential line fit, to represent the gradual development of supply chain capacity in the early 2020s before fuller expansion in the late 2020s.
[23] For each doubling of cumulative capacity, final installed cost = [original installed cost multiplied by the progress ratio], where the progress ratio (PR) is [1 minus the experience rate]. For four doublings in cumulative capacity, the PR can be calculated as the 4th root of the ratio of the final and original installed cost, which for a 70% cost reduction is 0.3. The 4th root of 0.3 is 0.74, giving an experience rate of [1 - 0.74] = 0.26, or 26%.
[24] More recently, in its 2022 Progress Report for the UK Parliament, the CCC presented an 'indicative pathway' for heat pump installed cost reduction consistent with UK Government targets, suggesting a required cost reduction of c.45% between 2022 and 2030. The CCC also suggested that installed costs had fallen by 7% in the UK between 2018 and 2021 (CCC, 2022, p.171).

heat pump installed costs still be more than double those for gas boilers by 2030 (Sissons, Wiley and Williamson, 2022).

However, these figures ignore any heat pump grants or loans, to help achieve cost parity, or other schemes which could offset heat pump installed costs.[25] The UK Government's Boiler Upgrade Scheme offers capital grants of £5,000 for ASHP installations (BEIS, 2021b), effectively halving the average cost for eligible installs. Assuming the scheme was expanded to cover most HP installations in the UK up to 2030[26], the % cost reduction to achieve cost parity becomes much less, around 40% – close to the highest single forecast in our review of 38%.

There is also a range of cost reduction expectations within UK industry, including some high cost reduction forecasts, especially for non-equipment installed costs. Perhaps most prominently, the energy company Octopus Energy has claimed that, taking into account the Government's Boiler Upgrade Scheme subsidy, it is already starting to offer heat pumps "at similar [installed] cost to a gas boiler for most homes" (Octopus Energy, 2022).

Expectations of high cost reductions in Government and among some firms reflect a perception of significant scope for more efficient supply chain and installation practices in the UK. According to the *Heat and Buildings Strategy,* heat pump cost reduction will be achieved through a combination of market competition, economies of scale and new financing models (BEIS, 2021a). A *UK Net Zero Research and Innovation Framework* (BEIS, 2021c) referred to 'industrialised' manufacture and supply chain innovation as cost reduction drivers. Government consultations with industry have suggested that installed cost reductions are achievable through 'modularisation' and more efficient manufacturing and installation processes (HMT, 2021).

Alongside its cost reduction ambitions, the UK Government is also aiming for a 30-fold increase in heat pumps manufactured and sold in the UK by 2030, to over 300,000 units a year by 2028, and the creation of over 10,000 manufacturing-related UK jobs (BEIS, 2021a). Based on consultations with UK and international manufacturers and suppliers (BEIS, 2020b), the Government described this huge expansion as 'realistic and achievable' (BEIS, 2021a). The Scottish Government's Heat Pump Sector Deal Expert Advisory Group envisages Scotland as a global centre of excellence for heat pump manufacture (Scottish Government, 2021).

The anticipated expansion of heat pump installations and manufacturing capacity in the UK, although particularly dramatic, is part of an international trend. Taking a global perspective, the IEA has estimated that global installations will need to rise from a current level of less than 20 million per year to more than 100 million per year by 2050 (IEA, 2021b). International heat pumps sales are now growing rapidly (EHPA, 2022) with high growth rates being seen in both established markets such as

[25] Some analysis suggests that, on a whole lifetime basis, heat pumps may already offer a cost competitive solution for many UK homes (Rosenow, 2022; Sissons, Wiley and Williamson, 2022).
[26] The Boiler Upgrade scheme is currently funded at £450m over three years, and so can offer £5,000 grants to only 90,000 total installations, around 2% of the estimated >4m cumulative installations required by 2030. As and when installed costs reduce in the 2020s, the subsidy required to help achieve cost parity will fall.

Norway, Switzerland and France, and emerging markets such as Poland and the Netherlands (EHPA, 2021; Rosenow and Gibb, 2022).

3.3. Wider energy innovation context

Expectations for heat pump cost reduction have developed against a backdrop of steep reductions for some energy technology costs over the past decade, particularly solar PV and windpower. Between 2010 and 2020, the total installed costs of solar PV globally fell by 81%, and by over 30% for both onshore and offshore wind energy (IRENA, 2021). At the same time, conversion efficiency and technical performance increased, particularly for windpower, so that the total 'levelised' (lifetime) costs for windpower halved over the decade (IRENA, 2021).

By contrast, costs for some energy generation technologies have at times increased rather than decreased (Harris *et al.*, 2013; Roser, 2020; IRENA, 2021). In explaining these differences, there is evidence that modularity – having a relatively small technology unit scale, and so being able to exploit standardisation and replication economies – has been an important factor (Wilson et al., 2020). Less modular ('lumpy') technologies such as nuclear power have exhibited diseconomies of scale and 'negative learning (Grubler,2010; Sovacool, Nugent and Gilbert, 2014).

Although partly modular, heat pump technologies are multi-component technologies with modular and customised elements. Heat pump units are assembled from standard components manufactured in competitive global supply chains among a small number of major manufacturers (IEA, 2022b), but assembly plants are more dispersed, including a small but growing number of UK based plants (BEIS, 2020b). Non-equipment costs, which make-up almost half of total installed costs, vary considerably with national and local context, particularly labour costs (IEA, 2022b).

Even for technologies which have shown long term cost reductions, progress has been irregular. In the late 2000s and early 2010s, both solar PV and windpower experienced rising installed costs, typically under a combination of rising demand and limited supply, supply chain bottlenecks, skills shortages and commodity price increases (Candelise, Winskel and Gross, 2013; Louwen and van Sark, 2020). In late 2021 and 2022, supply chain bottlenecks and commodity price increases returned, placing upward pressure on renewables technology costs for the first time for a decade (Rivero, 2021; IEA, 2022).

Drawing lessons from these wider experiences for heat pumps is not straightforward. Reflecting on the relevance of windpower cost reductions for heat pumps, Gidén Hember (2020) concluded that it was possible to reduce prices in parallel with efficiency improvements. However, another lesson that emerges is that even within a long term cost reduction trend, periods of static or increasing costs should be anticipated.

Expectations of a very rapid deployment growth present risks of cost increases, at least temporarily. Heat pump international supply chains and manufactures are facing increased component costs and capacity shortages (Slowe and Ashurst, 2022), and many European countries are experiencing labour shortages related to heat pump installation (IEA, 2022b).

Over time, as manufacturing capacities and supply chains respond to increased demand, scale economies, design standardisation and technological innovation should drive some reductions in equipment costs (IEA, 2022b). There are likely to be more substantial opportunities for non-equipment cost reduction, as installer capacities grow and installation practices become more efficient.

3.4 Conclusion

Decarbonising home heating is one of the biggest challenges involved in achieving the UK's net zero policy target, and a consensus has now emerged on the central role of heat pumps in addressing this challenge. Many other countries have also identified domestic scale heat pumps as critical technology for their energy transition.

A distinctive aspect of UK ambitions is the envisaged speed and scale of change for deployment growth and cost reduction, from a low base. The UK has one of the lowest number of heat pumps installed in Europe, and the lowest reported heat pump learning rate.

In the UK, there are now realistic prospects for reduced heat pump installed costs, but these are unlikely to be at a scale and speed to match policy ambition. Most forecasts, and most historic experience, suggest significant but relatively modest cost reductions over the next decade compared to the radical ones envisaged by policy.

This does not mean that ambitious policies to support rapidly rolling-out and reducing the installed costs of heat pumps are not desirable. Well-designed and sustained policy support is a critical enabler of deployment growth and cost reduction. Rather, our review highlights the need to align policy aspiration with a realistic assessment of evidence, drawing on international experiences and lessons from other technologies. Effective policies and regulations, underpinned by evidence, can drive high quality and lower cost heat pump installations in the UK.

Energy policies in the UK and elsewhere are being reframed in response to changed circumstances. In this context, the wider benefits of heat pumps – improved energy security and efficiency, and economic development opportunities – become more salient. Over time, heat pumps should also offer households lower and more stable energy costs. This suggests a wider framing of the heat pump proposition in the UK, beyond radical and possibly unrealistic goals for installed cost reduction.

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