International Renewable Energy Agency

RENEWABLE SOLUTIONS IN END-USES

HEAT PUMP COSTS AND MARKETS

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The **International Renewable Energy Agency (IRENA)** serves as the principal platform for international co-operation, a centre of excellence, a repository of policy, technology, resource and financial knowledge, and a driver of action on the ground to advance the transformation of the global energy system. A global intergovernmental organisation established in 2011, IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security, and low-carbon economic growth and prosperity.

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1. INTRODUCTION

If the world is to avoid dangerous climate change and meet the Paris Agreement's goals, policy makers need to address the challenges of reducing energy use and increasing the share of renewable energy in end-use sectors. Globally, the buildings sector accounts for around 3 gigatonnes (Gt) of direct carbon dioxide (CO_2) emissions per year, with electricity use and associated fossil fuel combustion for district heating raising that figure to 10 Gt of CO_2 per year (IRENA, 2021a). However, as the cost of renewable power generation – notably for solar and wind technologies – has fallen (Box 1.1), decarbonising the power generation sector has become increasingly economical. The indirect emissions from buildings will decline as electrical end-uses become less carbon intensive. Highly efficient, electricity-driven heat pumps will have a crucial role to play in decarbonising space and water heating in buildings.

Unfortunately, data on the costs and performance of heat pumps are difficult to find and, in many cases, unavailable. Policy makers are left having to make important decisions around the energy transition with less than adequate factual data to support their analysis of options for heat provision. It is therefore not uncommon to see economic analyses of heating options focus on only operating cost savings (*e.g.* IEA, 2019) or making single point cost assumptions for entire regions (*e.g.* JRC, 2019).

To help remedy that situation, this report presents the best available data for the costs of heat pump systems for residential buildings. The granular data on the installed costs and performance of heat pump systems in different market segments will allow policy makers, researchers, industry stakeholders and others to conduct more robust analyses. While the data in this report are the best available, they are far from ideal. Primary sources have been prioritised, but key differences in data, due to differing system boundaries, mean direct comparisons between markets are difficult. In many countries, robust data are simply unavailable and policy makers will be forced to rely on anecdotal evidence, or snapshots that may be more or less representative. More work to expand data collection and harmonise it across countries would be welcome.

In buildings, the direct use of fossil fuels is dominated by space and water heating, and cooking. In countries with significant heating seasons, and especially those with cold climates, space heating accounts for the largest share of total building energy consumption and also direct fossil fuel use. Energy efficiency can help address related emissions, but given the urgency of decarbonising the buildings sector and the difficulty of scaling up deep energy efficiency retrofits of the existing building stock, it is important to decarbonise heat supply. With the fall in renewable power generation costs, a solution is at hand. A decarbonised electricity sector makes the electrification of end-use sectors an avenue to rapidly reduce buildings emissions.

Heat pumps in buildings and industry represent a highly efficient solution for decarbonising sanitary hot water, space heating and low-temperature process heat needs. Heat pumps are the default technology for the cooling sector, but continuous technology improvements mean solutions are becoming more efficient, further reducing the emissions from cooling.

Heat pump technologies represent a mature, reliable and established technology solution for space and water heating. However, despite growing market deployment in recent years, their use in countries with substantial space heating demands – with the exception of the Nordic countries – remains low. This needs to change rapidly if the world is to keep the Paris Agreement goals in play.

As a result of significant innovation and technology development, the fossil fuel price crisis of 2022 and targeted policy support, heat pump installations are growing significantly in a number of existing and new markets. Scandinavian countries have long set the benchmark – heat pumps have been the top choice for new heating systems for years – but other, newer markets are now seeing rapid growth, from Belgium to Poland. This growth and potential are stirring manufacturers to raise production capacity.

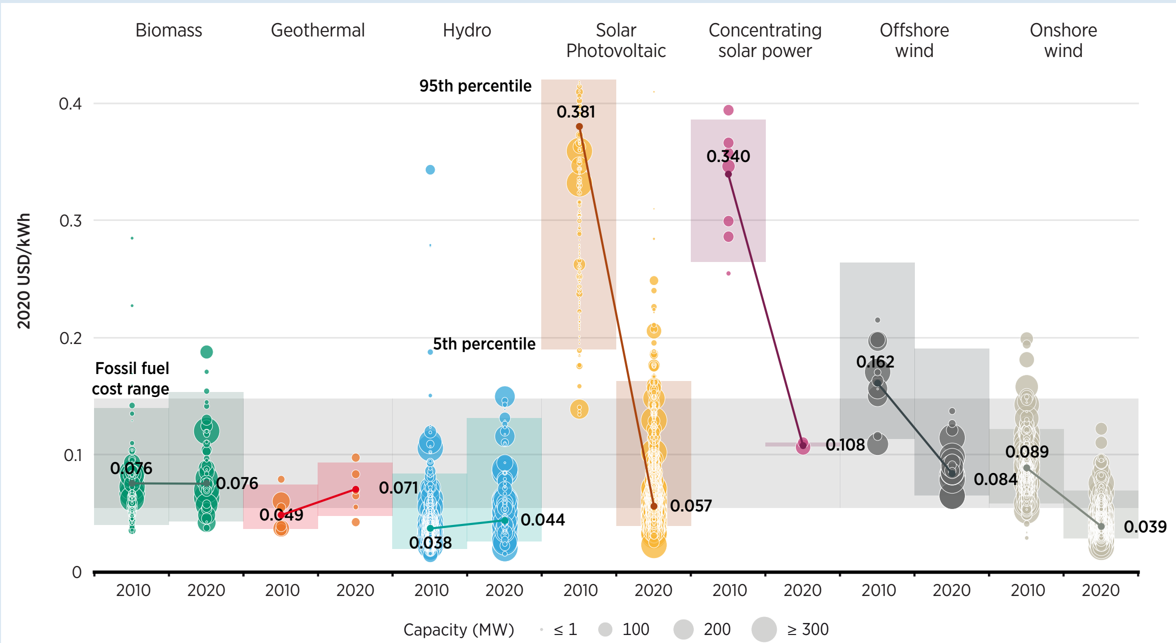
Yet despite these promising developments in heat pump deployment, particularly for new builds, progress remains below what is needed. In most countries with cold climates, home construction rates are low and the majority of heating systems are still boilers or furnaces using gas or oil. When these fail, there is often little time to plan for a heat pump installation and the current demand also means skilled and experienced installers are in short supply. This remains a key barrier in many cases to more rapid uptake.

In the past, the wide gap in capital expenditure needed between a heat pump and a fossil heating solution was a challenge. Although heat pumps are three to five times more efficient, electricity costs are typically higher than those of fossil fuels – in part due to the taxation burden being heavier for electricity than gas, in Europe at least. Fossil fuels, in most jurisdictions, still do not pay the real cost of their externalities (in terms of local and global pollutant costs) and indeed are often still receiving subsidies. Reform of this situation would help rebalance the competitive situation in favour of heat pumps. These factors obviously vary significantly by country, so the overall cost-benefit ratio of new heat pumps is not always clear. However, the current fossil fuel price crisis has changed that calculus and homeowners and businesses are now keenly aware that even before calculating the environmental and health costs, fossil fuel heating solutions are no longer cheap.

Box 1.1 Renewable power generation cost trends, 2010-2020

Renewable power generation technologies are increasingly the lowest-cost sources of electricity in almost all markets. It has been a remarkable decade of change for renewable electricity generation, and solar photovoltaic (PV) and wind power technologies in particular. Among newly commissioned projects, the global weighted average levelised cost of energy (LCOE) of utility-scale solar PV fell by 85% between 2010 and 2020, from USD 0.381/kilowatt hour (kWh) to USD 0.057/kWh (Figure 1.1). This is a precipitous decline. At one time more than double the cost of the most expensive fossil-fuel-fired power generation option, utility-scale solar PV can now compete with the cheapest new fossil-fuel-fired capacity. Over the same period, the global weighted average cost of electricity from concentrating solar power fell from USD 0.340/kWh to USD 0.108/kWh. This 68% decline in the cost of electricity from this technology – which now falls in the middle of the range of new fossil-fuel capacity – remains a remarkable achievement for a technology with cumulative installed capacity of just 6 gigawatts (GW) at the end of 2020.

Figure 1.1 Levelised cost of electricity by technology, 2010 and 2020



Source: IRENA, 2021b.

Wind power has experienced a slower rate of decline than solar PV, but is nonethless impressive in its own right. Between 2010 and 2020, the global weighted average cost of electricity from onshore wind projects fell by 56%, from USD 0.089/kWh to USD 0.039/kWh. For offshore wind, the global weighted average LCOE of newly commissioned projects declined from USD 0.162/kWh in 2010 to USD 0.084/kWh in 2020, a reduction of 42% in ten years (IRENA, 2022a).

In countries where buildings sector policies focus on energy efficiency and renewable requirements **in new buildings**, heat pump technologies can be the most economical solution. However, the same often does not hold true for the renovation segment. Moderate to deep energy efficiency renovations greatly enhance the economics of heat pumps by reducing required operating temperature (boosting efficiency) and reducing the size of the heat pump required. This is because older, "leaky" buildings using existing hydronic heat distribution systems (wall-mounted radiators) require relatively high flow temperatures that reduce the heat pumps' efficiency and also larger peak capacities to cope with the greater demand from poorly insulated homes. However, recent technology developments mean heat pumps that are suitable as a 'one-for-one' replacement for exisiting boilers are now available and can provide the 70°C flow temperatures needed in many poorly insulated buildings. Having said this, in recent years, policy makers have shifted focus to address this issue more holistically with a more flexible approach where a key consideration is if buildings or renovation packages meet a 'low temperature comfort standard', that is to say capable of achieving adequate comfort with a maximum heating system flow temperature of 55°C. This will help ensure higher efficiency and lower costs for the occupants of residential buildings.

Many countries are aware of the necessity to accelerate energy efficient and renewable heating systems and have now introduced significant subsidy schemes to accelerate the decarbonisation of new and existing buildings. However, renovations that include energy efficiency and a switch to CO_2-free heating systems remain a small fraction of total renovations, and their rate is below that needed to meet the Paris Agreement goals (IRENA, 2020a).

DECARBONISING THE ENERGY SECTOR: THE ROLE OF HEAT PUMPS

IRENA's *World energy transitions outlook* (IRENA, 2022b) outlines a pathway for the world to achieve the Paris Agreement goals and halt the pace of climate change by transforming the global energy landscape. The analysis presents options to limit global temperature rise to 1.5°C by bringing energy sector CO_2 emissions to net zero by 2050. The analysis offers high-level insights into the technology choices, investment needs, policy framework and the socio-economic impacts needed to achieve a sustainable, resilient and inclusive energy future.

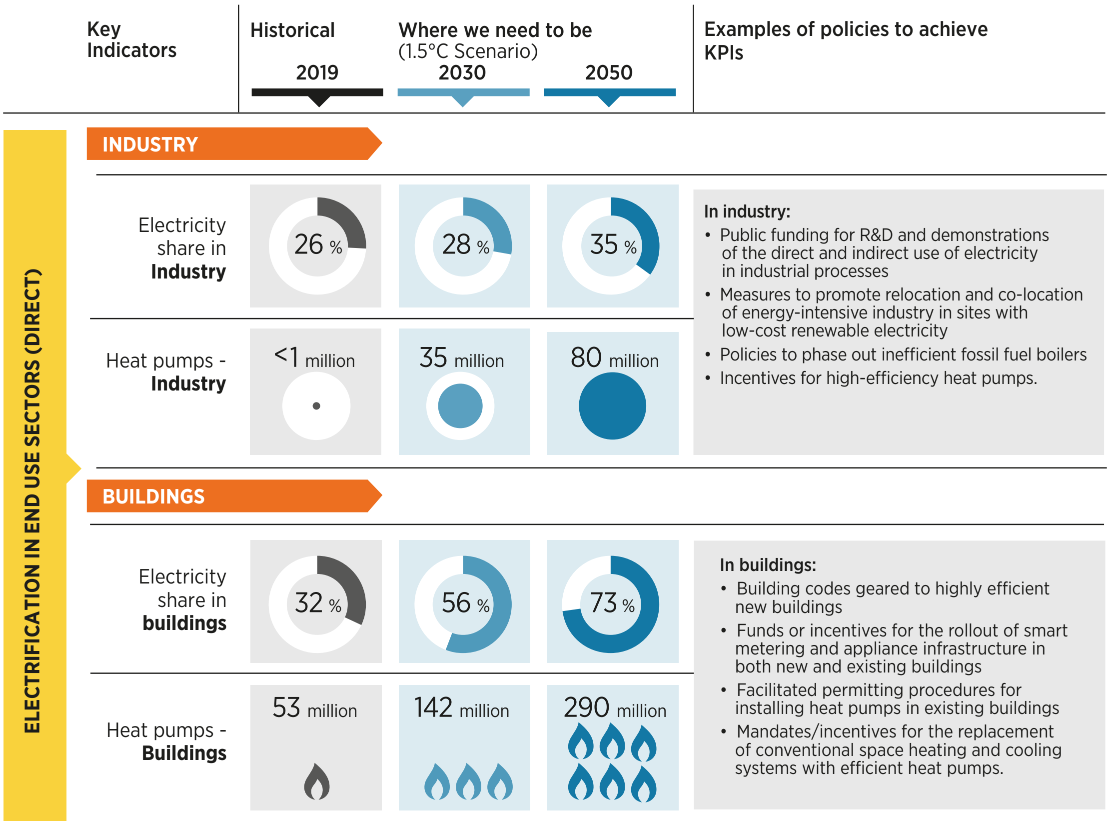
The detailed analysis shows that over 90% of the solutions shaping a successful outcome in 2050 involve renewable energy through direct supply, electrification, energy efficiency, green hydrogen and bioenergy combined with carbon capture and storage (BECCS). The technological avenues leading to a decarbonised energy system have crystalised, dominated by solutions that can be deployed rapidly and at scale. Technologies, markets, and business models are continuously evolving, but there is no need to wait for new solutions. In 2050, electricity will be the main energy carrier, increasing from a 21% share of total final energy consumption in 2018 to over 50% in 2050 as electricity generation becomes 90% renewable.

The falling costs of renewable power generation will accelerate the transition to a decarbonised electricity system, blurring the sectoral boundaries that have characterised the energy sector for so long. At the same time, the electrification of end-use applications in transport and heating will need to be accelerated rapidly to achieve the Paris Agreement goals and the pathway laid out in the *World energy transitions outlook*.

In the outlook's pathway to net-zero, electrification plays a primary role in the buildings sector. Direct electrification rates for the sector would be the highest of any end-use, reaching 73% compared to 32% in 2019. The total number of heat pumps providing space and water heating in cold-climate countries would rise close to ninefold, exceeding 142 million by 2030 and reaching 290 million by 2050 compared to the approximately 53 million installed in 2018 (IRENA, 2022b) (Figure 1.2). Investments in heat pumps would need to rise from an estimated USD 12 billion per year in the period 2017-2019 to an average of USD 144 billion per year between 2021 and 2030, before easing back to USD 77 billion per year in the period 2031-2050.

With tighter sector coupling, these investments can provide broader benefits beyond the buildings the heat pumps serve. Energy technologies integrated or used in buildings - such as heat pumps, solar PV, batteries and electric vehicles - all have the potential to become sources of system flexibility, creating a positive feedback loop and facilitating the integration of larger shares of variable renewable energy in the electricity system. Policies to reward this flexibility will be a small, but important, part of transforming the business case for heat pumps in the coming decade.

Figure 1.2 Heat pump deployment needs in the 1.5°C Scenario, 2019, 2030 and 2050



Source: IRENA, 2022b.

Note: R&D = research and development.

The use of heat pumps in the buildings sector will be crucial to achieving the 1.5°C Scenario pathway, with electrification accounting for around half of the reduction in direct CO_2 emissions in the buildings sector by 2050. Given the urgency of the goal, and the low rates of new construction or energy efficiency and renewable heating renovations in cold-climate countries (often 1% or less of the building stock), the need for policies to support the scaling-up of heat pumps – as well as the other solutions identified in the *World energy transitions outlook* – becomes evident.

2. AN INTRODUCTION TO HEAT PUMP TECHNOLOGIES

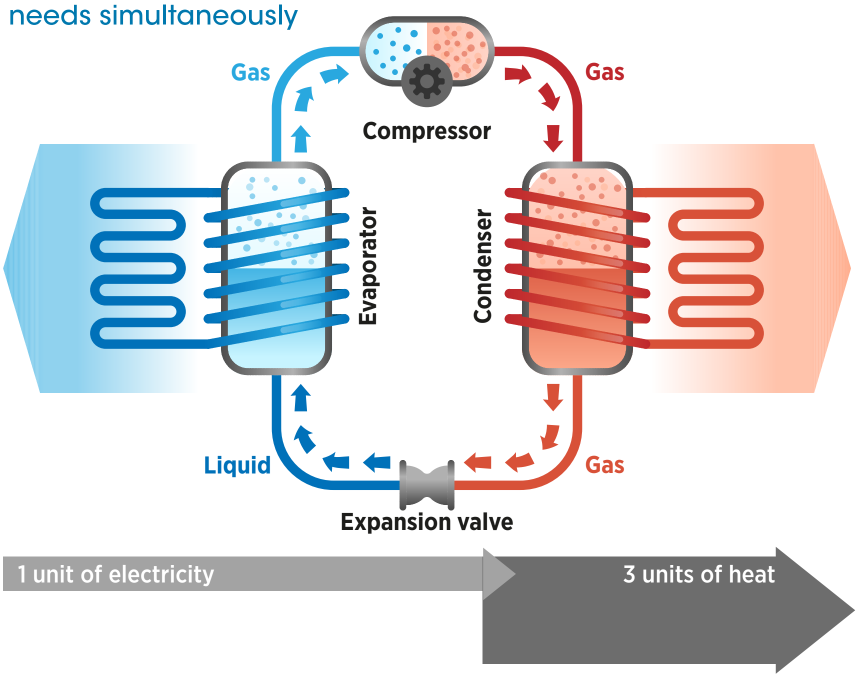
Heat pump technologies can provide space and water heating, and cooling for residential, commercial and industrial buildings, and also provide low-temperature process heat for industrial processes (with demonstration projects up to 180°C). Compared to the combustion of fossil fuels for the provision of heat, they are remarkably efficient, being capable of converting one unit of electrical energy into 2.5 to 5.5 units of heat (an efficiency range of 250% to 550%), depending on the heat pump technology, climate and end-use needs. In comparison, the average for the currently installed fossil fuel boilers might be in the 80-85% range, with new condensing boilers being up to 95% efficient.

Heat pumps are based on what is called the “refrigerant cycle”: electrical energy drives the system, but ambient renewable energy (from the air, water or ground) or low-temperature waste heat is the dominant energy source (hence the high efficiency). While a number of different heat pump technologies exist in the marketplace, the dominant variation is the vapour compression heat pump driven by electrical energy.[1]

In an electric compression heat pump, a transfer fluid (refrigerant) is deployed to transport heat from a low-temperature energy source to a higher-temperature energy sink. The cycle is based on the principles of evaporation and compression. It typically consists of a heat exchanger (the evaporator), the compressor (driven by electricity), a second heat exchanger (the condenser) and an expansion valve. The system also requires the refrigerant itself and a control unit (Figure 2.1).

In the first heat exchanger (Figure 2.1), the refrigerant is exposed to the energy source and evaporates – the energy source is cooled down in this process. The refrigerant vapour is then compressed which results in a temperature lift. The higher temperature is transferred to the heat distribution system via the second heat exchanger which results in the condensation of the refrigerant. This liquid (still under pressure) is then fed into an expansion valve. The resulting low-pressure, low-temperature liquid is then ready to enter the first heat exchanger (evaporator) again, and the cycle is closed.

Figure 2.1 Heat pumps: The vapour compression cycle can provide heating and cooling needs simultaneously



Source: EHPA.

[1] *Heat pumps that use thermal energy to drive the refrigeration cycle are called absorption heat pumps and can use a variety of heat sources, such as geothermal or waste heat, or gas or oil-fired solutions. Similar to electrically driven heat pumps they can achieve efficiencies above 100%, but unlike such pumps, rarely surpass efficiencies of 150-160%.*

Heat pumps are distinguished by the combination of the ambient energy source used (air, water, ground) and the heat distribution system (Table 2.1).[2] In Central Europe, in most residential buildings the distribution system for space heating is based on a hydronic (water-based) system with radiators for heat distribution. Around the Mediterranean basin and in many Scandinavian countries, this setup is less common and reversible heat pumps distributing heating and cooling by air have a larger share.

Table 2.1 Naming convention of heat pump systems

AMBIENT ENERGY SOURCE	HYDRONIC HEAT DISTRIBUTION	AIR-BASED HEAT DISTRIBUTION
Air	Air-water heat pumps	Air-air heat pumps
Water	Water-water heat pumps	Water-air heat pumps
Ground	Ground-water heat pumps	Ground-air heat pumps

Although heat pumps have modest to low shares of the stock of space and water heating equipment in most countries – with the exception of those in Scandinavia – the technology is, in fact, almost ubiquitous in buildings in member countries of the Organisation for Economic Co-operation and Development (OECD). Heat pumps are, literally, everywhere – small units are what provide refrigerators and freezers the cold required for them function, while the air conditioning (space cooling) systems of cars rely on heat pumps, as do the cooling and refrigeration systems in the cold chain for food and medicines. In the buildings sector, the largest number of heat pumps are deployed for space cooling purposes, but many are so-called 'reversible' systems which can also provide heating. Heat pumps are also increasingly to be found providing sanitary hot water and space heating needs either as forced air (in North America) or via hydronic radiators and underfloor heating (in Europe). In industrial applications, they are typically used in drying processes, in food production, in textile production and cleaning as well as in tobacco and leather production. Today, the largest heat pumps are typically found in district heating systems.

Capacities for space and water heating needs in buildings range from a couple of kilowatts (kW) in white goods, to some 5-400 kW in residential and commercial applications, all the way up to bespoke systems with capacity in the megawatt range, designed to provide heating and cooling to hospitals and other large commercial buildings, industrial processes and district heating systems. The biggest single heat pumps today have a capacity of around 35 MW and are used in district heating systems, but BASF and MAN Energy Solutions have announced a 120 MW will be built to provide process steam.

Residential heat pumps typically provide hot water up to 70°, but dedicated hot water heat pumps using CO_2 as the refrigerant can provide water up to 90°C. Heat pumps for industrial applications are now able to provide process heat at a temperature of up to 160°C, with prototypes in demonstration capable of reaching 180°C. On the energy source side, residential and commercial heat pumps can now operate at temperatures as low as -25°C, with many still able to maintain efficiency rates over 100% even at -10°C or less.

In the context of the energy transition, it is important to remember that heat pumps can also provide flexibility to the electricity system. Heat pumps, when water storage is incorporated, can run when electricity prices are low and store energy as heated water, for release as needed and when electricity prices are high. It is also possible, with smart controls, to aggregate heat pumps as part of demand-side services offered to the grid (*e.g.* providing frequency response services) in order to manage growing electricity loads, as well as the increasing share of solar and wind power in electricity systems (IRENA, 2022c).

[2] *In this report air-source heat pumps (ASHPs) and ground-source heat pumps (GSHPs) are often used to refer to the generic technology. These encompass the variety of heat/cold distribution methods, and in the case of GSHPs also different ground sources in some markets. Also note that for individual country data, the original naming convention has been retained in this report in order to make the identification of the original source easier for readers. This is at the expense of consistency, unfortunately.*

HEAT PUMP EFFICIENCY METRICS AND DRIVERS

The efficiency of heat pumps is determined as the ratio between total useful energy output and input needed to run the system. There is, unfortunately, a range of efficiency metrics in use for heat pumps. It is important to be aware of the differences between these metrics in order to understand how comparable they are and what each metric is communicating.

Three different system boundaries are typically used to arrive at three slightly different metrics of efficiency:

1. Efficiency measured in laboratories in a "static" way using testing points (*e.g.* input and output temperatures, and volume flow) from internationally accepted standards and assessed as the **coefficient of performance (COP)**.
2. A **seasonal efficiency** determined by adjusting the COP with actual climate data for source input temperatures, resulting in a seasonal coefficient of performance (sCOP). This is sometimes also referred to as an **annual performance factor (APF)**.
3. The **seasonal efficiency** as **measured** on site for a full season. The result is a **seasonal performance factor (SPF)** that, by design, explicitly includes the impact of annual weather variation and consumer behaviour.

Efficiency always depends on the test points used, the building characteristics, the climate and user behaviour. As a result, the declared efficiencies are only comparable if the methods to determine them are identical. This can make the comparison of efficiencies across jurisdictions, even for the same metric, with different test regimes difficult. In the following sections, when efficiency is referred to, the results should be considered indicative and cannot be easily compared across countries and sometimes sources for individual country values.

With constant improvements in the technology, the efficiency of heat pump units and systems has increased. Much depends, however, on the design of the installation and ensuring it is optimised to perform as efficiently as possible. Poorly designed or installed systems will not reach their potential.

The key points to understand when looking at heat pump efficiency are that:

- The main determinant of efficiency for a given technology is the temperature "delta" or "uplift" for space heating and "downshift" for cooling – the delta or uplift/downshift being the difference in temperature of the energy source (air or water) and the desired output temperature for the system.
- As a general rule, the lower the temperature delta (in absolute terms), the higher the efficiency. For instance, a temperature uplift of 30°C would result in a theoretical COP of 5 (*i.e.* 500% efficiency), while if it was 70°C the COP would fall to 2.5 (Figure 2.2; EHPA, 2019).

The implications of this are:

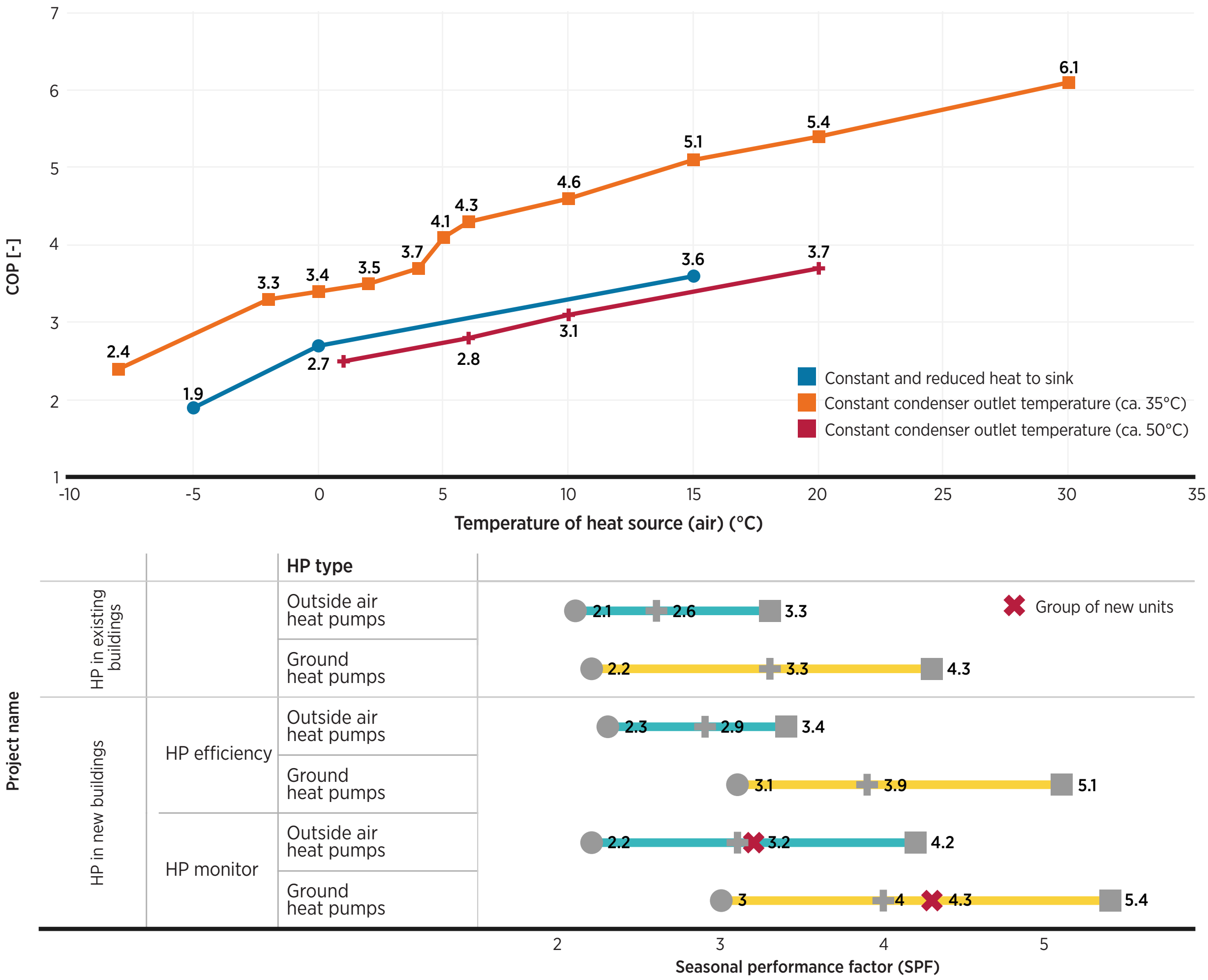
- The higher the temperature of the renewable energy source, the greater the efficiency
- The lower the set-point temperature of the heating system, the greater the efficiency

Leaving aside for the moment the critical importance of heat pump design and installation for efficiency, one of the key considerations is the temperature of the renewable energy source tapped to provide the ambient energy.

Air source heat pumps will see their efficiency change with the outdoor air temperature, while systems using a water source or geothermal loops will have more stable temperatures, but also will be influenced by the outside air temperature. The technology is being constantly improved, however, and residential and commercial heat pumps are now available that can operate at temperatures as low as -20°C and still maintain an efficiency over 100% (NEEA, 2020).

The combined effect of air temperature and set point temperature for an air source heat pump can be seen in Figure 2.2 (left-hand side). A higher COP is achieved at a lower given outlet temperature, that is to say a lower temperature uplift, while efficiency at any set point increases as the outside temperature rises (reducing the temperature uplift needed). The right-hand side of Figure 2.2 highlights that since ground source heat pumps and those relying on a water source will see proportionately lower variation in the source temperature, they are likely to be on average more efficient over the heating season, yielding higher average efficiency (COPs) (right-hand side of Figure 2.2).

Figure 2.2 COP for heating for air source heat pumps in Switzerland and annual SPFs in Germany: Air source and ground source heat pumps, existing and new



Source: EHPA, 2019; Haller *et al.*, 2014 and Miara *et al.*, 2017.

As can be seen, optimising a heat pump system involves certain trade-offs. Maximising efficiency implies minimising the temperature uplift, so ground- and water-source heat pumps are appealing, as they see higher source temperatures in cold weather. However, they also have higher installed costs due to additional piping and installation costs (and potentially, parasitic pumping losses). Similarly, increasing the surface area of the heat distribution system (*e.g.* radiators or underfloor heating) can allow lower temperature setting, increasing efficiency. In new buildings, with stringent energy efficiency standards, this can easily and economically be achieved.

In the current stock of buildings, building age and pre-existing heating systems have an impact on optimal heat pump systems' design and efficiency. Older buildings often rely on higher outlet temperatures in their radiators to compensate for the leaky nature of the building envelope, raising the temperature uplift. Raising the surface area of the heat distribution system can allow lower temperatures and greater efficiencies, but means replacing existing radiators or, ideally, installing underfloor heating, which can help reduce the required outlet temperatures and improve efficiency.

Deep or moderate efficiency refurbishments, focusing on increasing insulation of the building envelope, improving air tightness and reducing/eliminating thermal bridges can reduce heat loss, allow a smaller heat pump and lower temperature lift – and hence improve COP. However, there is a trade-off between the reduced heat pump sizing and efficiency with a renovated building and the cost of the refurbishment. In practice, a building simulation is required to identify the least-cost solution, which may not favour deep renovation.

As heat pumps automatically generate heat and cold in the evaporation and compression cycle, the greatest cost-effectiveness can be achieved if the system is designed to utilise both – if there is significant cooling and heating demand.[3] This is most commonly the case in commercial buildings, or industrial applications, but is also true in residential buildings in many temperate climate zones – and when we consider sanitary hot water in hot climates as well.

Another significant advantage of heat pumps, given the urgency of change required to meet shared climate goals, and the difficulty of addressing heating in buildings, is that the environmental benefits of an entire existing fleet of installed heat pump systems is continuously increasing as the share of renewable and other emission-free power sources used for electricity generation grows. In this respect, heat pumps installed today are future proofing heating and cooling end-uses for the energy transition.

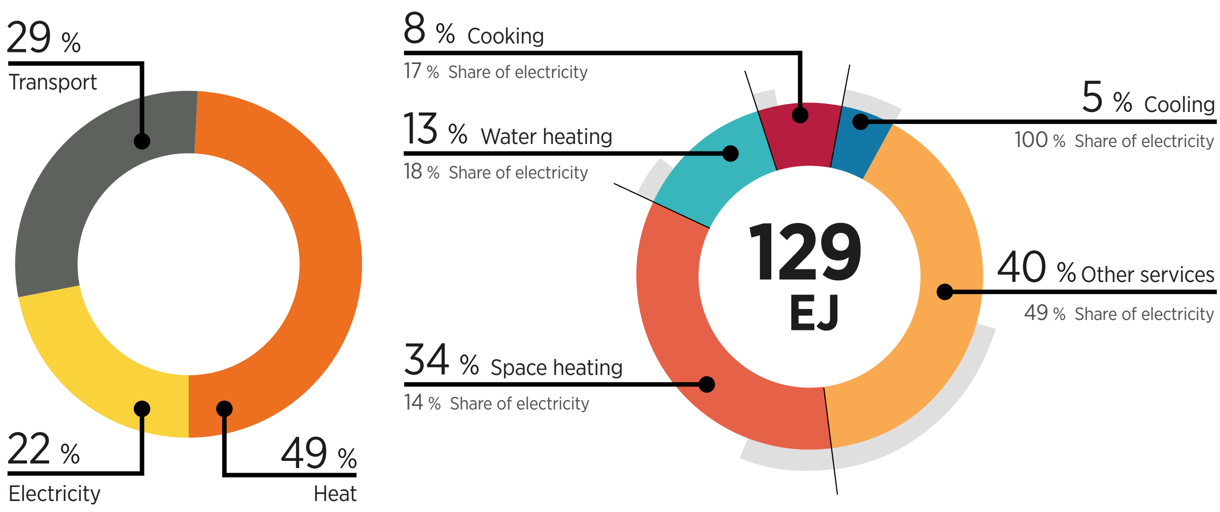
The main challenges facing the industry today include preparing the value chain for the mass market to deliver production cost reductions by optimising and scaling-up production, including a higher amount of pre-fabrication of systems, simplifying installation (and hence cutting costs), integrating solutions into renovation processes and also integrating heat pumps with the supply-side as part of the move towards “smarter” electricity grids. These will, in parallel, require an increase in trained installers, standardised system evaluation tools, certification and quality assurance mechanisms, and policy assistance to overcome current market failures.

[3] *Where heating and cooling are simultaneously required, heat pumps are highly efficient, as the system is using the otherwise wasted heat or cold generated on either side of the compression/evaporation cycle.*

3. THE IMPORTANCE OF HEAT: APPLICATIONS FOR HEAT PUMP TECHNOLOGIES

Decarbonising the generation of heat for sanitary hot water, space heating and process heat is vital if we are to achieve the Paris Agreement goals. Energy consumption to generate heat accounted for around half (49%) of all the energy consumed in end-use sectors in 2018 and only slightly less (47%) of the energy consumed in buildings (Figure 3.1). Heat pumps are an important solution for the decarbonisation of heat in buildings (and industry) given that they can provide heating and cooling in buildings, delivering efficiency improvement and increasing the use of renewables.

Figure 3.1 Share of heat in total final energy consumption and energy consumption by end-use in buildings, 2018



Source: IRENA, OECD/IEA and REN21, 2020.

Heat pumps are the default choice for space cooling globally, while also the dominant solution for the cold chain. In many temperate climate zones significant cooling and space heating needs already mean reversible air-to-air heat pumps provide cooling in summer and space heat in winter. However, to decarbonise space and water heating, they need to be rolled out more widely. There are encouraging signs, with annual new installations rising in many markets, but still at rates well below those required to decarbonise the buildings sector.

RESIDENTIAL SANITARY HOT WATER AND SPACE HEATING (AND COOLING)

The energy requirements of residential buildings depend heavily on the climate zone they are built in and the performance standard they meet – defined by national or sub-national building regulations for new, and in some cases, existing buildings. The actual energy consumed will depend on this and the type of heating technology used, as this is driven by the efficiency of the heating unit.

But the situation is more complex than this from a design perspective, as the heating system needs to be dimensioned in conjunction with the heat distribution system to ensure that the system can maintain a comfortable indoor temperature even when it is very cold outside in that location. Standardised calculations are available to building engineers for the design phase, an important consideration given that heat pumps' upfront costs are higher than for boilers. Thus, boiler installers' norm of over-sizing systems "just to be safe" is untenable. In addition to space heating needs, all residential buildings and most commercial buildings also require the provision of sanitary hot water. The combined provision of space and water heating offers some synergies and economic benefits, but also adds complexity and costs.

Heat pump technology can meet these requirements for space and water heating in a variety of ways, including:

a) Stand-alone space heating units (hydronic or "forced air" distribution).

b) Stand-alone sanitary hot water units.

c) Combi-heat pumps providing space heating and sanitary hot water.

d) Hybrid systems, combining a heat pump with a direct electric resistance heater, a fossil/biomass boiler or a solar thermal system.

e) Large industrial heat pumps for district heating networks.

The heat distribution system and surface area for hydronic systems, typically via radiators in the past, but increasingly underfloor systems (in new buildings), determine the flow temperature that is required for a given system/climate. Systems relying on air to distribute the heat are different and these "ducted" systems are less common in Europe and more common in North America.

For each building type, the heat distribution system and age/level of renovation will impact distribution temperature needs and the efficiency of the heat pump. The distribution temperature level needs have been generalised for the European context in Tables 3.1 and 3.2. They vary mainly as a result of the renovation level of the building (*e.g.* how well it retains heat), but also as a result of the normal building techniques or style prevalent in a given region. Hydronic heat distribution systems typically require higher temperature levels than air-based systems.

Table 3.1 Guide to temperature levels needed to provide space and water heating in residential buildings using hydronic heat distribution

	NEW/DEEP RENOVATION	AIR-BASED HEAT DISTRIBUTION	SOME RENOVATION	OLD/UNRENOVATED	HOT WATER PROVISION
Single-family dwelling	Air-water heat pumps	Air-air heat pumps	40°C-50°C	50°C-70°C (sometimes even 90°C)	60°C-65°C
Multi-family dwelling	Water-water heat pumps	Water-air heat pumps	40°C-60°C	60°C-80°C	60°C-65°C

Table 3.2 Temperature levels in buildings using air-based (ducted) heat distribution

	NEW/DEEP RENOVATION	SOME RENOVATION	OLD/UNRENOVATED	HOT WATER PROVISION
Single-family dwelling	24°C-26°C	40°C-50°C	Uncommon outside the United States	60°C-65°C
Multi-family dwelling	24°C-26°C	40°C-50°C	Uncommon outside the United States	60°C-65°C

Hydronic heat distribution systems are dominantly used in central/Eastern Europe and the United Kingdom while air-based systems are more typical in the United States, Scandinavia, the Baltic countries and countries around the Mediterranean.

Recent developments in achievable flow temperatures (at acceptable efficiency) and capacity for heat pump technologies allow their deployment in almost all climates and building situations, but certain segments can be more challenging either from a performance or cost perspective. The following sections offer an overview of these challenges across several types of buildings.

NEW AND DEEPLY RENOVATED RESIDENTIAL BUILDINGS

As already indicated, in this market segment, heat pump technology is fit for purpose; existing solutions operate reliably and can cover 100% of the demand for heating, cooling and sanitary hot water. In these buildings, heating and cooling needs are minimised, depending on the stringency of the building code and the climate, to relatively low levels and smaller-sized systems can be used (3-5 kW).

In cold climates hydronic systems using air, water or ground as an energy source and distributing heating via large radiators or floor/wall heating can be used. In these systems, the provision of cooling – whether passive or active – is limited. In warmer climates, the use of reversible air-air units is most common, and these are often designed to provide space heating and cooling, as well as hot water. In warm climates, space heating is more of a secondary application and running hours for cooling can greatly exceed those for space heating.

Heat pumps are often cost competitive with fossil-fuel-based solutions in those areas of the world where ambitious minimum performance requirements for new buildings have to be met to obtain a building permit. The alternatives (gas boiler with solar thermal heating, biomass boiler, connection to district heating) have a similar or even higher price tag and often higher operating expenditure.

Small heat pumps can also operate efficiently and competitively in deeply renovated buildings, but progress in this area remains slow. Governments, generally, have not yet set the policy conditions that address this market failure. Such action would increase the replacement rate of heating equipment, as well as reduce the energy demand of buildings. There are encouraging signs that the current fossil fuel price crisis is driving policy makers to reassess the need to set policies and provide finance to accelerate this market.

RESIDENTIAL BUILDINGS THAT HAVE UNDERGONE MINOR OR NO RENOVATION

Heat pump technology can be economically deployed in buildings that have undergone some renovation measures (new windows, wall insulation, an insulated roof, a new low temperature heat distribution system, *etc.*). As a rule of thumb, most residential and commercial buildings that have undergone some energy efficiency renovation can use heat pumps efficiently, if the heat distribution system can operate with a feed-in temperature of 55°C or below. Operation at higher temperatures, if the existing radiators are under-sized, is feasible, but will require higher operating temperatures that will reduce the efficiency.

However, this boundary is about to be lifted upwards with new heat pumps that can efficiently provide temperatures of up to 75°C. Such solutions would then be able to cover nearly all demand for heating, cooling and sanitary hot water in the majority of buildings without the need to replace existing radiators. Consequently, these units could directly compete with fossil boilers in the case of a boiler replacement. However, if space permits, the installation of new, larger radiators will allow more efficient operation even in unrenovated buildings.

Unfortunately, today's technology cannot compete with a replacement boiler when it comes to speed, space requirements and costs of the exchange, especially in the event of an existing boiler failure. With the current acceleration in heat pump deployment and current product developments, this is likely to change in the next 5–10 years and possibly even in the next 3-5 years given the impetus from the current fossil fuel price crisis.

Box 3.1 Heat pumps in commercial buildings and industry

This report focuses on the cost of heat pumps for the provision of, primarily, space heating and sanitary hot water in residential buildings. Although heat pumps for multi-family dwellings can be quite large, they are typically much smaller than those used in commercial and industrial applications. However, space and water heating in commercial buildings and industrial process heat represent important sources of greenhouse gas emissions and need to be addressed in the transition to a sustainable energy future. This box briefly discusses these two applications and highlights some of the key points relating to the use of heat pumps.

In many regions of the world, the greatest energy demand is for heating and cooling, depending on the season, and in some circumstances at the same time. Mainly two systems are used:

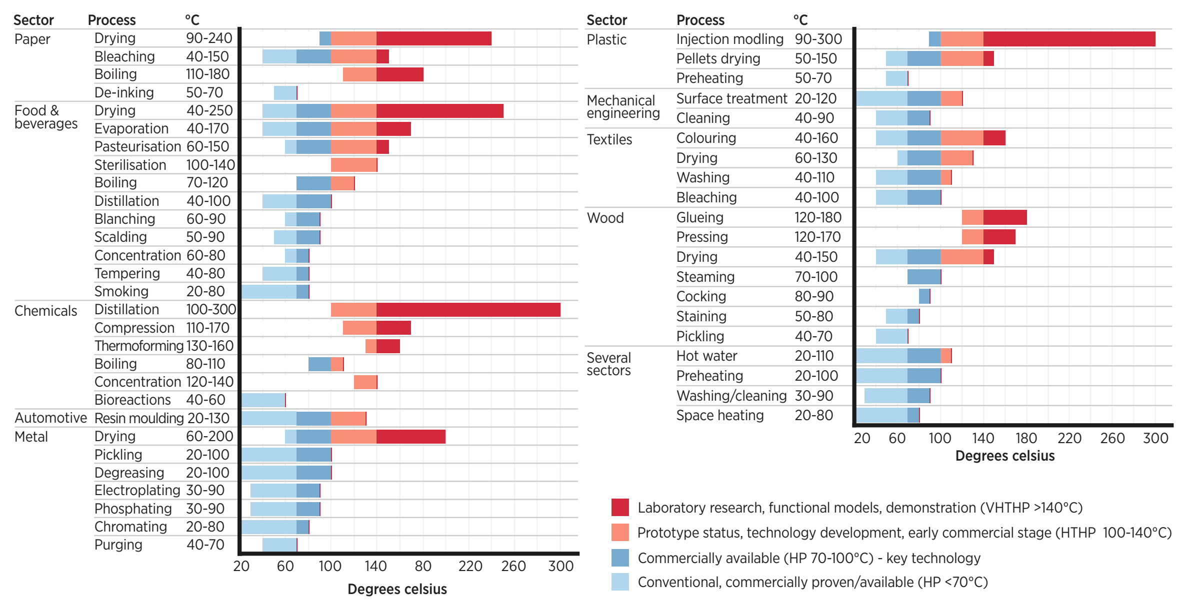
- Hydronic (water-borne) systems
- Direct expansion systems, often referred to as DX (refrigerant) systems

Both systems transfer the cooling or heating load by liquid into the conditioned room/building area. It can be delivered via fan coil units or floor/wall heating. If an air distribution system is used, the air can either be delivered to the room via ducts or via fan coil units installed directly in the room.

Refrigerant-based systems are based on a pipe system transporting the refrigerant to multiple indoor units throughout the building. They use the refrigerant as the cooling and heating medium. This refrigerant is conditioned by an outdoor condensing unit. If heat recovery is included, such systems can heat and cool different areas of a building simultaneously using a two- or three-pipe distribution system. DX systems are used mainly for cooling and in the range of up to 50 kilowatts' demand, while water-based chillers (heat pumps) are mainly used for bigger applications.

Compared to commercial buildings, industrial processes have a different and often unique set of requirements. This increased diversity of end-use applications and requirements (from low-temperature heat for drying to high-temperature process steam), is a challenge for heat pumps today, with the exception of low-temperature heat. The provision of medium-temperature process heat and steam using heat pumps capable of delivering outlet temperatures of above 100°C is a relatively recent development using novel refrigerants, often in conjunction with a waste heat source. Industrial heat pumps can provide temperatures of up to 160°C, but remain predominantly in the demonstration stage of deployment, with ongoing research and development. They can utilise air, water, ground and waste heat as energy sources, but work best with a relatively high-temperature waste heat source to minimise the temperature lift, as with all heat pumps. A good overview of heat pump deployment potential relative to technology development in different industries has been given by Apergaus and Bless (2017) (Figure 3.2).

Figure 3.2 Industrial applications for heat pumps and their technology readiness level



Source: Arpagaus and Bless, 2017.

RESIDENTIAL AND COMMERCIAL BUILDING STOCK IN EUROPE, THE UNITED STATES AND CHINA

Residential and commercial buildings are incredibly diverse, both around the world and within each country. The building type (single- or multi-family dwelling), occupancy and location all drive the relative residential end-use energy demand across a building stock. Commercial buildings also vary by function, from offices to hospitals and restaurants to warehouses and beyond. To take just one example, the end-use consumption of energy for refrigeration will be very different between a cold storage facility and a dry cleaners.

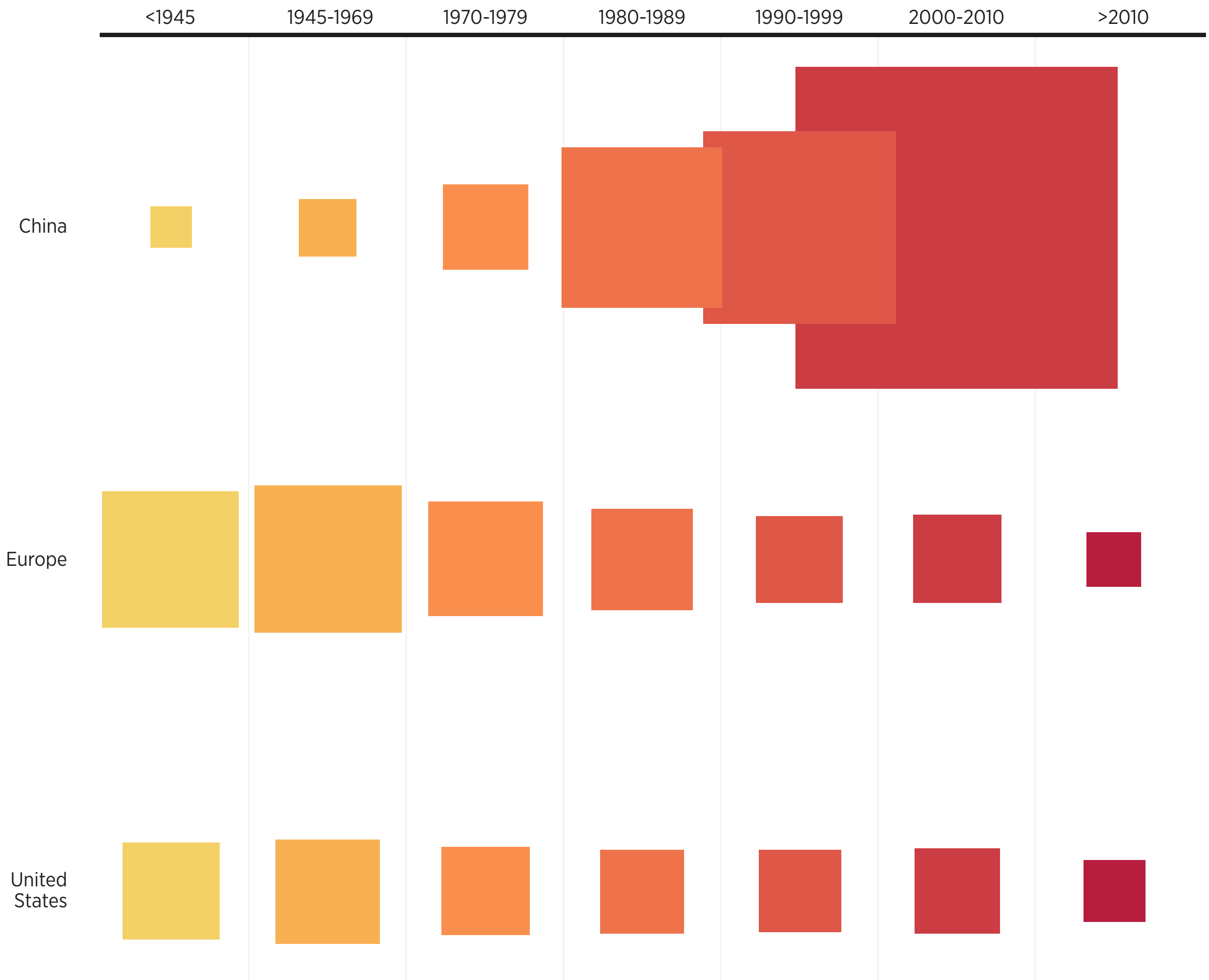
At the same time, construction codes, building norms and materials used can vary widely between different countries and even within a country. This is especially true for residential buildings, particularly with older building stocks. The age distribution of a building stock, in conjunction with the local climate, has a disproportionate impact on expected energy use. Before the oil shock of the 1970s, building codes typically were not focused on energy efficiency, as heating fuels were relatively inexpensive. Buildings built prior to 1970 usually therefore require much more energy for heating and cooling than those built after, unless they have undergone a significant energy efficiency upgrade. The degree to which building codes were strengthened after the first oil shock also varies by jurisdiction.

The complexity doesn't end there, as the energy consumption of a specific building will also depend on the climate zone and the level of user comfort/services expected. The nature of the existing stock of heating and cooling appliances is also an important driver, not only of energy consumption but emissions as well. In short, understanding the building stock, what heating and cooling appliances are used and what building users' needs/expectations are with respect to comfort are very important in order to identify the challenges and opportunities presented by heat pumps as a means of decarbonising the buildings sector.

Although it is beyond the scope of this report to set projections, it is useful to analyse the building stock in a number of major heating markets, given its importance to heating demand and the opportunities for heat pumps.

In Europe, one-fifth of the residential building stock was built prior to 1945 and two-fifths before the first oil crisis of the 1970s. There is quite significant variation in the age of the building stock by country in Europe. The energy consumption for space heating in buildings built before 1970 is generally very high, as the share of deep energy efficiency retrofits is still relatively modest. The stock of commercial buildings in Europe is somewhat older on average (Figure 3.3). The share of residential dwellings built before the 1970s in the United States is very similar to that of Europe, at slightly less than two-fifths (39%).

Figure 3.3 Residential and service sector building age distribution in China, the European Union and the United States



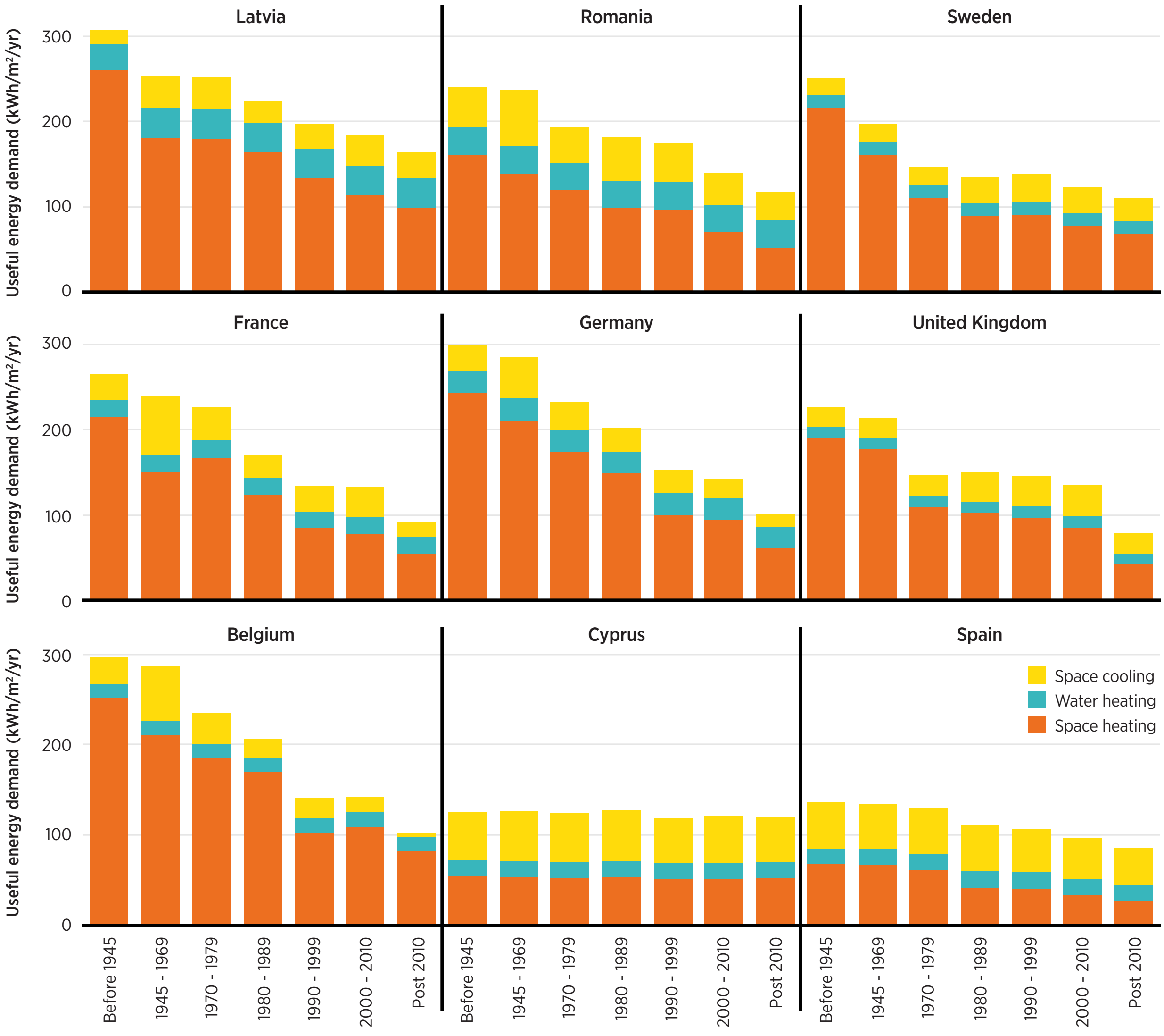
Source: IRENA analysis based on EIA (2022), European Commission (2022), Evergrande Research Institute (2021) and Rogoff and Yang (2020).

Note: Data for China is only available for 2000+

The contrast with China is stark. With rapid economic development only really occurring after the 1970s, China's residential building stock is much younger; most was built after 1980. China experiences very different climatic conditions across its regions; to generalise, the heating seasons in the northern latitudes are significant, while the southern regions often require both heating and cooling. With relatively relaxed building standards until recent times, the average energy efficiency of the building stock by decade is not comparable to most member countries of the OECD.

The importance of a building's date of construction for its space heating and cooling demand can be seen in Figure 3.4, which shows the estimated useful energy demand[4] for space heating, water heating and space cooling in residential buildings in nine European countries. It is notable that in cold climates, where regulations for newly constructed buildings were tightened systematically after the first oil shock, the space heating demand needs fall as the construction becomes newer. The link is weaker in warmer countries, for example, Spain, due to the effect of the outdoor air temperature.[5]

Figure 3.4 Residential building stock's useful energy demand for space and water heating, and cooling by date of construction in nine European countries



Source: European Commission, 2022.

[4] *Useful energy demand is an estimate of the necessary energy required to provide the energy service required, i.e. space or water heating. The technology used will then determine the actual energy consumed. For instance, for space heating, if a gas boiler is used the energy consumption will be greater than the required useful energy, as there are losses in the combustion process. In contrast, with a heat pump with an average efficiency of, say 300%, the electricity consumption would be the useful demand divided by three, as the rest of the useful energy needed is extracted from the heat source (air, water or ground).*

[5] *Building shell energy efficiency is not the focus of this report, but it should be clear from this discussion that comparing space heating "efficiency" across countries and building ages needs to normalise for temperature, to make even limited comparisons in any robust way.*

4. MAJOR HEAT PUMP MARKETS

EUROPE

According to data from the European Heat Pump Association (www.ehpa.org), the European heat pump market has experienced double-digit growth since 2015.

In 2020, 1.6 million heat pumps were sold, resulting in a total of 14.9 million units installed, while the market increased 34% in 2021, with an additional 2.2 million heat pumps added, raising the total installed to around 17 million. This trend is likely to continue, as:

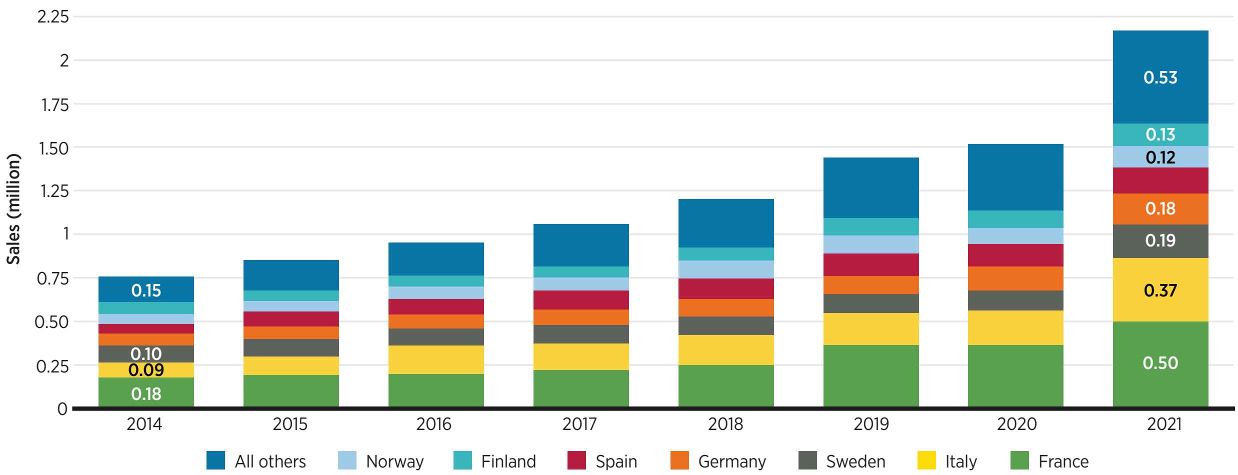
- The legislative framework ihas, for some time now, recognised heat pumps as an efficient technology to provide renewable energy and reduce CO_2 emissions. The technology is also seen as a contributor to a larger share of renewable electricity in the power generation mix by providing demand-side flexibility, especially when thermal energy storage is included in the heat pump design.
- The ongoing growth leads to additional investments in the technology and economies of scale result in lower unit costs.
- Costs fall with growing economies of scale and technology development opens new application areas and market segments for heat pumps.
- Countries and consumers increase efforts to reduce their reliance on fossil fuels for heating in response to the fossil fuel price crisis.

In 2019, the heat pump stock in Europe provided 202 terawatt hours (TWh) of useful heat, of which 129 TWh was of renewable origin. Avoiding the use of fossil energy, the heat pumps installed reduce CO_2 emissions by 33 Mt each year. In 2020, this had risen to 253 TWh of useful heat, reducing CO_2 emissions by an estimated 41.1 $MtCO_2$. In 2021, the avoided CO_2 emissions reached 44 $MtCO_2$ from 283 TWh of useful heat, representing 179 TWh of renewable energy.

No precise numbers exist on the split between new and renovated buildings, but as an estimate, it can be assumed that 80% of all heat pumps installed are operating in new buildings, while 20% operate in renovated ones.

In 2020, France, Italy, Germany, Spain, Sweden and Finland all saw sales in excess of 100 000 units, with France reaching almost 400 000 units and Italy seeing 233 000 sales in 2020. The top three markets (France, Italy and Germany) accounted for almost half of all sales in the 21 EU countries for which data are available. In 2021, France, Italy and Germany were again the largest markets, with 537 000 heat pumps installed in France, 380 000 in Italy and 178 000 in Germany.

Figure 4.1 Heat pump sales in 21 European markets, 2010-2021



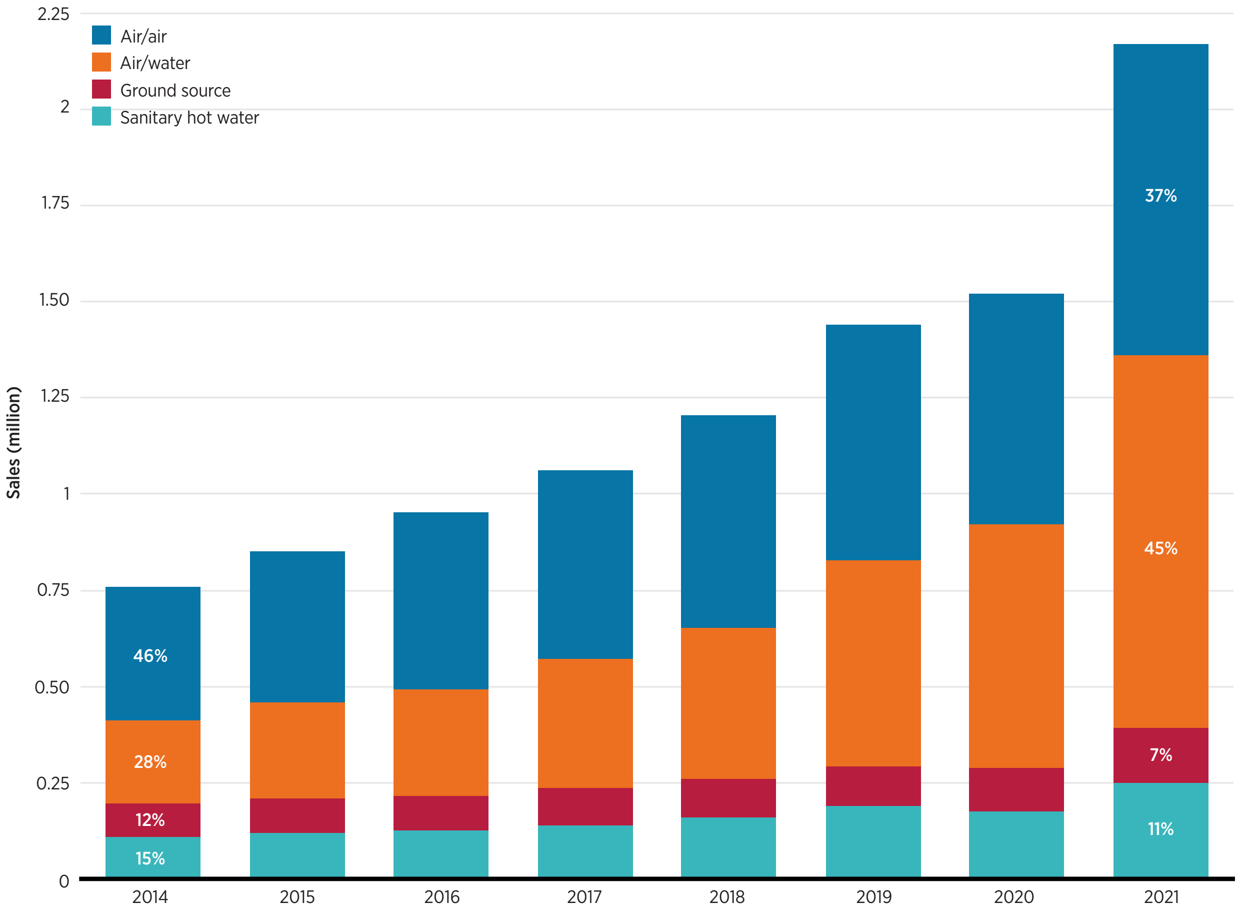
Source: EHPA, 2022.

Four other European countries saw sales in excess of 100 000 units in 2021. Spain saw sales of 149 000, Sweden 133 000, Finland 129 000 and Norway 125 000.

Looking at the data from a different perspective, the top five countries for installed systems per 1 000 households in 2020 were Norway with 41.7 per 1 000 households in 2020, followed by Finland (39 per 1 000 households), Estonia (29.3 per 1 000 households), Denmark (27.5 per 1 000 households) and Sweden (24.4 per 1 000 households) (EHPA, 2022).

The split between the types of heat pumps sold depends a lot on the building tradition, the type of heat distribution system deployed and the climate zone. In central European countries hydronic heat distribution systems dominate (*e.g.* Germany, Austria, Switzerland, parts of France, the Netherlands, Belgium, Czech Republic and Poland). Other markets are dominated by systems using air as the distribution medium, typically air-to-air systems, including cold-climate countries like Estonia, Finland, Norway and Sweden, but also Denmark. In warmer climates, air-to-air systems dominate due to the ability of reversible air-to-air systems to provide heating and cooling, depending on the season (*e.g.* the markets of Spain, Italy and parts of France) (EHPA, 2021).

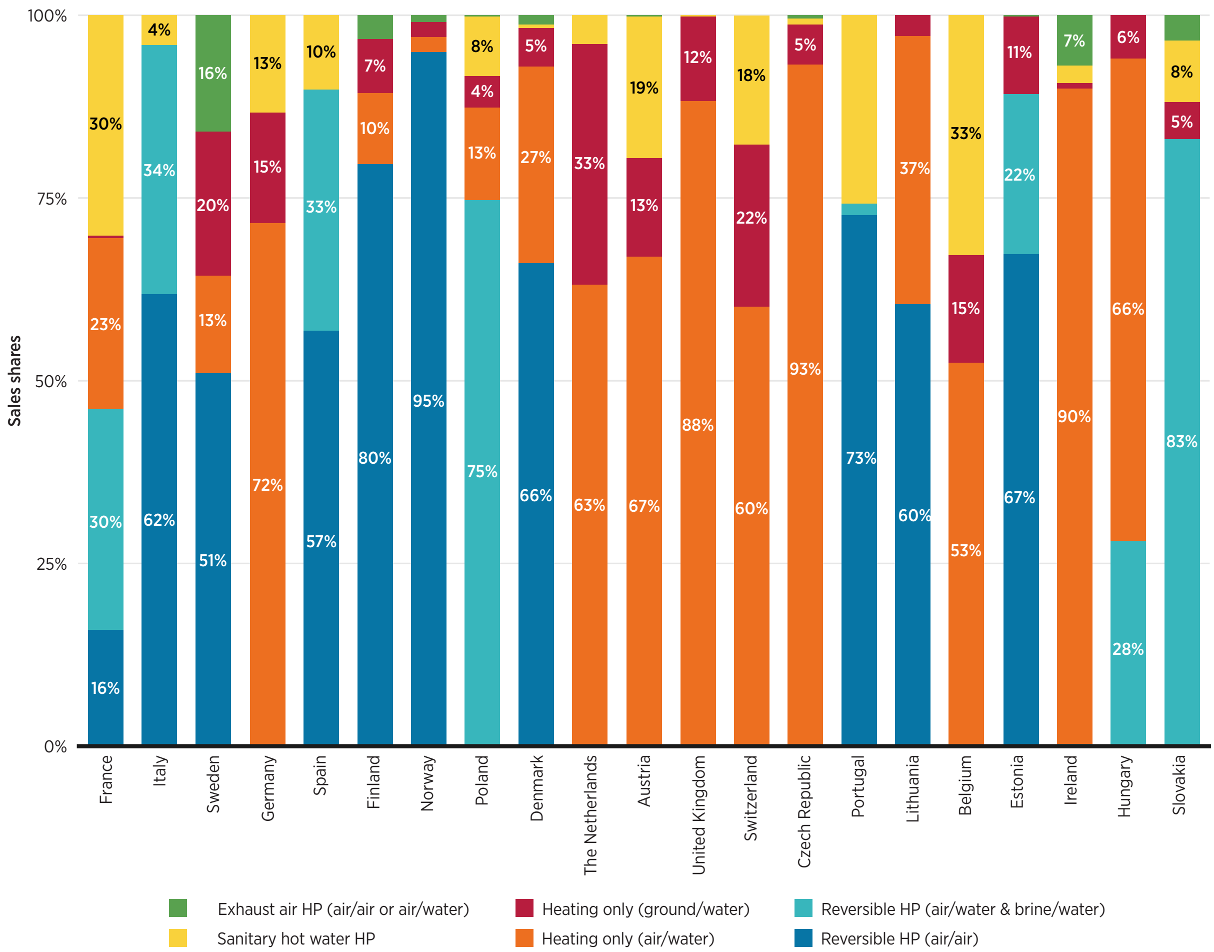
Figure 4.2 Heat pump sales in 21 European markets by heat source or application, 2010-2021



Source: EHPA, 2022.

Air source heat pumps, with their lower capital costs than ground-source systems, now dominate most European markets (Figure 4.3). Air-water heat pumps for heating and sanitary hot water dominate in countries of central Europe, where hydronic heat distribution systems are the norm and colder climates are the norm. France, Portugal, Spain and Italy; with large populations in more temperate weather zones, see the majority of sales being reversible air-to-air heat pumps. However, they are also dominant now in many cold climate countries, including Denmark, Estonia, Finland, Lithuania and Sweden.

Figure 4.3 Shares of heat pump sales by technology, heat source and country in 21 European countries, 2021



Source: EHPA, 2022.

CHINA

In China, air source heat pumps are deployed in order to increase air quality by replacing conventional fossil boilers using coal. Deployment over the last decade has accelerated in line with policies to improve air quality, notably to phase down the use of coal boilers with subsidies for heat pumps. Technology development is very fast, with improvements in performance and reliability, and has been building on the experiences gathered and economies of scale realised in the air conditioner and white goods sectors.

Air source heat pumps are deployed in residential, commercial and industrial applications; mainly for heating and drying, across China, with a strong focus on Beijing and neighbouring provinces. In 2019, the Chinese market for air-to-water heat pumps saw 1.8 million units sold (BSRIA, 2020), up from around 1 million units in 2013 (Zhao, Gao and Song, 2017) and grew to 2.5 million units in 2021.[6] However, the bulk of the market is still room air conditioners, with around 42 million units sold in 2018 (JRAIA, 2019), around 90% of which are likely to have been reversible (Zhao, Gao and Song, 2017). However, these are predominantly used for heating in the milder southern provinces, where annual use runs to around 300 hours per year, compared to 1 000 hours for cooling. In South China an estimated 31% of urban households use reversible room air conditioners for heating and a further 27%, simple electric resistance heating (Su and Urban, 2021).

[6] *For more details, see http://data.chinaiol.com/ecdata/index.*

JAPAN

The Japan Refrigeration and Air Conditioning Industry Association statistics suggest that total shipments of room air conditioners in Japan reached 9.35 million in 2021 (JRAIA, 2022), with the market likely being 99% reversible units – if past trends continued (Shah, Waide and Phadke, 2013) – providing heating and cooling over the year as the season required. The total stock of reversible room air conditioners was about 110 million units, with around 86% of households having at least one room air-conditioner unit and the average having 2.4 units. In addition to this, larger commercial systems saw sales in 2021 of 0.8 million units (JRAIA, 2022).[7]

In addition, since 2001 residential sanitary hot water heat pumps have been offered, with sales growing steadily to 0.55 million per year in 2010, before falling back somewhat thereafter, and recovering to 0.53 million shipped in 2021. The total stock of these heat pump hot water systems now stands at around 7.8 million units (JRAIA, 2022).

CANADA AND THE UNITED STATES

The United States Energy Information Administration (EIA) periodically surveys the energy use and stock of energy-using equipment in residential and commercial buildings. The total number of residential buildings using heat pumps for space heating was around 13.4 million in 2015, with an additional 0.7 million geothermal heat pumps installed. The total number of households with a central heat pump air conditioning system was around 20.7 million.

The US building stock is mainly equipped with ducted air heat distribution systems. Data from the Air-conditioning, Heating and Refrigeration Institute (AHRI) suggest sales of air source heat pumps (ASHPs) in 2020 reached 3.42 million units (both packaged and split systems) in 2020 and 3.92 million in 2021, more than twice the 1.75 million sales in 2010.[8] An additional 5.91 million central air conditioning systems were shipped in 2020 and 6.28 million in 2021.[9]

In the United States, around 0.74 million commercial buildings used heat pumps for space cooling and another 0.67 million for space heating in 2018. Slightly less than two-thirds of these systems are in mixed/humid regions, so some are likely to be providing both heating and cooling, depending on the season. An added complication is that smaller commercial premises maybe using multiple ductless split systems for individual rooms, boosting the total number of systems, relative to the number of buildings served.

Data for Canada suggest that the stock of ASHPs and ground source heat pumps (GSHPs) in residential buildings reached 0.83 million, or about 5% of the 15.8 million heating systems at the end of 2018, up from 0.64 million in 2010. Heat pump sales in Canada in 2018 were around 29 000 units.

Overall, these data suggest that the total stock of heat pumps for heating and cooling (excluding cooling only systems) could have been in the order of 36 million in Canada and the United States in 2018.[10]

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[7] *Data on what percentage of these systems are reversible are not readily available.*

[7] *See www.ahrinet.org/resources/statistics/historical-data/central-air-conditioners-and-air-source-heat-pumps.*

[8] *For more details, see www.ahrinet.org/analytics/research/historical-data/central-air-conditioners-and-air-source-heat-pumps.*

[9] *This is somewhat higher than estimated by the IEA (32.5 million), and may be explained by differences in estimates of the number of central heat pump systems providing both heating and cooling.*

5. RESIDENTIAL HEAT PUMP COSTS AND PERFORMANCE

With a large number of stakeholders, relatively little economies of scale in manufacturing and installation, and a multitude of distribution channels; the collection of cost and performance data for end-use technologies in buildings remains a perpetual challenge. As a result, and based on previous experience in the collection of heat pump data, a multi-pronged approach to data collection was undertaken with key stakeholders. The goal was to elicit the best possible data available, while anticipating that the type and quality of data available by country were likely to be heterogeneous, limiting comparability.

The approach, in common with IRENA's renewable power generation cost data (IRENA, 2021b), was to the largest extent possible to collect primary data for individual installations. Given the many thousands of sales each year in major markets, this can be somewhat less daunting than it sounds, as sample sizes of several thousand would provide statistically robust data. Unfortunately, this is rarely available, so secondary data sources need to be identified and mined for data. The data that follow come primarily from the following sources:

1. Government databases where cost and performance data are routinely reported in order to gain access to financial support.
2. Industry stakeholder surveys that collect cost and/or performance data.
3. Industry association surveys.
4. Government research or, more often, energy or climate modelling input data (often surveyed from the sector on behalf of the government by private consultancies).
5. Private sector market intelligence services and consultancies.
6. Academics and researchers.
7. Direct responses from installers to IRENA's request for data in certain markets.

Of the data available, the most robust and comprehensive[11] tend to be available from the first four sources. Where these are not available, any other sources found to have robust data have been compiled in order to arrive at an estimate of the representative costs in different markets. Unless specifically noted, the cost data presented in the following sections is the real cost of the systems. Grants, tax relief and other subsidies may reduce the final cost to the consumer below these values.

The data collection has focused on the cost of equipment and installation of heat pumps, in their various configurations. It therefore excludes the costs of the heat distribution system, which can vary widely by country, whether for new build or renovation, age of the building and scale of the local market.

Data are presented based on average system size and per insert

kilowatt thermal of capacity (kW_{th}) when these data are also available. Unfortunately, in many cases the available data do not specify the exact system sizing; where this is the case complementary sources for representative system sizes have been used, while acknowledging this may not yield exact values. This is an area where future efforts may be directed to ensure more comparable data become available for a wider group of markets.

[11] *Not all of these sources are, however, equally transparent which can lead to some issues with data interpretation.*

It should be noted that the large number of different heat products makes the concept of the 'average cost' of heat pumps somewhat problematic. The price to the owner is influenced by production cost, brand value, competitive position of heat pump technology in each market (if heat pumps are a high-end product, price is generally higher) and the feature set of the system. Costs typically rise, but not always, with more stringent requirements on efficiency and noise for instance. Installations that are bespoke solutions for challenging installations will also have higher costs that homes where a more standardised. As can be seen in the following sections, the result of this is that there are significant variations in costs both within and between countries.

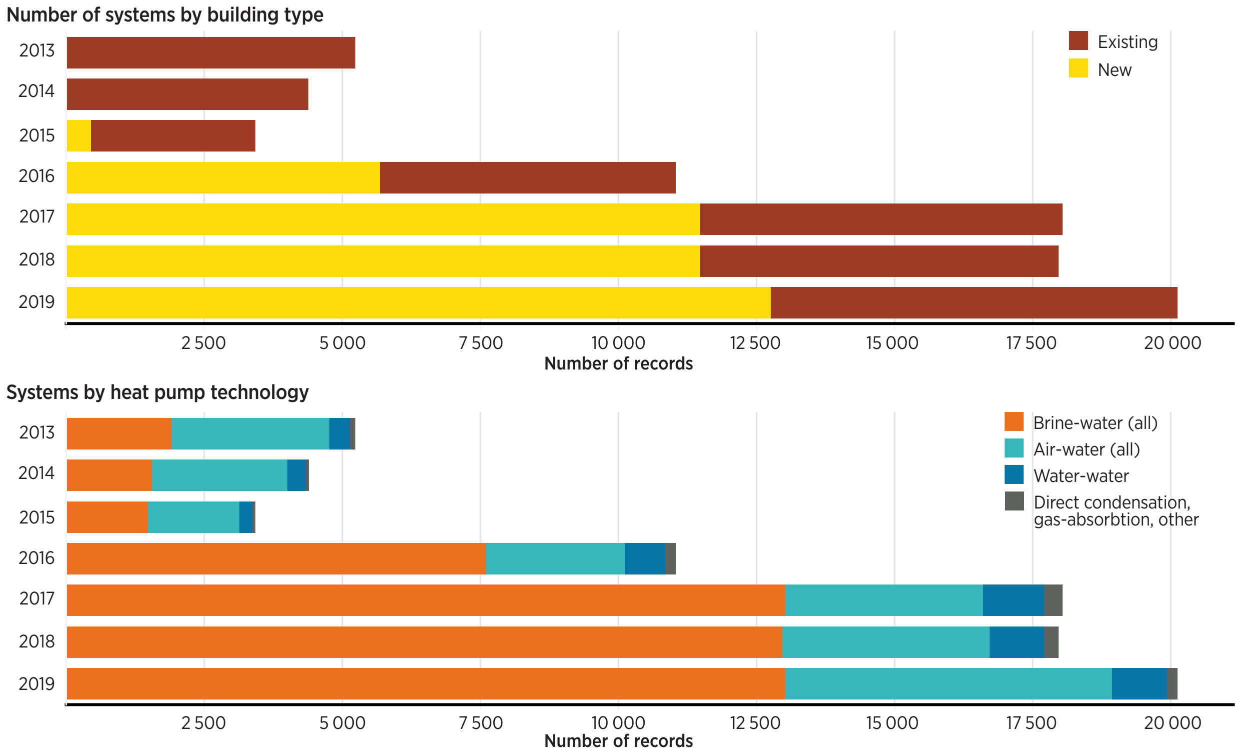
GERMANY

In Germany, the Federal Ministry for Economic Affairs and Energy manages the Market Incentive Programme (MAP) for the transition to renewable heating, providing financial support to increase the use of renewable energy to generate heat. Investment grants of up to 50% are available for heat pumps that are replacing oil-fired boilers, with a grant of 50% available for all others.[12] Since 1 January 2021 the Market Incentive Programme (MAP) has been superseeded by the Bundesförderung für effiziente Gebäude (BEG), a new federal incentive scheme, that has bundled the MAP and other incentive schemes related to buildings, heating and energy efficiency.

Since the year 2000, the MAP has supported the installation of over 150 000 heat pumps. Detailed data are available for 80 000 systems between 2013 and 2019, including data on heat pump cost and type, capacity, building installation (new or renovation), support received, and seasonal performance factors. The data are a subset of installations, but in 2019 represented around 63% of the ground source (brine/water) heat pumps installed. The share is significantly lower for air-to-water systems, which have grown to dominate the market in Germany, with 65 800 installations in 2019 and around 95 000 in 2020.

Cost data for heat pumps are available for renovations in the period 2013-2015, before becoming more representative of the split between installations in new buildings and existing ones. This has an impact on cost trends, given the nature of the work required for new installations.

Figure 5.1 Heat pump installations in Germany with cost and performance data from the Market Incentive Programme (MAP), 2013-2019



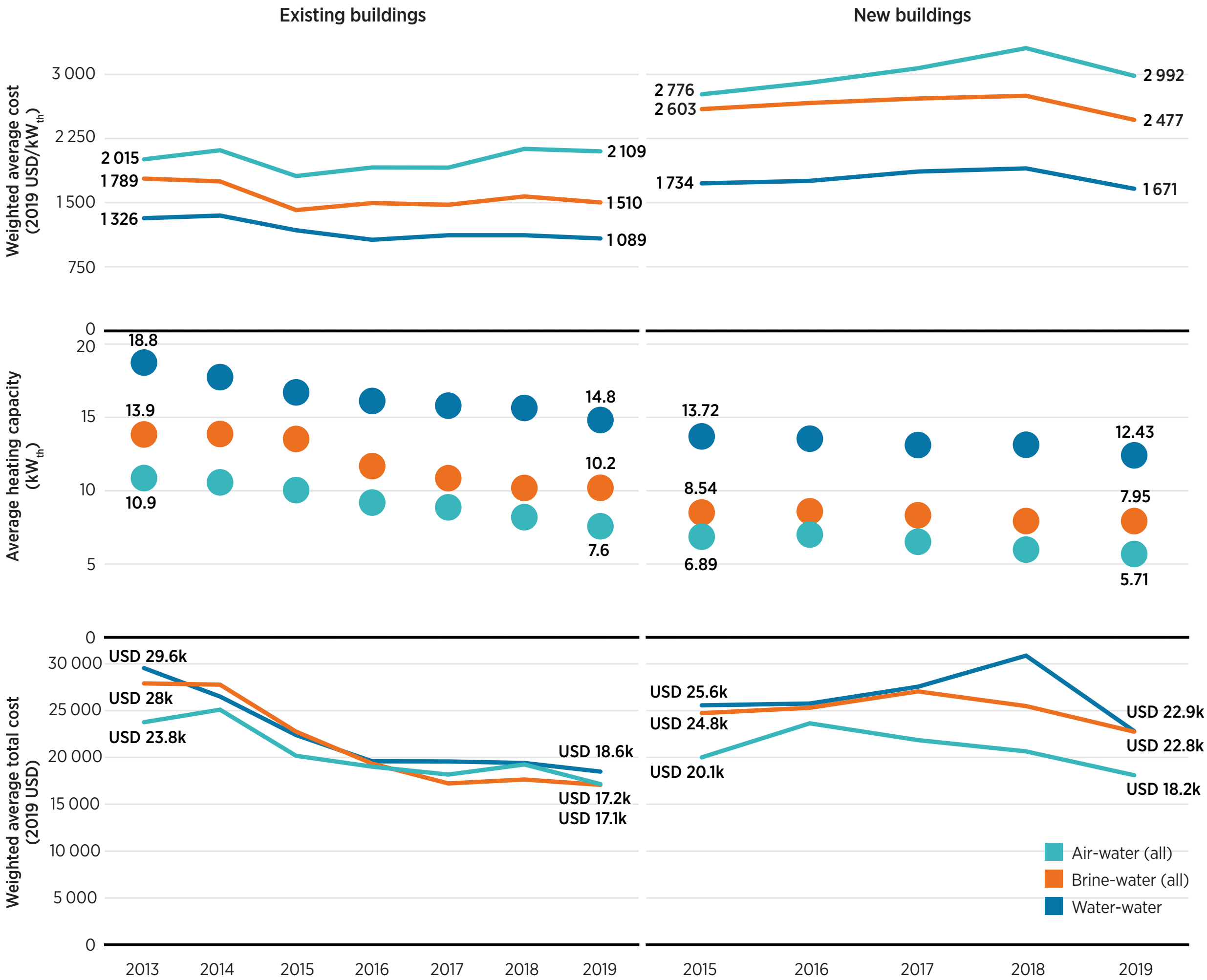
Source: Federal Ministry for Economic Affairs and Energy, 2021.

[12] *There is also a programme to assist businesses and municipalities install larger heat pumps with low-cost finance and repayment subsidies, which is supported via the German Development Bank (KfW).*

Figure 5.2 presents the cost data for the three main heat pump technologies newly installed in Germany by year for installations in new and existing buildings. In existing buildings, costs for air-to-water heat pumps per kW_{th} increased by 5%, from USD 2 015 to USD 2 109/kW_{th}, over the period 2013-2019. Because the average size of systems being installed declined by 30%, the overall system cost fell 28% over the period. Geothermal (brine-to-water) and water-to-water heat pumps installed in existing buildings saw their specific costs per kW fall by 16%, from USD 1 789 to USD 1 510/kW_{th}, and 18% from USD 1 326 to USD 1 089/kW_{th}, respectively between 2013 and 2019. System sizes also declined over this period, by 26% for geothermal systems and 21% for water-to-water systems. The total system cost for geothermal heat pumps installed in existing buildings fell by around 39% to USD 17 000 and those of water-to-water systems by 37% to USD 19 000. The weighted-average specific costs in USD per kilowatt are inversely related to those of the system size, suggesting economies of scale are an important factor in overall system costs across technologies.

The costs per kilowatt are higher for new installations than for existing buildings, which may appear counter-intuitive, but is partly explained by the smaller sizing required for new buildings, where more energy-efficient building shells and windows reduce heat losses and therefore system sizing to meet comfort needs.[13]

Figure 5.2 Weighted-average costs and system sizes for new heat pump installations in Germany by technology and building type, 2013-2019



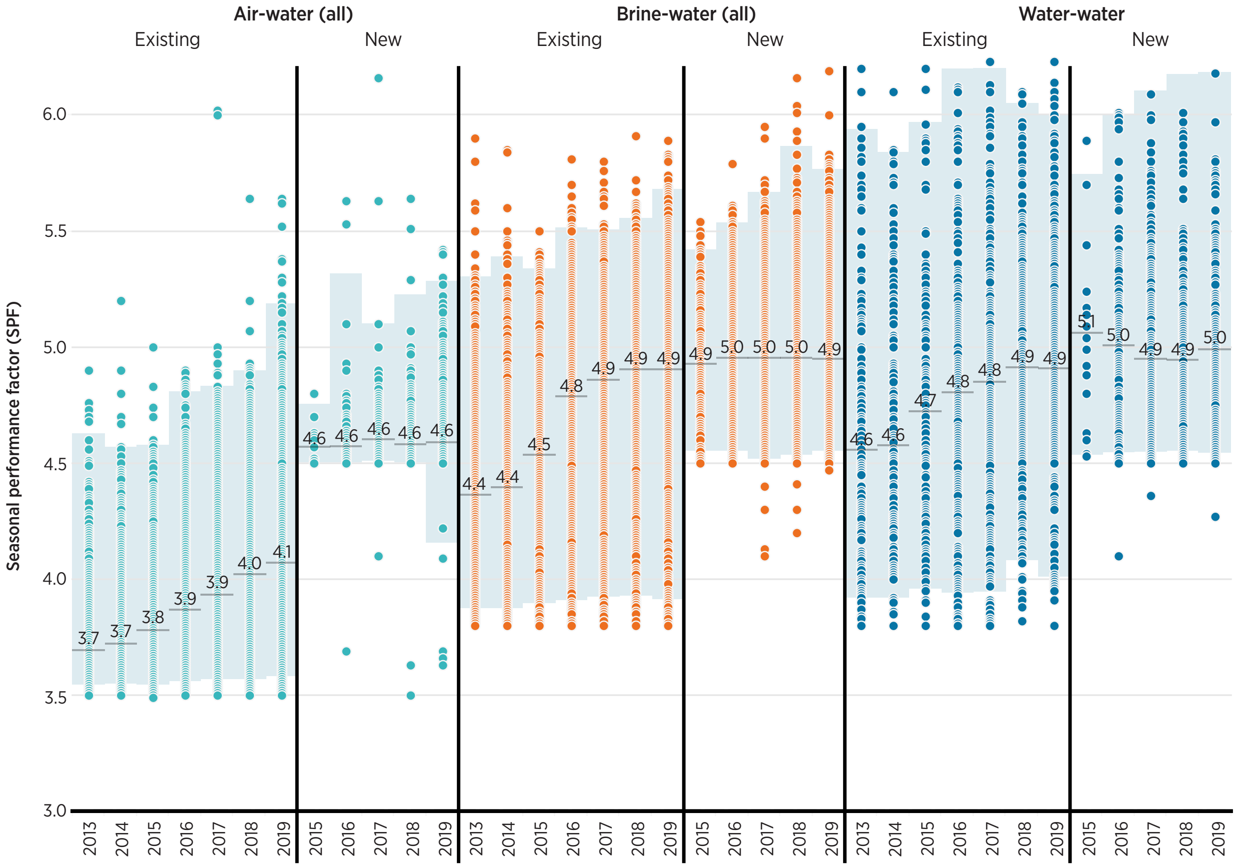
Source: Federal Ministry for Economic Affairs and Energy, 2021.

[13] *This hypothesis is explored in more detail in the following section, as additional plumbing required for new systems (separate to the heat distribution system itself) are possibly also driving the cost differential between new and existing installs. This raise questions about whether the system boundaries for the two categories in the MAP database are really directly comparable.*

The average seasonal performance factor of the installations in the MAP database suggest that, particularly for installations in existing buildings, technology improvements have been significant (Figure 5.3). This is likely driven by two important factors. The first centres on technology improvements, system optimisation and design, as well as advanced control systems in order to maximise heat pump efficiency and minimise parasitic auxiliary loads, especially in existing buildings where temperature lift requirements may be higher. The second driver is likely to have been an increase in additional energy efficiency investments at the time of the switch-out, whether whole-building retrofits, or simply a change in the number of radiators to ensure greater surface area for heating (allowing comfort levels to be achieved with lower circulation temperatures).

By 2019, it was noticeable that the SPF of new systems in existing buildings had almost completely closed the gap with systems in new buildings, where more freedom to optimise systems from scratch exists, for geothermal and water-to-water heat pumps. This was likely driven by efforts to optimise system design, as well as minimising auxiliary loads from pumping the working fluids, coupled with advanced controls. As might be expected, a noticeable differential exists between installations in existing and new buildings for air-to-water heat pumps. The lower heat source temperature afforded by air, when combined with higher temperatures needed in space heat distribution systems in existing buildings, means a larger temperature lift is required on average compared to ground or water source heat pumps.

Figure 5.3 Weighted-average seasonal performance factors for new heat pump installations in Germany from the MAP, 2013-2019



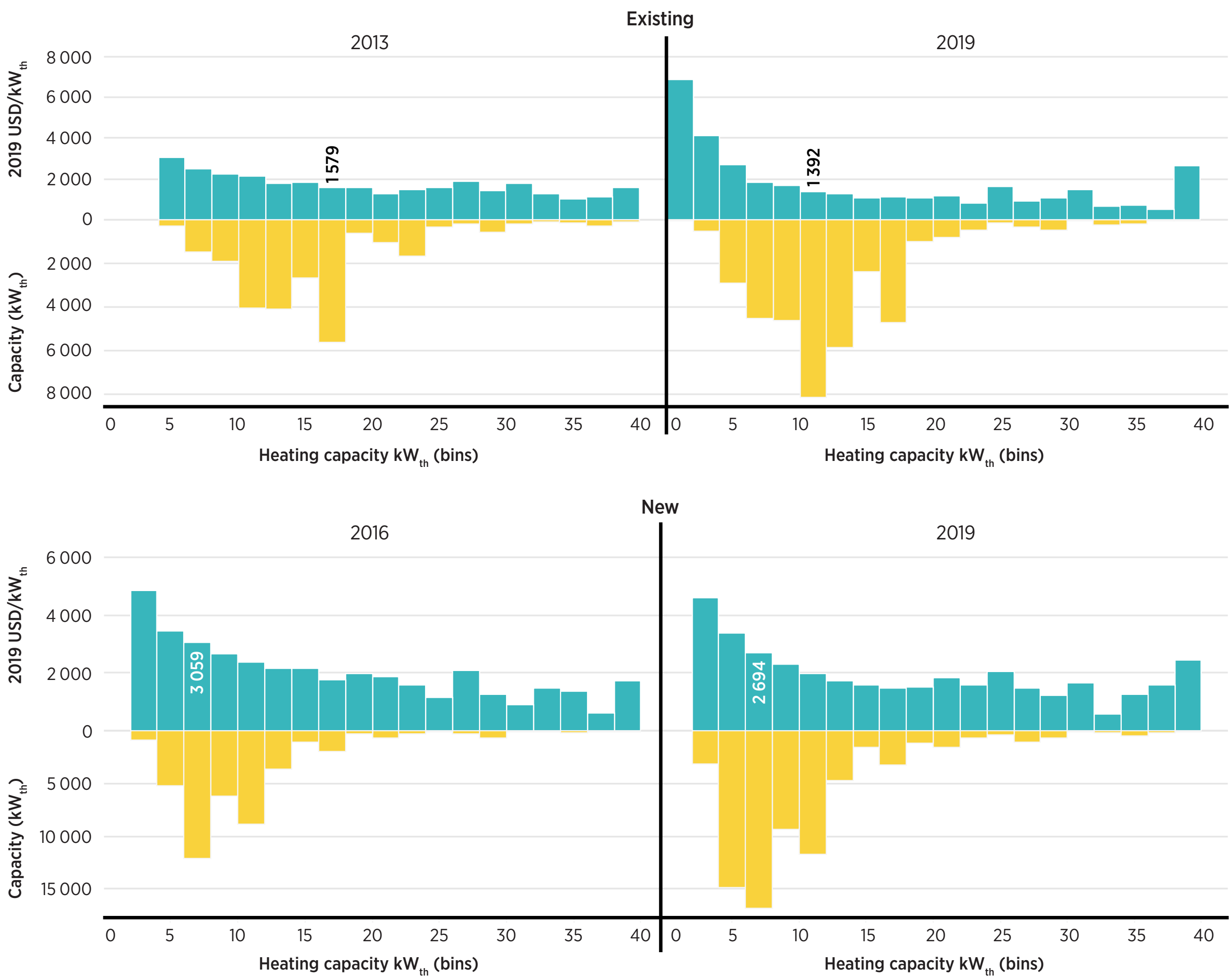
Source: Federal Ministry for Economic Affairs and Energy, 2021.

Figures 5.4, 5.5 and 5.6 highlight the distribution of costs by capacity and also the volume of capacity represented by each 2 kW_{th} "bin" of capacity in the database. For new installations in existing and new buildings, and across the years, there appear to be significant economies of scale to system size, although data becomes more variable when moving to larger sizes with very few data points.

For geothermal (brine-water) installations in existing buildings, the sizing that saw the most installs was in the 16-18 kW_{th} range in 2013, with a weighted average cost of USD 1 759/kW_{th}. By 2019, the largest size range for system installs had fallen to systems in the 10-12 kW_{th} range, with weighted average costs of USD 1 359/kW_{th}. For installations in new buildings, the most installations were in the 6-8 kW_{th} range in 2016 and 2019, but with a shift in the overall distribution to smaller sizings. Total installed costs for these systems were USD 3 059/kW_{th} in 2016 and USD 2 694/kW_{th} in 2019.

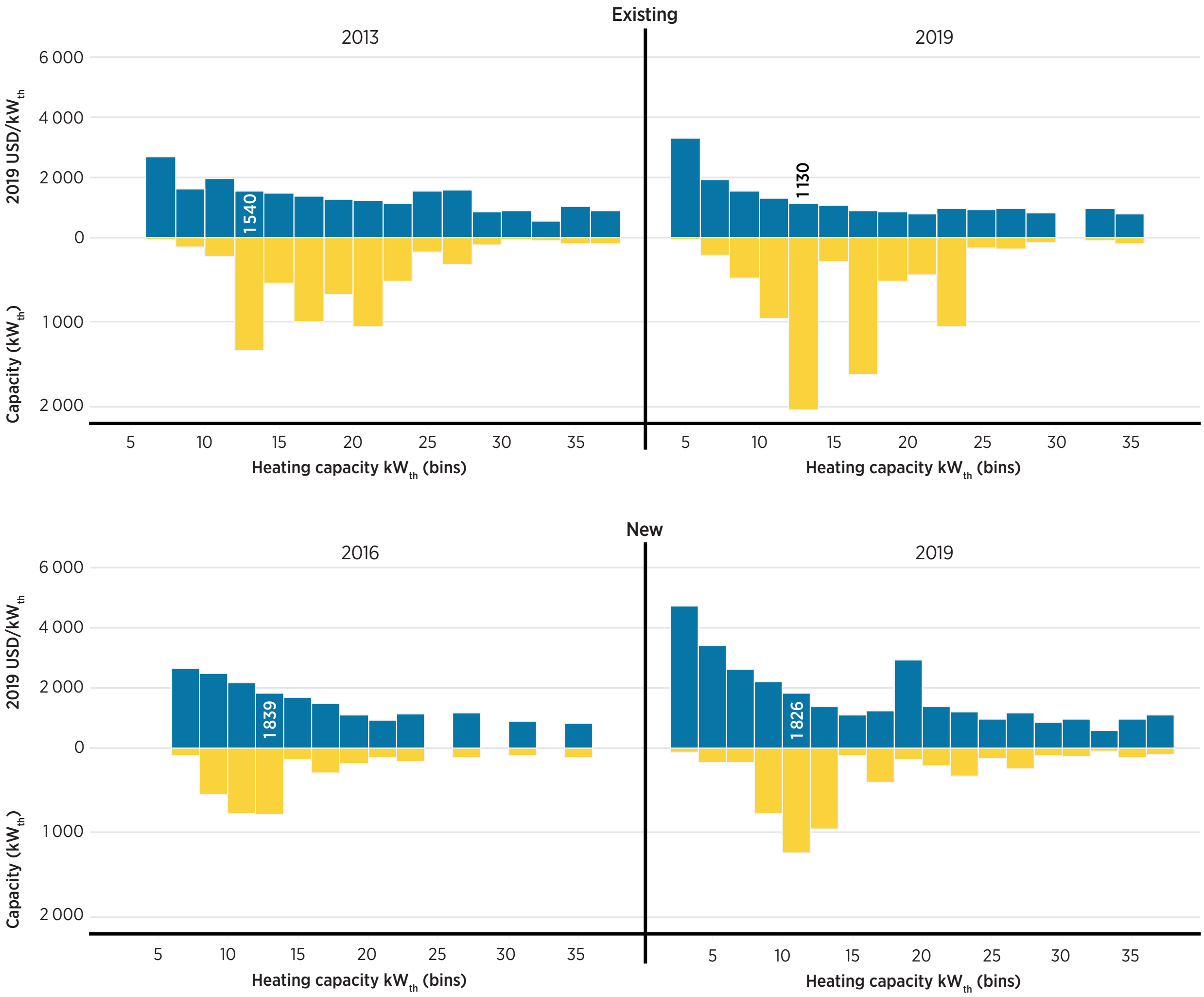
For water-to-water installations in existing buildings, the system capacity that experienced the most installs was in the 12-14 kW_{th} range in both 2013 and 2016. The weighted average cost of systems in the 12-14 kW_{th} range was USD 1 540/kW_{th} in 2013, but had fallen to USD 1 130/kW_{th} in 2019. For installations in new buildings, the most installations were in the 12-14 kW_{th} range in 2016, but in 2019 it was the 10-12 kW_{th} range, again, with a shift in the overall distribution to smaller sizings. Total installed costs for systems in the 12-14 kW_{th} range in 2016 were USD 1 839/kW_{th} and for 10-12 kW_{th} systems in 2019, it was USD 1 826/kW_{th}.

Figure 5.4 Average geothermal (brine-water) heat pump costs and new capacity installed by system size, 2013 and 2019



Source: Federal Ministry for Economic Affairs and Energy, 2021.

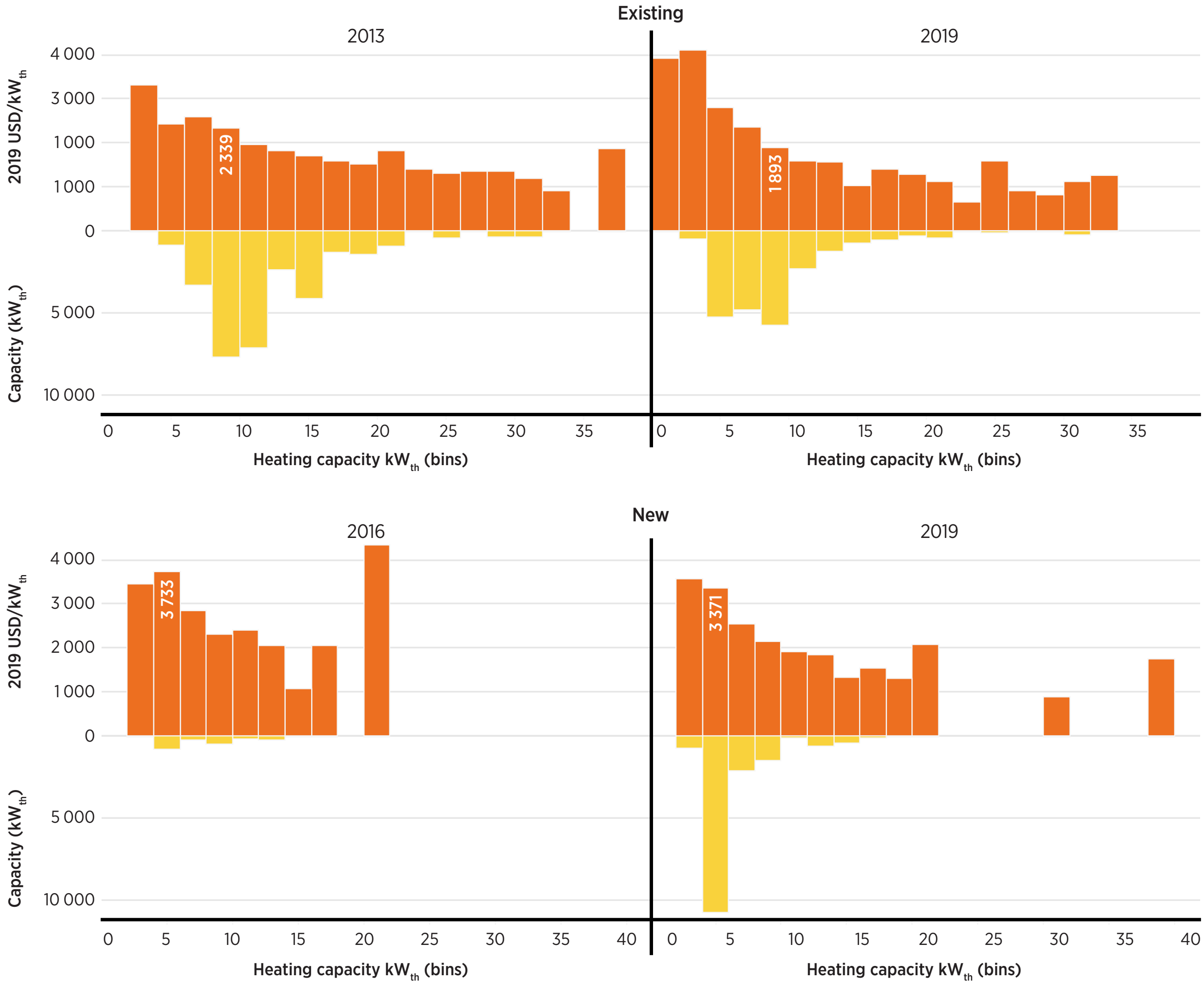
Figure 5.5 Average water-water heat pump costs and new capacity installed by system size, 2013 and 2019



Source: Federal Ministry for Economic Affairs and Energy, 2021.

Similar to water-to-water systems, the system capacity for air-to-air heat pumps that experienced the most installs was the same (8-10 kW$_{th}$) in 2013 and 2019, but with a significant shift in the overall distribution to smaller sizings in 2019. The weighted average cost of systems installed in existing buildings in the 8-10 kW$_{th}$ range was USD 2 339/kW$_{th}$ in 2013, but had fallen to USD 1 893/kW$_{th}$ in 2019. For installations in new buildings, the data for 2016 are minimal and drawing inferences from the cost data by capacity band is likely to be misleading. In 2019, the vast majority of systems are in the 4-6 kW$_{th}$ range, reflecting the strict building standards for new buildings in Germany today creating a narrower range of installations. The weighted average costs for these systems in 2019 was USD 3 371/kW$_{th}$.

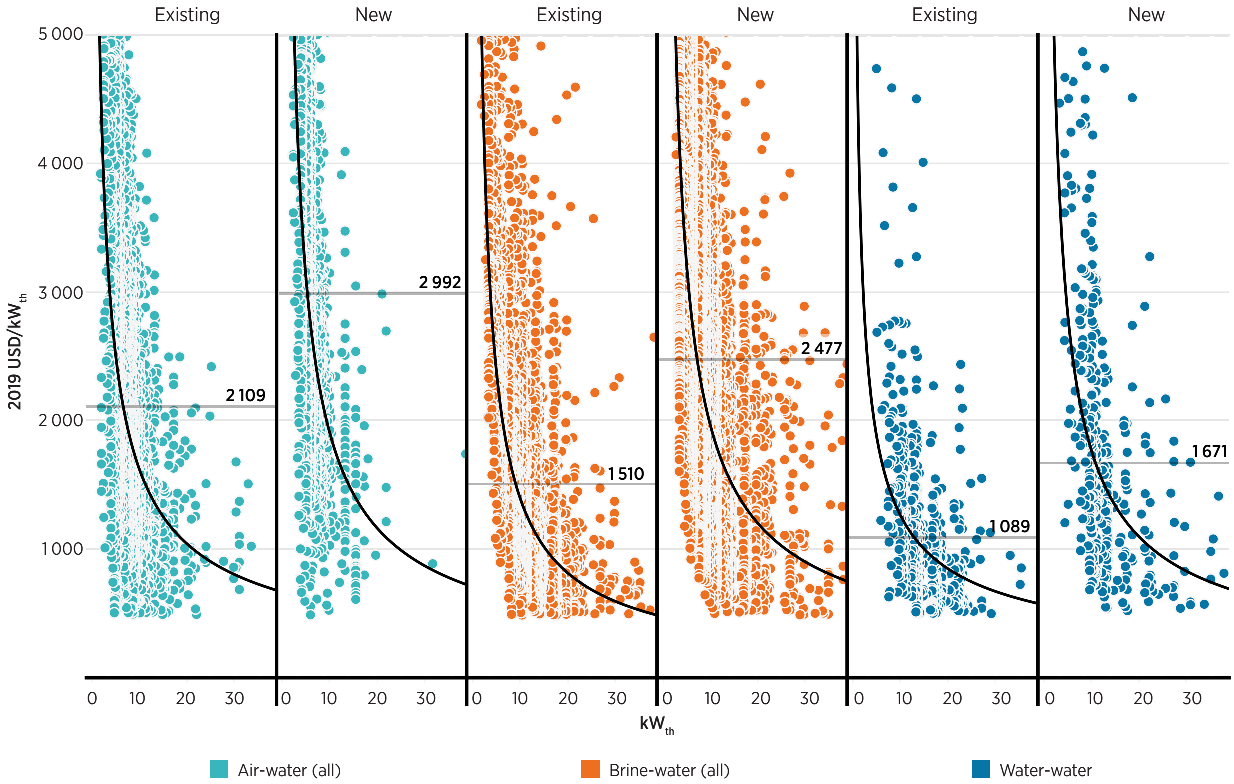
Figure 5.6 Average air-water heat pump costs and new capacity installed by system size, 2013 and 2019



Source: Federal Ministry for Economic Affairs and Energy, 2021.

Focusing in on the economies of scale based on heat pump system size, Figure 5.7 highlights the data for air-to-water, geothermal and water-to-water heat pump costs in existing and new buildings for 2019. All three types experience significant economies of scale, as can be seen by the fitted line. The economies of scale for installations in new buildings are quite uniform, at least in 2019 across all three technologies. However, for installations in existing buildings, the economies of scale experienced vary, with water-to-water systems having smaller economies of scale than air-to-water systems, and geothermal (brine-to-water) systems experiencing the most significant economies of scale.

Figure 5.7 Economies of scale of installed costs for heat pump installations in new and existing buildings in Germany, 2019

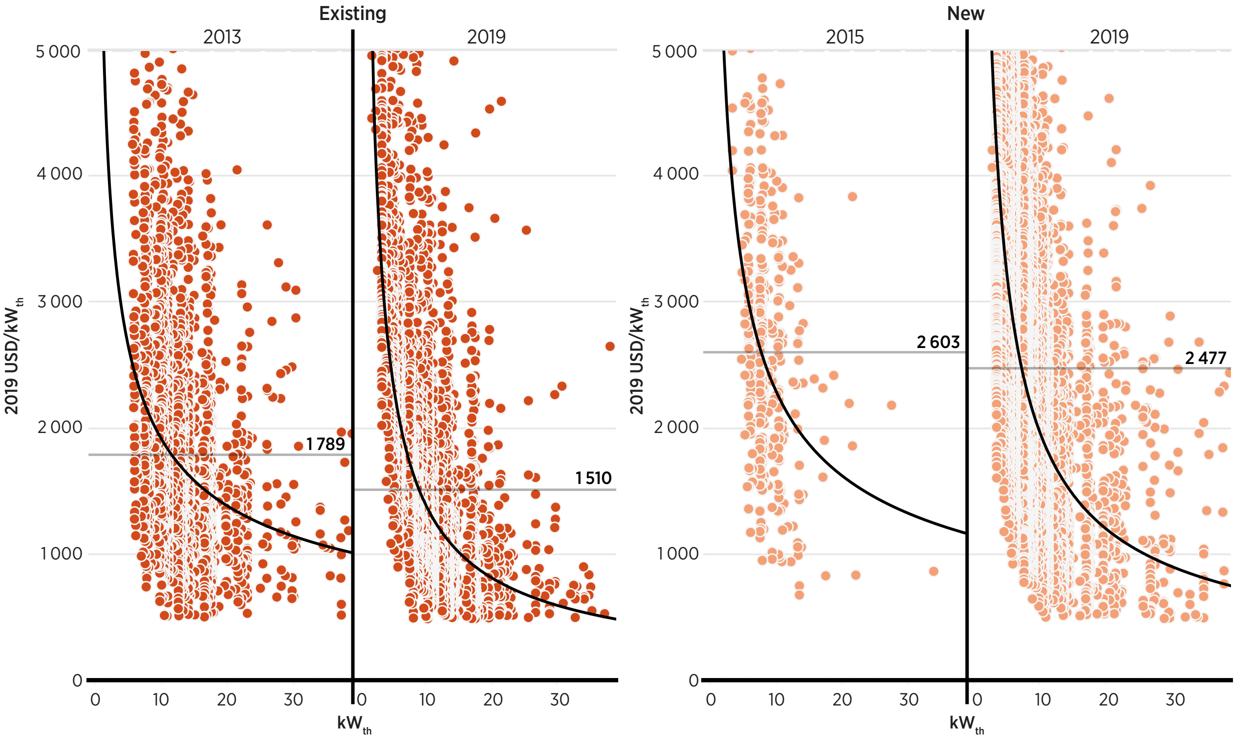


Source: Federal Ministry for Economic Affairs and Energy, 2021.

Figure 5.8 shows the evolution through time of the economies of scale for geothermal (brine-to-water) heat pumps in Germany for installations in new and existing buildings. There is a clear trend towards a lower weighted-average cost in both market segments, but what is noticeable is that the implied economies of scale (the slope of the fitted curve) also becomes more important through time.[14] The results for geothermal heat pumps tend to suggest that two competing factors are at work in trends of heat pump costs per kW_{th} in Germany. The first, the classical learning by deployment benefits (*e.g.* greater market size, competition and technology improvements) are driving down costs. Second, improved performance amid the deeper energy retrofits of existing buildings are allowing smaller system sizes.

[14] This holds true for geothermal heat pumps installed in new buildings if we use 2016 data, where significantly larger data points are available. However, the result is somewhat weaker than a comparison with 2016.

Figure 5.8 Geothermal (brine-water) heat pump costs in Germany by size for installations in new and existing buildings, 2013 and 2019

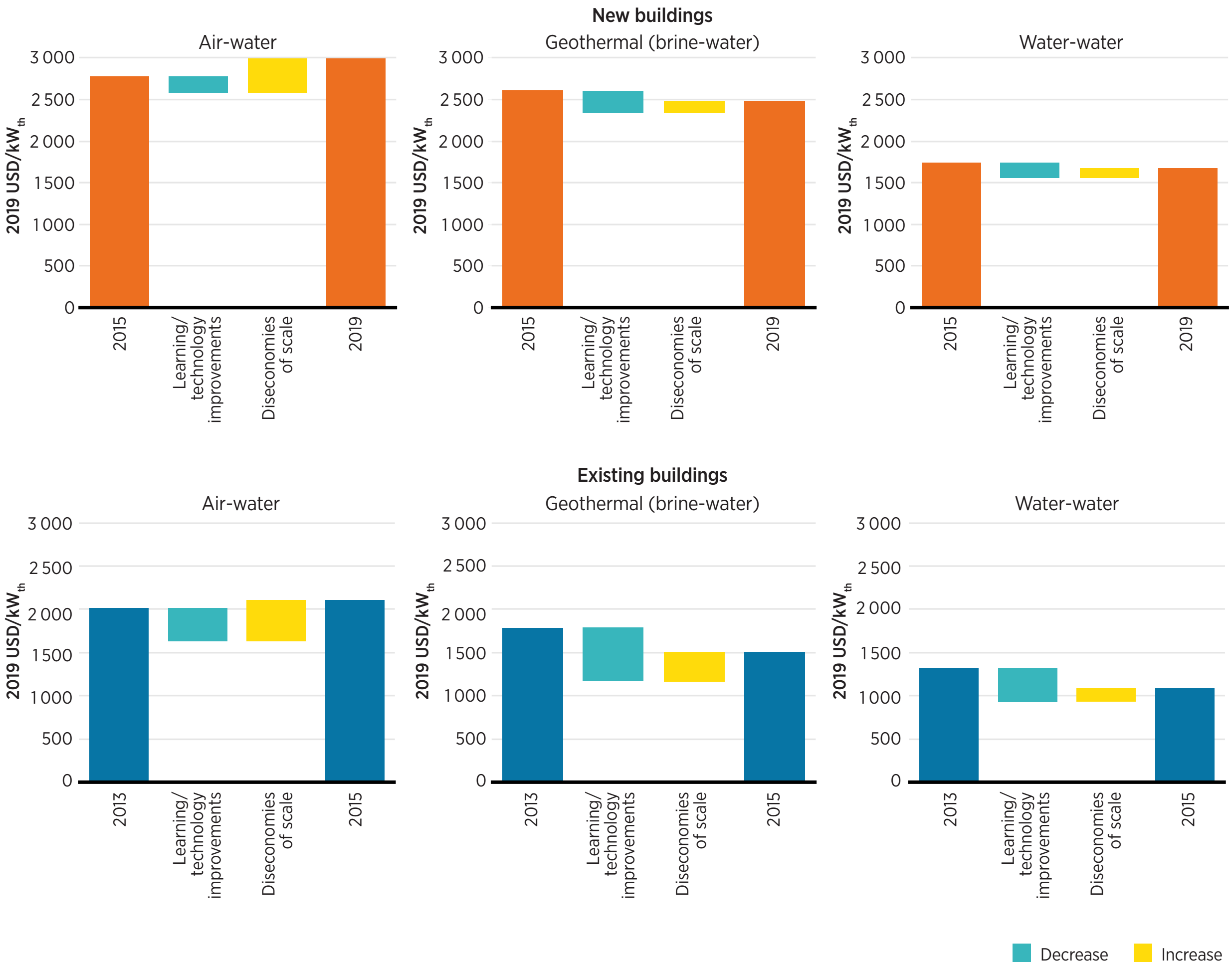


Source: Federal Ministry for Economic Affairs and Energy, 2021.

Figure 5.9 provides an estimate of the technology improvements and learning by doing, while controlling for system capacity and the impact of diseconomies of scale. The implied economies of scale seen in Figure 5.7 for 2019 are used to estimate the average installed cost in 2019 if system capacities had remained at their 2013 or 2016 levels, for existing and new buildings respectively. This provides a value for the average system cost in 2019 that excludes the impact of the change in system size on the economies of scale at the unit level. The data should be considered approximate, but give a reasonably accurate estimate of the order of the magnitude of the impact of diseconomies of scale, as system sizes have reduced.

Given the very steep slope of the curves at smaller system sizes, the air-water heat pumps have seen their underlying cost reduction trend hidden to a greater extent, than for the geothermal and water-to-water heat pumps, which had larger system sizings in 2013 and 2019. For installations in both new and existing buildings, the reduction in system size and the diseconomies this entails more than offset the underlying trend in cost reduction. In all other cases, the diseconomies of scale from the shift to smaller system sizes did not offset completely the specific cost per kW and these declined between 2013/15 and 2019.

Figure 5.9 Underlying cost reduction trends and the impact of diseconomies of scale from smaller system sizes in Germany, 2013-2019



Source: IRENA analysis based on Federal Ministry for Economic Affairs and Energy, 2021.

How reduced system size affects the economics of heat pumps between 2013 and 2019 is only apparent, however, when examining the overall cost of delivered heat. The impact of smaller system sizes on the total installed cost, where all systems and applications on average cost less than at the beginning of the period (Figure 5.2), also needs to be considered in relation to the lower electricity demand from these smaller systems. The analysis in Figure 5.9 is simply an attempt to separate out the impact of diseconomies of scale in order to see more clearly the underlying trend in equipment cost reductions.

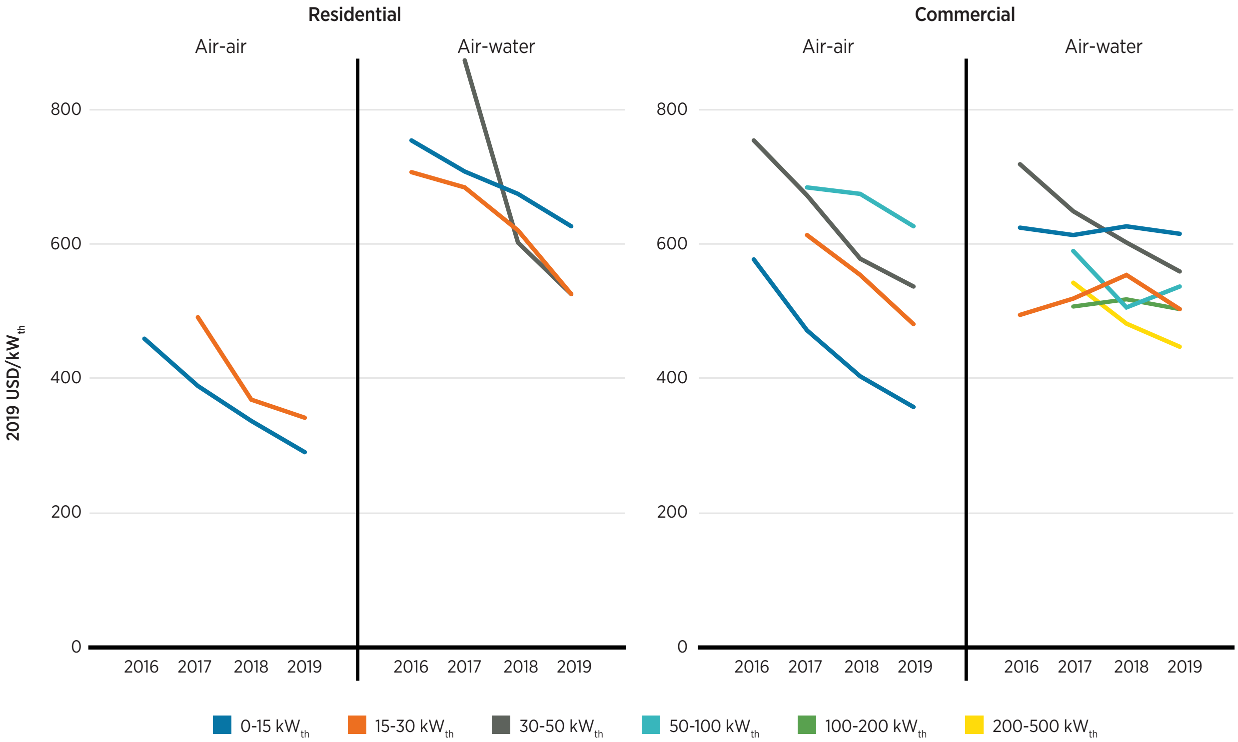
ITALY

Italy was the second largest market for heat pumps in Europe, with 233 000 new installations in 2020. This included 159 000 air-to-air systems, 58 000 air-to-water systems and 7 000 dedicated sanitary hot water systems. Across a range of warm and temperate climate zones, heat pumps are the incumbent technology to provide space cooling (predominantly) and some space heating. They are also being used more often to provide water heating in relatively climate zones, and now account for around 20% of the market for new installations (EHPA, 2021).

Italy has supported the deployment of heat pumps in buildings under a small installation support scheme, Conto Termico, since 2013. The support scheme was not just for the equipment itself, but also to support the overall heat distribution system, so care should be taken in interpreting the results that follow.

Data are available for around 10 000 new installations per year under the support scheme and of this stock, around 25 000 projects have been analysed for cost data over the period 2016-2019 (GSE, 2020). The trends for the period are shown for both residential and commercial systems of different sizes in Figure 5.10. The costs of air-air systems in Italy in the residential sector fell by 37% for systems up to 15 kW_{th}, from USD 460/kW_{th} to USD 291/kW_{th}, and by 30% for systems with capacities of between 30 and 50 kW_{th}, falling from USD 492/kW_{th} to USD 342/kW_{th}. It's not clear why larger systems are more expensive, but this probably relates to the additional ducting work for larger heat pumps in multi-family dwellings. This is also likely driving the higher specific costs for air-air heat pumps in commercial buildings at all sizes, while additional control system costs may also be contributing, given varying user needs in commercial building spaces. Air-air heat pump costs per kW for up to 15 kW_{th} systems in commercial buildings fell 38% between 2013 and 2019 to USD 358/kW, those of 15-30 kW_{th} and 50-100 kW_{th} fell by 22% to USD 482 and USD 627/kW_{th} in 2019, while costs for systems in the 30-50 kW_{th} range fell by 29% to USD 358/kW_{th}.

Figure 5.10 Heat pump cost trends in the residential and commercial sectors for air-to-air and air-to-water systems in Italy, 2016-2019

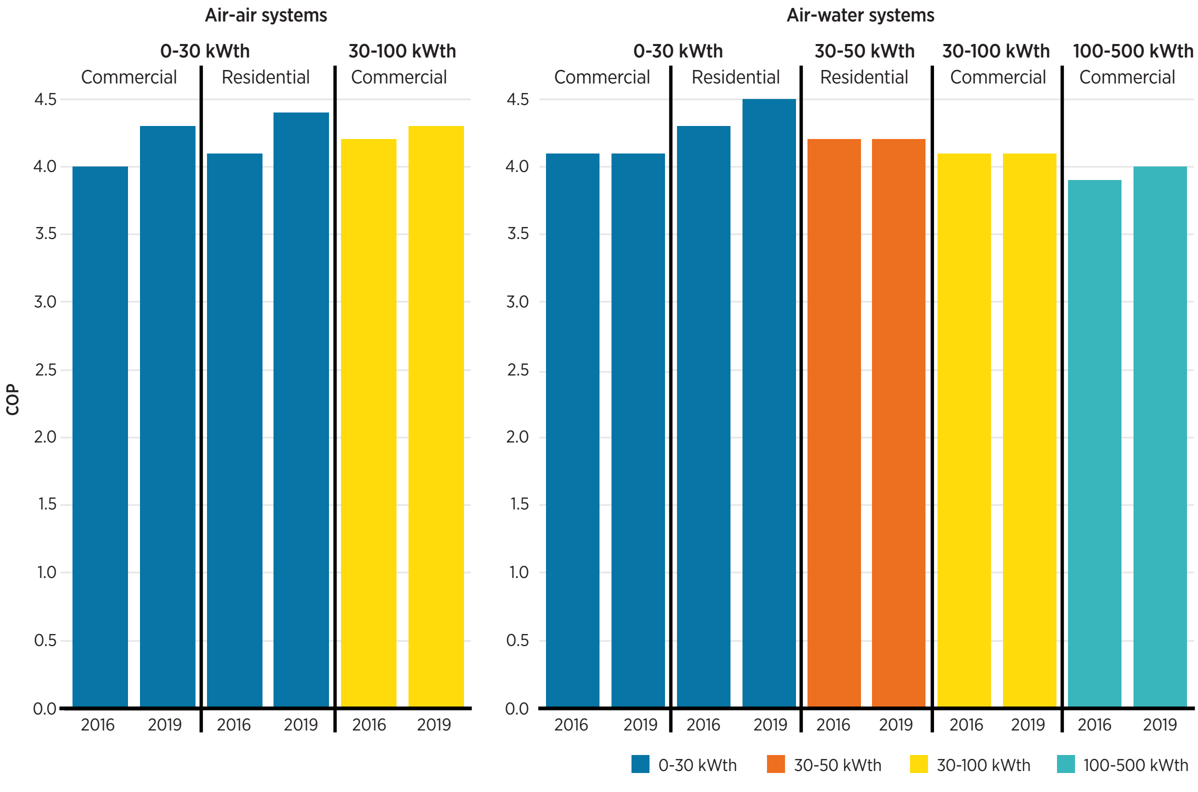


Source: GSE, 2020.

Residential air-water systems in Italy have higher costs than simpler air-air systems, but their costs have also been falling. Costs for new systems up to 15 kW_{th} fell by 36% between 2016 and 2019 to USD 627/kW_{th}, while those for systems in the 15-30 kW_{th} range fell by 26% to USD 526/kW_{th}. Larger systems, in the 30-50 kW_{th} range, saw an even more dramatic cost reduction, falling by 40% between 2017 and 2019 to USD 526/kW_{th}. Commercial air-water systems in Italy have had a mixed experience in terms of cost reduction, with only systems in the 30-50 kW_{th} and 200-500 kW_{th} ranges experiencing significant cost declines of 26% for the former (2016-2019) and 18% for the latter (2017-2019).

The support scheme in Italy set minimum performance standards, based on COP, for systems to be eligible for financial support. The median COP of the systems supported increased over time for residential systems, with the exception of the larger 30-50 kW_{th} systems, where the COP remained unchanged in 2019 compared to 2016 at 4.2, albeit with systems installed in 2018 seeing a value of 4.5 (Figure 5.11). Commercial systems tend to have a lower median COP across the board compared to the same technology and size in residential systems, possibly due to the more challenging operating conditions and/or greater auxiliary loads. Air-water systems in the commercial sector saw little movement in their COPs between 2016 and 2019, with the exception of large systems in the 100-500 kW_{th} range, which saw their median COP increase from 3.9 to 4.0.

Figure 5.11 Heat pump COP trends in Italy by technology, sector and system size, 2016-2019



Source: GSE, 2020.

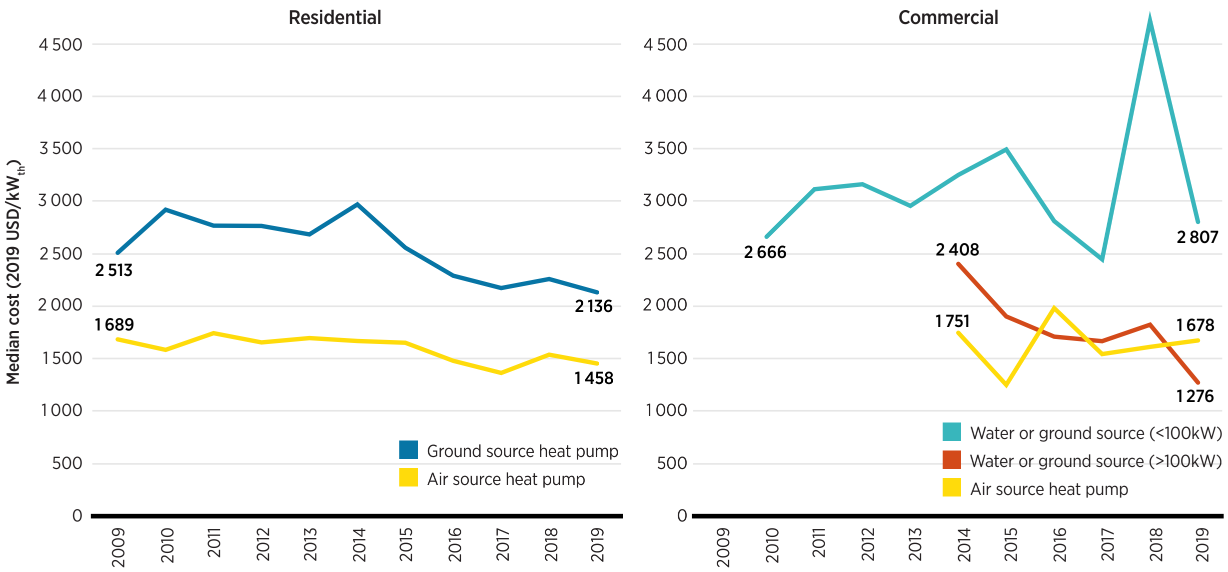
UNITED KINGDOM

The heat pump market in the United Kingdom has historically been relatively modest, with sales in 2020 of around 37 000 units,[15] but it is accelerating, with an estimated 67 000 units likely to have been installed in 2021 (Heat Pump Association, 2021).[16] Deployment in the United Kingdom has been driven by support offered under the Renewable Heat Incentive (RHI), with two distinct schemes available to domestic (*i.e.* residential customers) and non-domestic customers (most applications were from the agricultural, accommodation and services/commerical sector). The two schemes have seperate rules surrounding eligibility, remuneration rates (which are set in pence/kilowatt hour), rules and application processes – all of which are administered by the United Kingdom's independent energy regulator, Ofgem.[17]

Data are available on deployment under both schemes and at the end of 2021, 22 000 applications had been accredited for non-domestic customers with a total capacity of 5.5 gigawatts and 98 000 applications for domestic customers for a total of 1.2 gigawatts (BEIS, 2022). The non-domestic scheme opened to applicants in 2011 and closed in 2021, while the domestic RHI scheme launched in 2014 and closed to applicants on 31 March 2022.

Figure 5.12 presents the data collected by BEIS from RHI applications that show the trend in the median cost of different heat pump technologies under the domestic and non-domestic incentive schemes. For residential systems, GSHPs were almost twice as expensive per kW as ASHPs in 2009 and 2019, but have been as much as 75% more expensive. Both technologies saw their costs decline over the period 2009 to 2019, reductions of 14-15% and total installed costs of USD 1 458/kW$_{th}$ for ASHPs and USD 2 136/kW$_{th}$ for GSHPs. In the commercial sector, systems with 100 kW$_{th}$ of capacity or less have experienced quite volatile pricing, especially since 2015, and in 2019 cost USD 2 807/kW$_{th}$, up from USD 2 666/kW$_{th}$ in 2009. The market for larger water or geothermal heat pumps has experienced quite a different trend, with costs falling by 47% between 2014 and 2019 to USD 1 276/kW$_{th}$ in 2019. ASHPs in the commercial sector also saw costs per kW$_{th}$ decline, but by a more modest 4% over the same period.

Figure 5.12 Heat pump costs in the United Kingdom by sector and technology, 2009-2019



Source: BEIS, 2020.

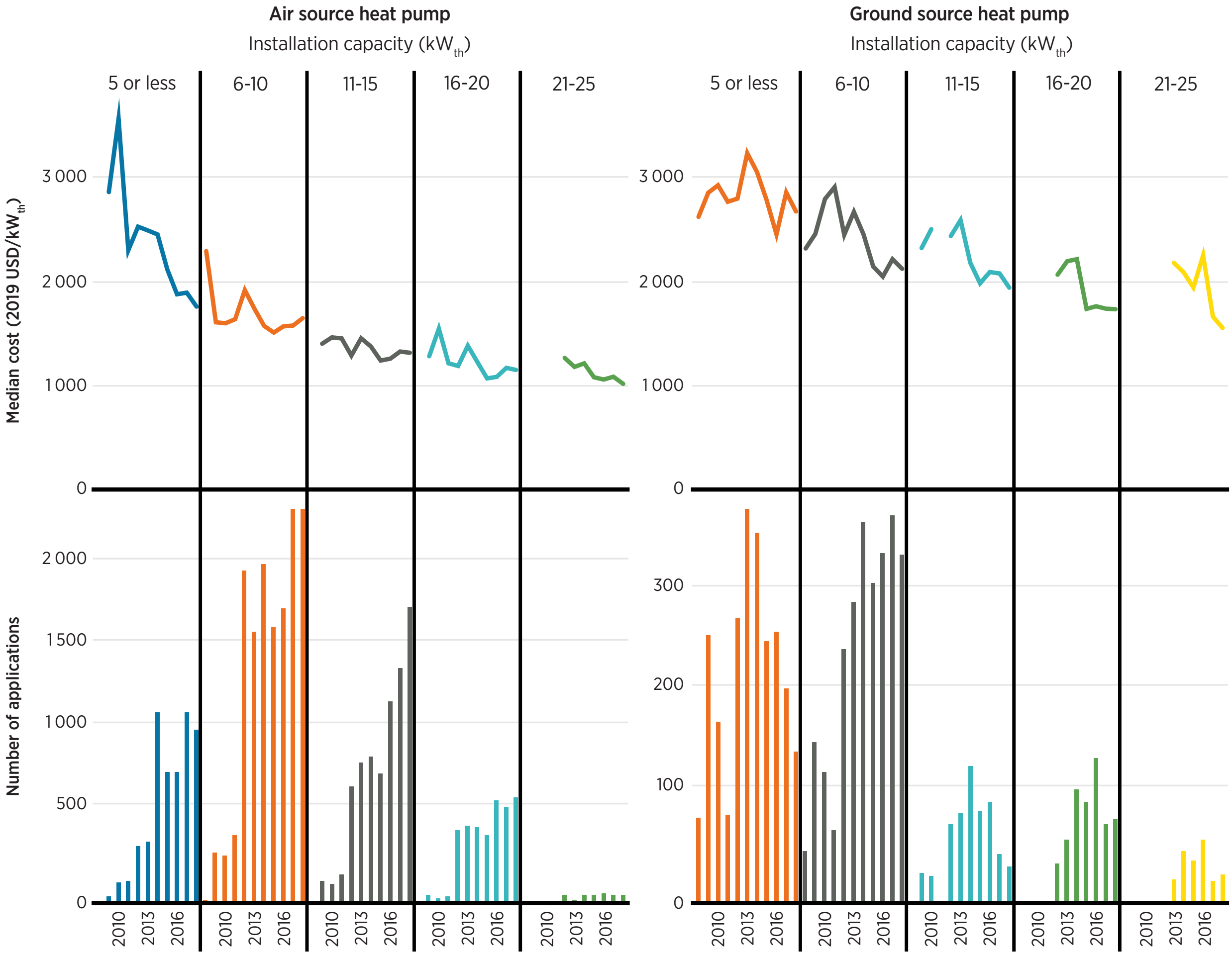
[15] See https://blogs.bsria.co.uk/2021/03/29/uk-heat-pump-market-has-weathered-covid-19-challenges-coherent-policy-support-is-now-needed-to-unlock-its-full-potential/; accessed 3 February 2022.

[16] www.heatpumps.org.uk/uk-heat-pump-market-set-to-almost-double-this-year/; accessed 3 February 2022.

[17] www.ofgem.gov.uk/environmental-and-social-schemes/non-domestic-renewable-heat-incentive-rhi; accessed 3 February 2022.

Figure 5.13 examines the cost trends for residential heat pumps by size category and technology. For ASHPs, the most systems were supported in the 6-10 kW_{th} range in almost all years, while for GSHPs this flipped to larger 11-15 kW_{th} systems from 2015 onwards. For ASHPs the largest cost reductions occurred for the smallest 5 kW_{th} or less category, but all size groups saw significant declines. The experience for GSHPs was somewhat different, with the smallest category to see significant deployment (6-10 kW_{th}) experiencing a volatile cost path, which left it little changed between 2009 and 2019. There were, however, more significant cost reductions for the larger capacity categories, with all categories above 16 kW_{th} having median costs below USD 2 000/kW_{th} by 2019, with GSHPs in the 26-30 kW_{th} category falling to USD 1 560/kW_{th} by 2019.

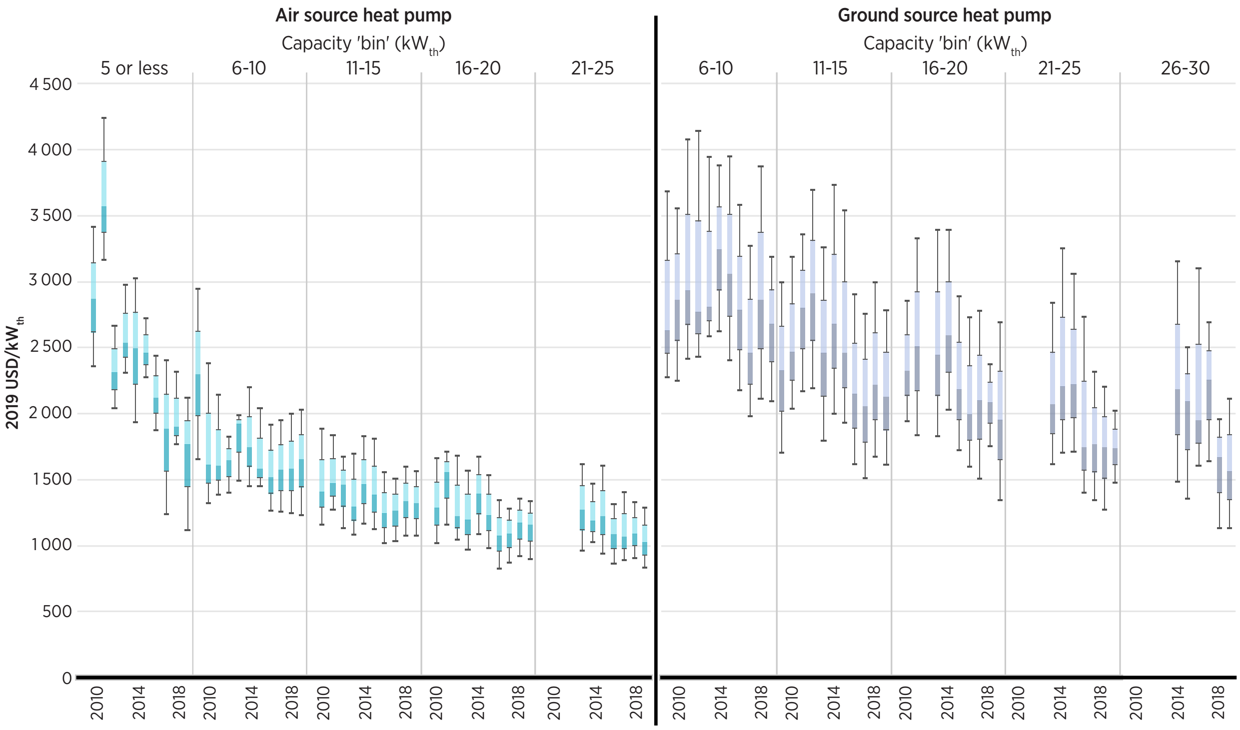
Figure 5.13 Heat pump costs in the United Kingdom by sector and technology, 2009-2019



Source: BEIS, 2020.

GSHPs, in addition to having higher overall specific costs, also experience a wider variation in costs for a given size (Figure 5.14). This is related to the wider variation in costs related to the project-specific parameters for GSHPs. Each project brings its own special considerations with respect to the design of the ground loop to be installed that will be influenced, not just by the needs of the building with respect to design points, but also related to the size of the area available on-site, as well as ease of access for the works. These factors, as well as the fact that the sample size is much lower for GSHPs compared to ASHPs, explains the wider variation.

Figure 5.14 Median, upper and lower quartile heat pump costs in the residential sector in United Kingdom by technology and system size, 2009-2019



Source: BEIS, 2020.

Data on the coefficient of performance (COP) or the seasonal performance factor (SPF) are not readily available for the United Kingdom under the RHI data collection system. A minimum SPF of 2.5 has been required, although the method of calculation has changed over the period of the incentive scheme. Data from monitoring of the existing systems have, however, been collected and provide some insights into the real-world performance of the systems installed. In the United Kingdom, three major research efforts have looked at installed heat pumps performance in 2009-10 (Energy Savings Trust, 2013), 2013-15 (sponsored by the Department of Energy and Climate Change, summarised by Lowe [2017]), and in 2016-19 with data from Ofgem (Meek, 2021). The data suggest that the optimisation of GSHPs has improved over time and is delivering higher SPF factors, while the evidence for ASHPs is less compelling: with a large body of ASHPs now installed, real world SPFs appear to be stabilised around 2.7. These are for heat pumps that were installed prior to the trials, in some cases a number of years earlier, so if heat pump optimisation and performance improvements are being achieved, these data will be lagging what new installs might be achieving by 2-4 years.

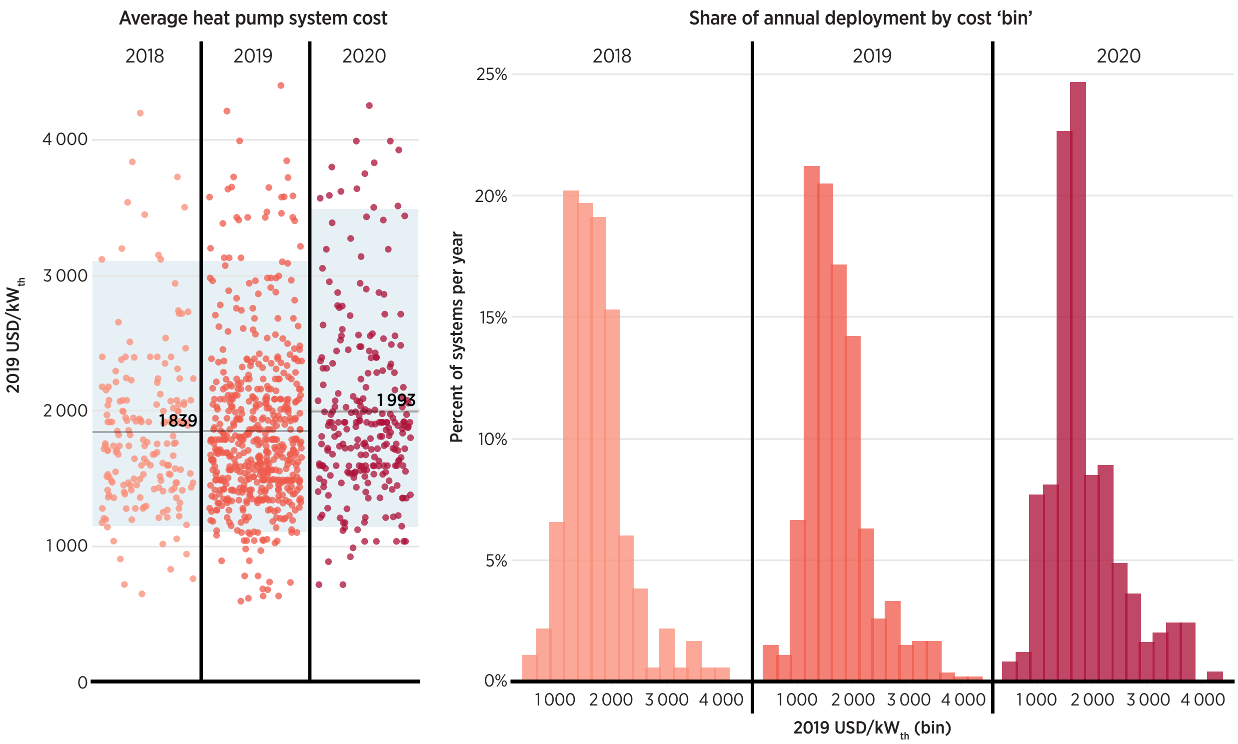
IRELAND

The market for heat pumps in Ireland is relatively modest, with sales of around 8 430 units in 2020, with around 7 000 of those being air-to-water heating systems. This represents a market share of around 10% for the space heating market (EHPA, 2021). Support for heat pump deployment in residential buildings is given in the form of grants under the Better Energy Homes programme, which is administered by the Sustainable Energy Authority of Ireland (SEAI).

Data for just over 1 000 installations are available from SEAI for installations between 2018 and 2020, inclusive. Most of the cost data (95%), as for the deployment, are for ASHPs, with the same percentage of the balance being GSHPs, and only a few entries for water-water systems. The data are available by dwelling type and distinguish between whether systems are monoblock or split systems. Unfortunately, data on the thermal capacity of each system are not available, so total installed costs (which may or may not include the heat distribution system) are converted to per kW_{th} costs based on the assumption of an average system size of 7.5 kW_{th}.

Heat pump costs in Ireland appear to have been broadly stable between 2018 and 2020, taking into account the uncertainty surrounding trends in system size per year in the absence of data (Figure 5.15) and the average ranged from USD 1 839/kW_{th} in 2018 to USD 1 993/kW_{th} in 2020. The increase in the share of systems in the USD 1 500-1 750/kW_{th} and USD 1 750-2 000/kW_{th} was behind the increase in 2020 over previous years.

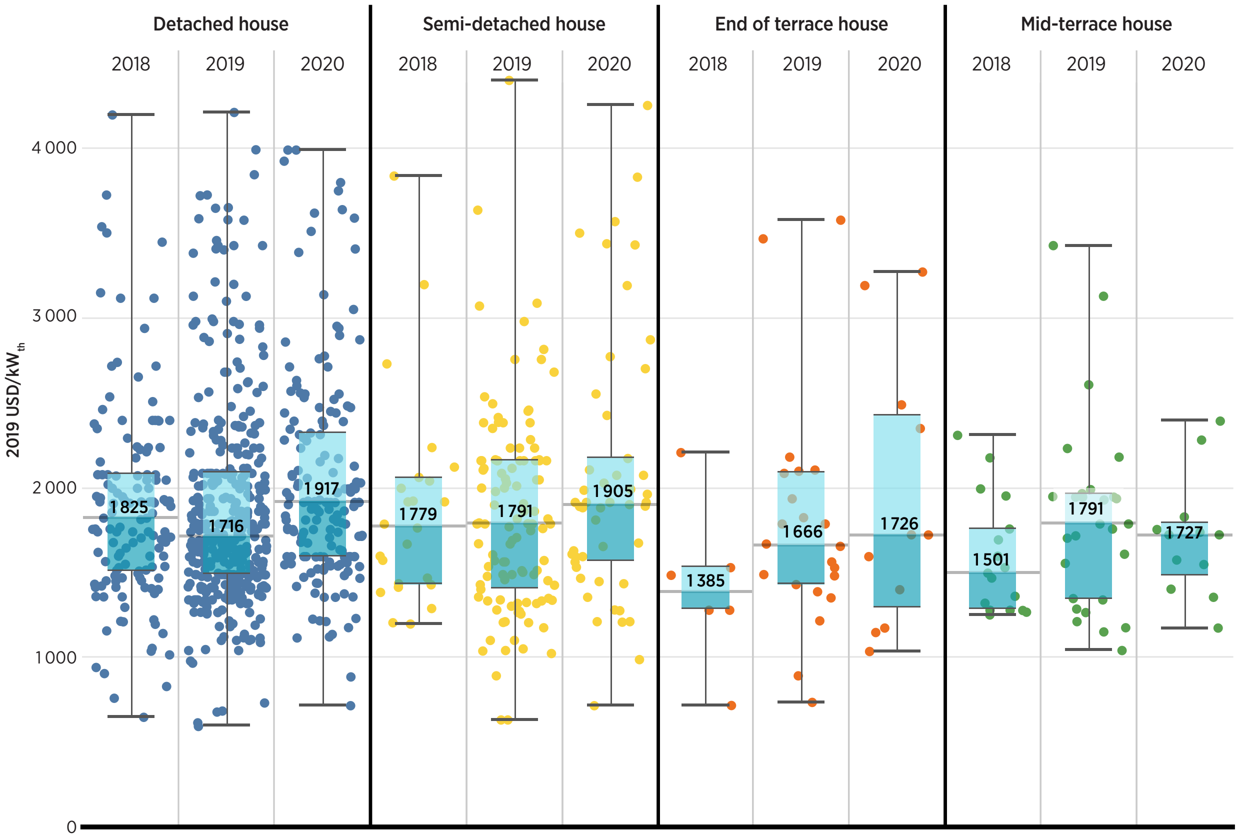
Figure 5.15 Heat pump costs and their distribution in the residential sector in Ireland, 2018-2020



Source: SEAI, 2020.

Looking at the median system cost by dwelling type confirms that the possible increase in costs in 2020 over 2018, was driven by a general increase in system costs across dwelling types (Figure 5.16), although the smaller sample sizes for terraced houses should be taken into account.

Figure 5.16 Median ASHP costs and distribution by dwelling type in the residential sector in Ireland, 2018-2020



Source: SEAI, 2020.

With data available to analyse the cost differential between split and monoblock ASHP systems, we can see that in 2018, the median cost premium for split units was USD 114/kW$_{th}$ or, about 7% more than monoblock systems, falling to USD 97/kW$_{th}$ (6%) in 2019. This premium was probably related to the additional installation costs for split systems. However, in 2020, this premium had become a discount. This change was primarily driven by changes in cost for the smaller market of ASHP in semi-detached houses, where the cost of monoblock systems increase by 20% from USD 1 694/kW$_{th}$ in 2019 to USD 2 032/kW$_{th}$ in 2020 at the same time as they fell in this segment for split systems by 3% from USD 1 903/kW$_{th}$ in 2019 to USD 1 850/kW$_{th}$ in 2020. With 159 data points for 2019 and 2020 for semi-detached houses, compared to 544 for detached homes, it is not clear if this change is statistically significant. Data for 2021 might shed more light on whether this trend is being sustained.

Figure 5.17 Median ASHP costs and distribution by dwelling type in the residential sector in Ireland, 2018-2020

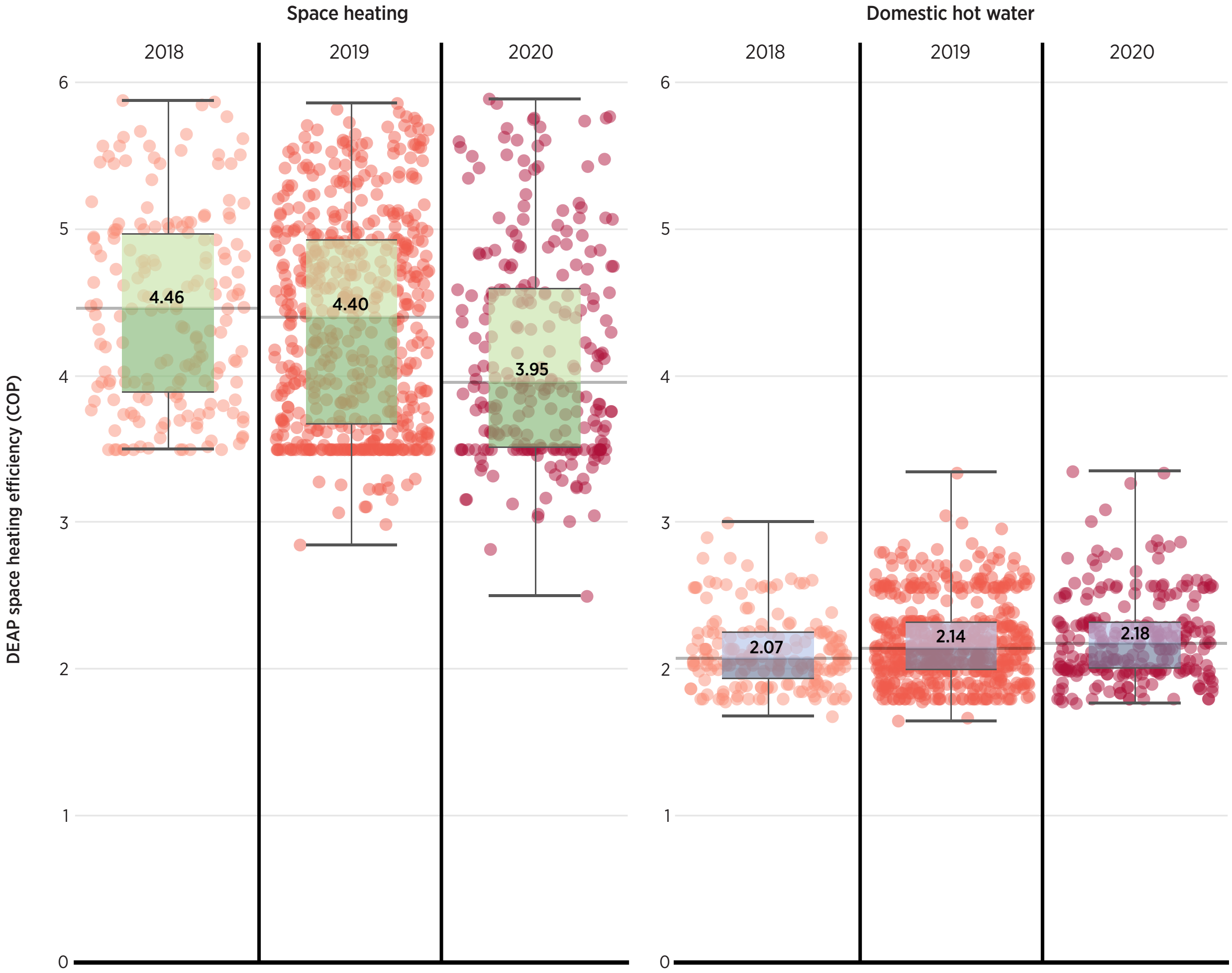
Source: SEAI, 2020.

Figure 5.18 shows the estimated COP performance as calculated using the Dwelling Energy Assessment Procedure (DEAP), which is used to make a Building Energy Rating (BER) for each dwelling. The methodology calculates energy consumption and carbon dioxide emissions for buildings, considering space heating, ventilation, water heating and lighting in a dwelling. DEAP is then used by registered BER assessors to calculate the rating for new and existing dwellings and to demonstrate compliance with the grant applications.[18] Unfortunately, DEAP was revised part way through the data sample, so data for 2020 are not directly comparable to 2018 and 2019.

First, it's important to note the significant difference between the COP of the heat pump in space heating mode, where temperature lift can be minimised in new homes with underfloor heating and that for sanitary (domestic) hot water, where a minimum temperature of 60°C is required. A COP of 3.95 for systems commissioned in 2020 would seem reasonable, given that the analysis of 16 houses with ASHPs during the exceptionally cold weather of late February/early March 2021 resulted in average COPs for combined water and space heating of not less than around 2.4 even when the average daily temperature was around -4°C (Kenny, 2021).

[18] *For more details, see www.seai.ie/home-energy/building-energy-rating-ber/support-for-ber-assessors/domestic-ber-resources/.*

Figure 5.18 Median ASHP COP and distribution space and domestic hot water heating in the residential sector in Ireland, 2018-2020



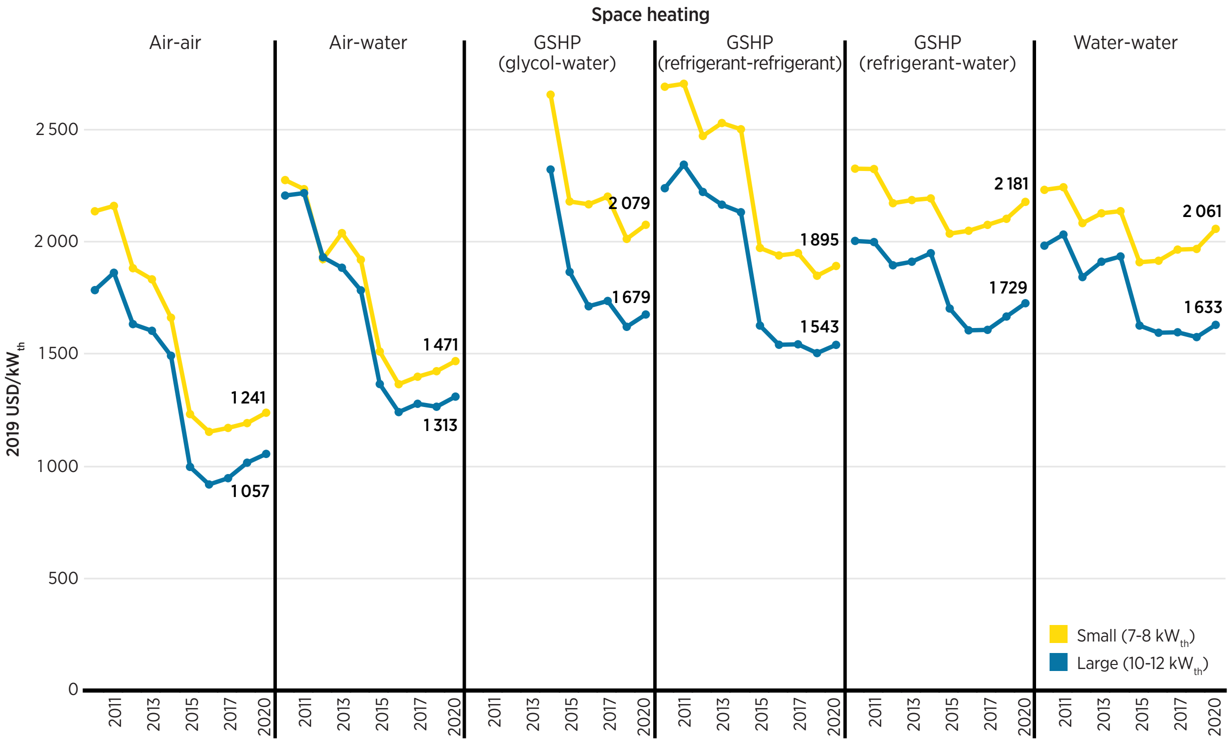
Source: SEAI, 2020.

FRANCE

France has become the largest market for heat pumps in Europe, with 394 000 new installations in 2020. Notably, this included 110 000 sanitary hot water heat pumps and 175 000 air-water heat pumps. Relatively competitive residential electricity-to-gas price ratios, as well as financial support in the form of grants under the MaPrimeRénov' programme, the energy efficiency certificates bonus and interest-free loans, with eligibility often meaning households can access all three financial assistance programmes.

The growth in the market saw costs fall significantly between 2010 and 2016, but these have increased in recent years, notably for air-air and air-water systems (Figure 5.19). Between 2010 and 2020 small (7-8 kW_{th}) air-air system costs fell 42% to USD 1 241/kW_{th} in 2020, while for large systems (10-12 kW) the decline was 41% to 1 057/kW_{th}. For air-water systems, costs fell by 35% between 2010 and 2020 for small systems and 41% for large systems. In 2020, at USD 1 471/kW_{th} small air-water systems were USD 230/kW_{th} (19%) more expensive than air-air systems, while for large air-water systems, the premium was USD 256/kW_{th} (24%). Data are available for different types of GSHPs, with costs falling by between 6% and 30% between 2010 and 2020, with costs in 2020 in the range of USD 1 895 to USD 2 181/kW_{th} in 2020. For large GSHPs, the cost reduction was between 14% and 31%, for costs of between USD 1 543 and USD 1 729/kW_{th} in 2020. Water-water systems saw costs decline 8% between 2010 and 2020 from USD 2 234/kW_{th} to USD 2 061/kW_{th} for small systems and by 18% from USD 1 985/kW_{th} to USD 1 633/kW_{th} for large systems.

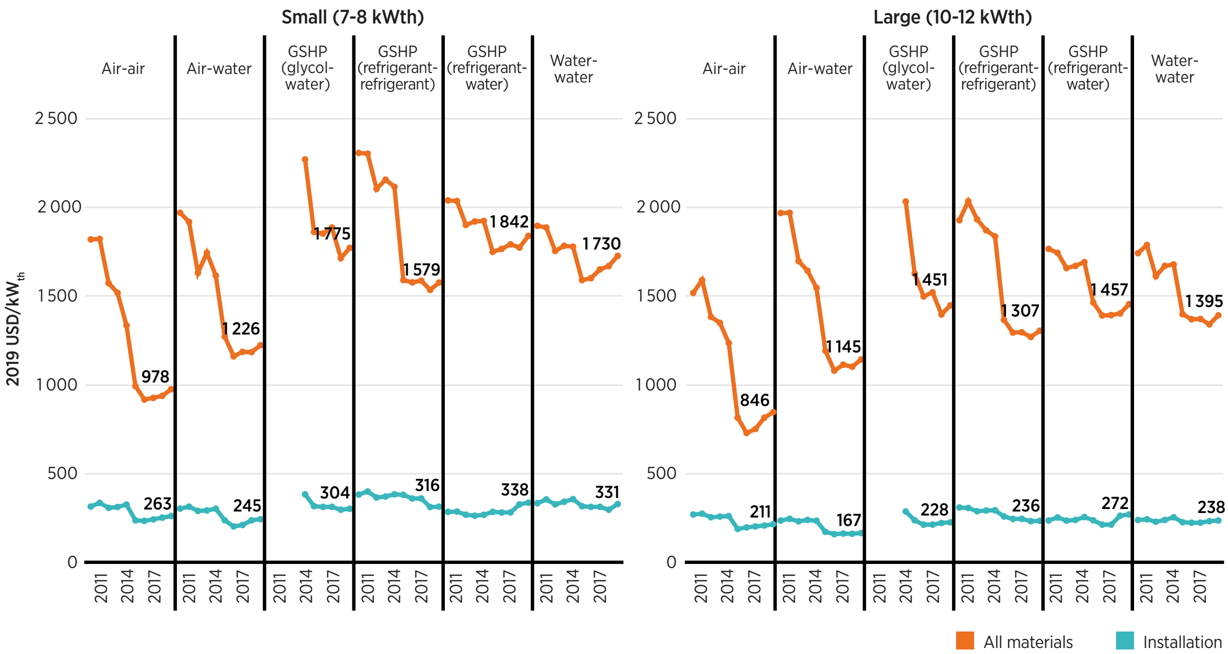
Figure 5.19 Price evolution of residential heat pumps by technology and capacity in France, 2010-2020



Source: L'Observatoire des énergies renouvelables, 2021.

Looking at a simple breakdown of the costs of the different heat pumps for which data are available shows that for water-water heat pumps, installation costs have been broadly stable over the period. For GSHPs, installation costs have fallen for two of the three categories tracked. For ASHPs, installation costs per kW declined between 2010 and 2020, with a steep change in 2015, but have either been stable or increased slightly since 2015. Given these trends in the cost of installation, the increase in costs between 2016 and 2020 shown in Figure 5.20 for ASHPs have been primarily driven by the costs, excluding installation (*i.e.* the costs of the heat pump, balance of plant and plumbing costs). For air-air ASHPs, of the USD 85/kW_{th} increase in costs between 2016 and 2020, USD 27/kW_{th} came from higher installation costs for small systems, while for larger air-air systems the installation accounted for USD 18 of the USD 136/kW_{th} increase. For air-water systems, of the USD 103/kW_{th} increase between 2016 and 2020 for small systems, USD 41/kW_{th} came from rising installation costs, while for larger systems, rising installation costs accounted for just USD 6/kW_{th} of the USD 69/kW_{th} increase.

Figure 5.20 Price evolution of installation and systems costs for residential heat pumps by technology and capacity in France, 2010-2020

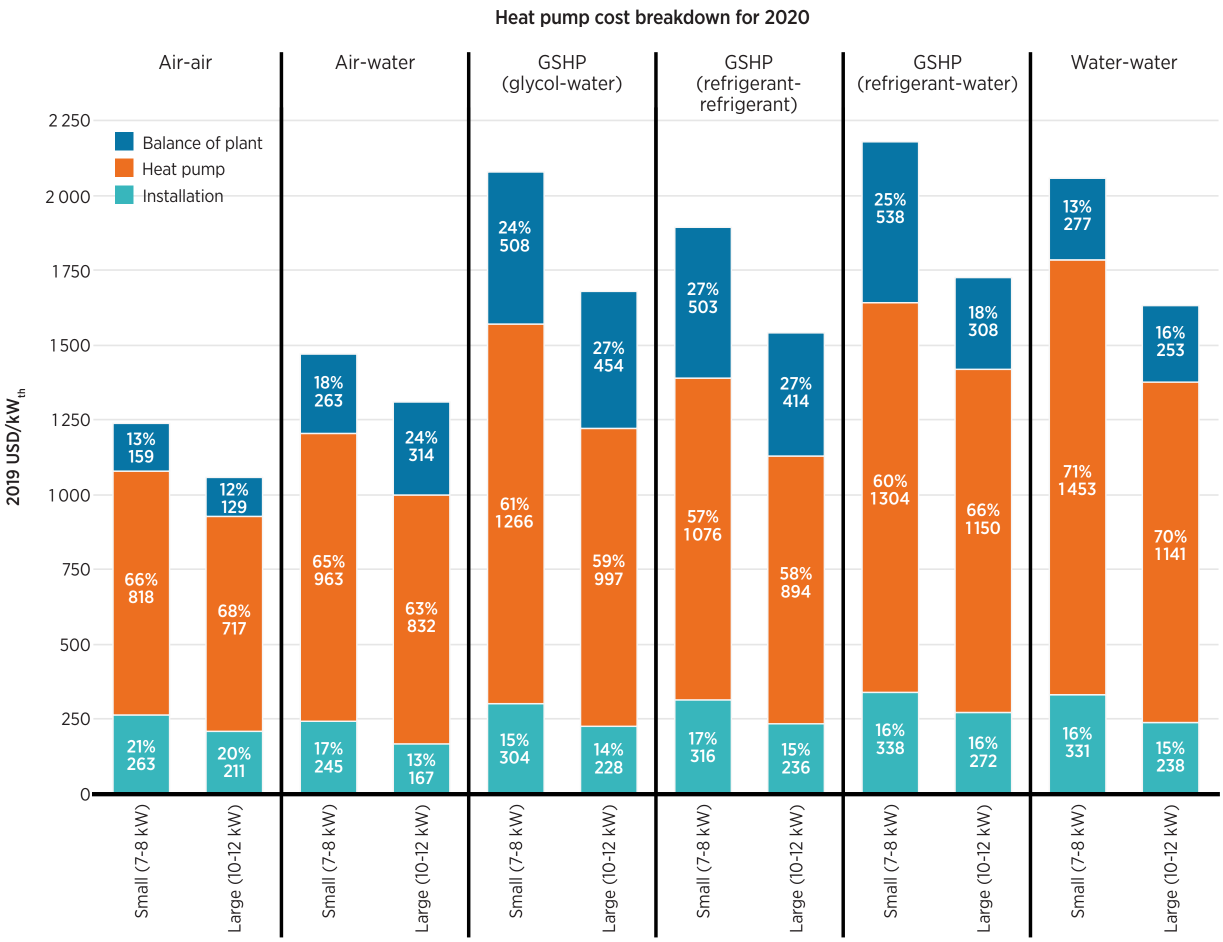


Source: L'Observatoire des énergies renouvelables, 2021.

With the cost of the heat pumps and other materials falling more rapidly than installation costs, the share of installation costs has increased through time, notably for both ASHP systems for which data are available. The share of installation in total costs increased from 15% in 2010 to 21% in 2020 for small air-air systems and from 15% to 20% for large systems. For air-water systems, the higher costs see installation take up a smaller proportion of costs and have shown a smaller increase as well. For small air-water systems, the share of installation increased from 13% to 17% between 2010 and 2020 and from 11% to 13% for larger systems. For both GSHPs and water-water systems, the share of installation only increased by 1-2 percentage points. Overall, the overall contribution of installation to total costs is a smaller share in larger systems, but the difference is not pronounced, except for air-water systems (Figure 5.21).

More detailed data are available for 2020 that include the cost of the heat pump separately. In 2020, the share of the heat pump in the total installed cost for ASHPs was between 63% and 68%, that of installation between 13% and 21%, and that of the balance of costs between 12% (for large air-air systems) and 24% (for large air-water systems). The share of the heat pump in the total installed cost of large GSHPs was between 59% and 66%, balance of system costs 17% to 28% and installation between 14% and 16%. For small GSHPs, the heat pump itself was between 57% and 61% of total installed costs, balance of system costs between 24% and 27%, and installation costs between 15% and 17%.

Figure 5.21 Heat pump cost breakdown by technology and capacity for residential heat pumps in France, 2020



Source: L'Observatoire des énergies renouvelables, 2021.

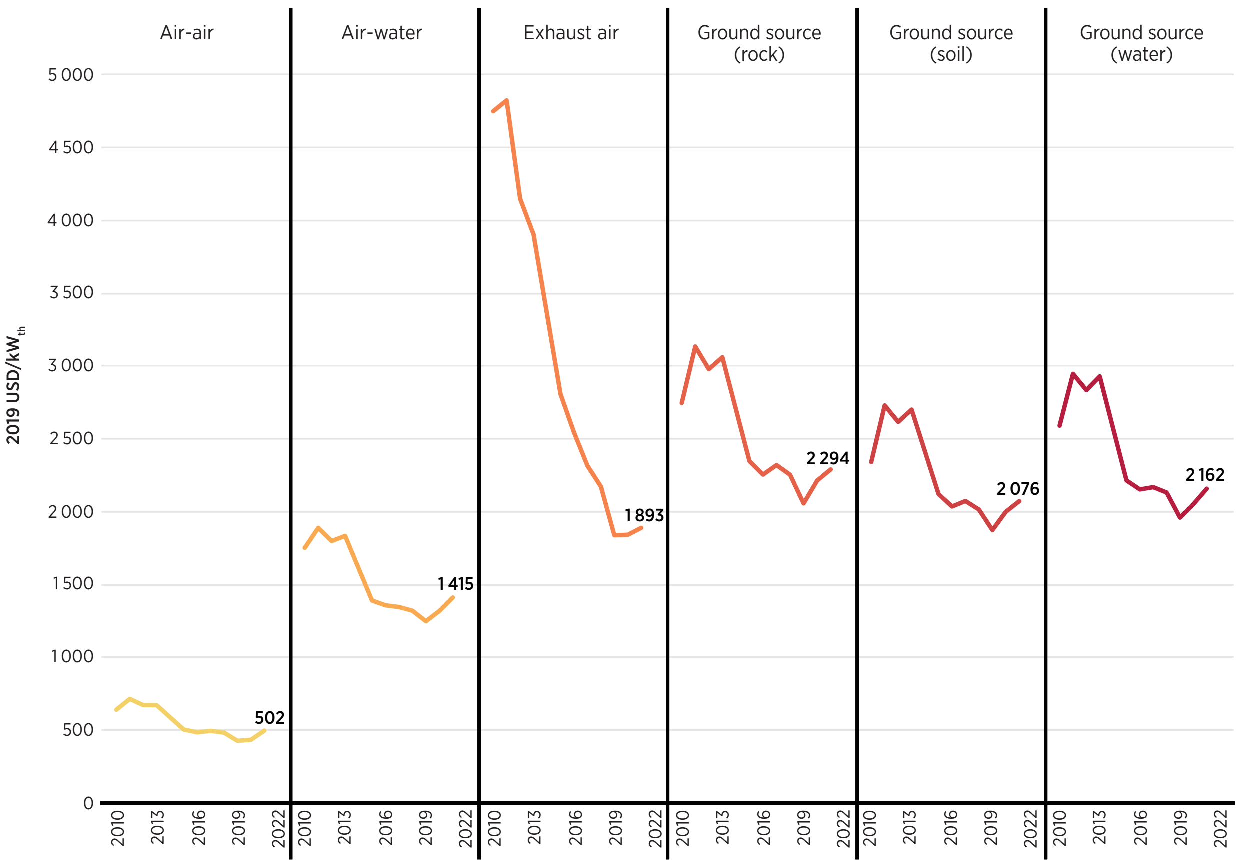
SWEDEN

The Swedish heat pump association (Svenska Kyl & Värmepumpföreningen, SKV) statistics include data for average system costs since 2010. The data are based on a survey of their members and in 2021, 139 out of 645 responded to their online survey. The trend in system costs since 2010 has generally been downward, but currency fluctuations have had an important impact on costs in 2020 and 2021.

Air-air systems costs per kW fell by 22% between 2010 and 2021 and those of ASHPs (air-water) fell by 19% (Figure 5.22). The costs for exhaust air systems, have fallen rapidly per kW, assuming that average system size has increased from 2 kW in 2010 to 5 kW in 2021. The major cost reduction driver has therefore been economies of scale for these systems.

For geothermal systems, the costs fell between 11% and 17% in the period 2010-2020. However, system costs fell in 2021 in local currency, but were more than offset by the weakening of the Swedish Kronor against the USD in 2021.

Figure 5.22 New heat pump cost trends by technology for residential heat pumps in Sweden, 2010-2021



Source: Svenska Kyl & Värmepumpföreningen (2021); and personal communication with Gustav Hammarberg (SKV).

OTHER COUNTRIES

Data collection for other major heat pump markets proved challenging or yielded much more aggregated data, albeit from comprehensive data sources. Data were collected through monitoring of support schemes, by surveying installers, market analysis reports commissioned by IRENA Member State governments, academic research, industry sources and commercial market research reports.

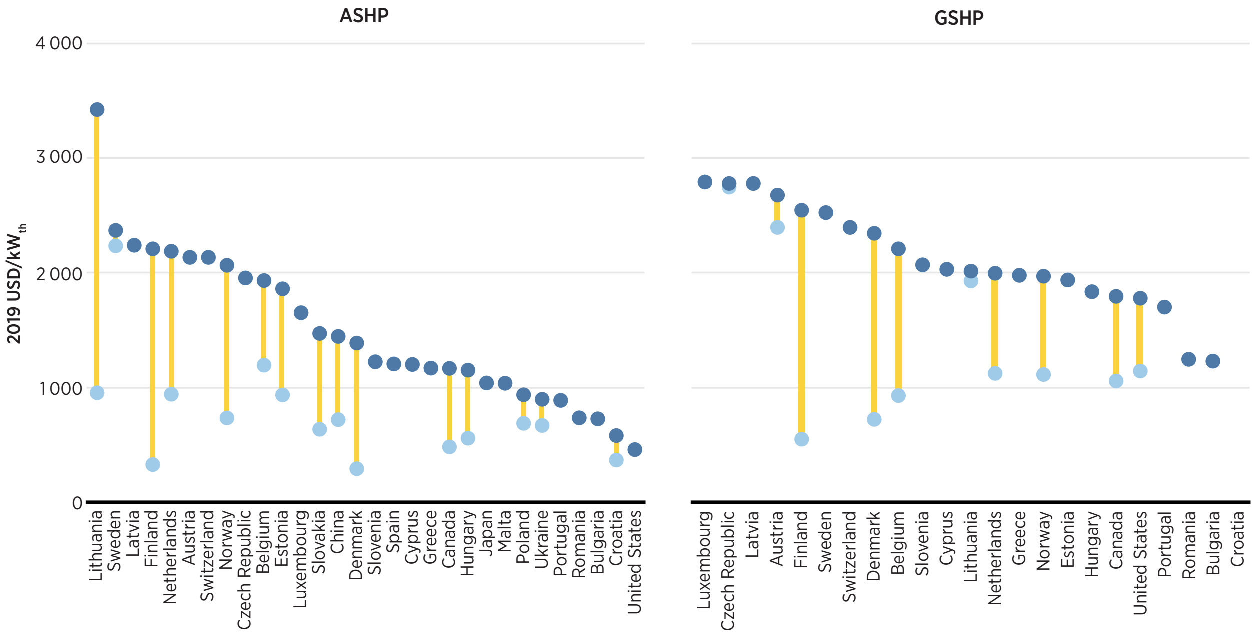
Data boundaries were sometimes unclear, but most, if not all, are on comparable basis to the country-level data presented in the previous sections. Data were often only available as representative values or ranges, so the representativeness of the data for some countries remains to be verified. Given the paucity of data, cost estimates span a wide range, from 2012 to 2020, depending on the country and there is no time series data.

Taking these caveats into account, Figure 5.23 presents the range of costs per country for ASHPs and GSHPs for the countries for which data were available. Wide cost ranges for ASHPs exist in countries where air-air and air-water systems are utilised, with the lower bound representing the costs of air-air systems for space heating only, while the upper bound usually represents small (3-4 kW_{th}) air-water systems. Finland and Lithuania both have wide cost ranges for ASHPs, from under USD 332/kW_{th} for small air-air systems in Finland, up to USD 2 213/kW_{th} for small air-water systems. However, the data for Finland are much more robust, dating from 2020, while the data for Lithuania date from 2014. Sweden, Latvia, Austria and Switzerland all have estimates of above USD 2 000/kW_{th}, but the data date from 2014. The data for Norway and the Netherlands are for 2019, with a range of USD 945 to USD 2 191/kW_{th} in the Netherlands and USD 739 to USD 2 069/kW_{th} in Norway. The data for ASHPs in Denmark also span a wide range, with air-air systems at USD 296/kW_{th} up to air-water systems at USD 1 392/kW_{th}. Data for North America suggest ASHPs in Canada cost between USD 486 and USD 1 171/kW_{th}, while in the United States, large central forced air systems cost on average USD 463/kW_{th}.

The market for GSHPs is typically smaller, given their higher specific costs (per kW_{th}) and higher overall costs (with, on average, larger system sizes). This translates into less data generally being available, and a greater number of countries with single point estimates. A wide variation in costs exists for systems in Belgium, Denmark and Finland, with the lower end of costs for these markets being USD 934/kW_{th}, USD 726/kW_{th} and USD 553/kW_{th}, respectively, up to as much as from a low of USD 1 234/kW_{th} in Bulgaria, through to Norway, where the data from the support scheme have seen costs range from USD 1 117/kW_{th} up to USD 7 356/kW_{th}.

Although little data through time are available, it appears that costs have fallen for ASHPs and GSHPs in Denmark, Finland, the Netherlands, Norway and Poland. The robustness of this result is yet to be verified with more data, however.

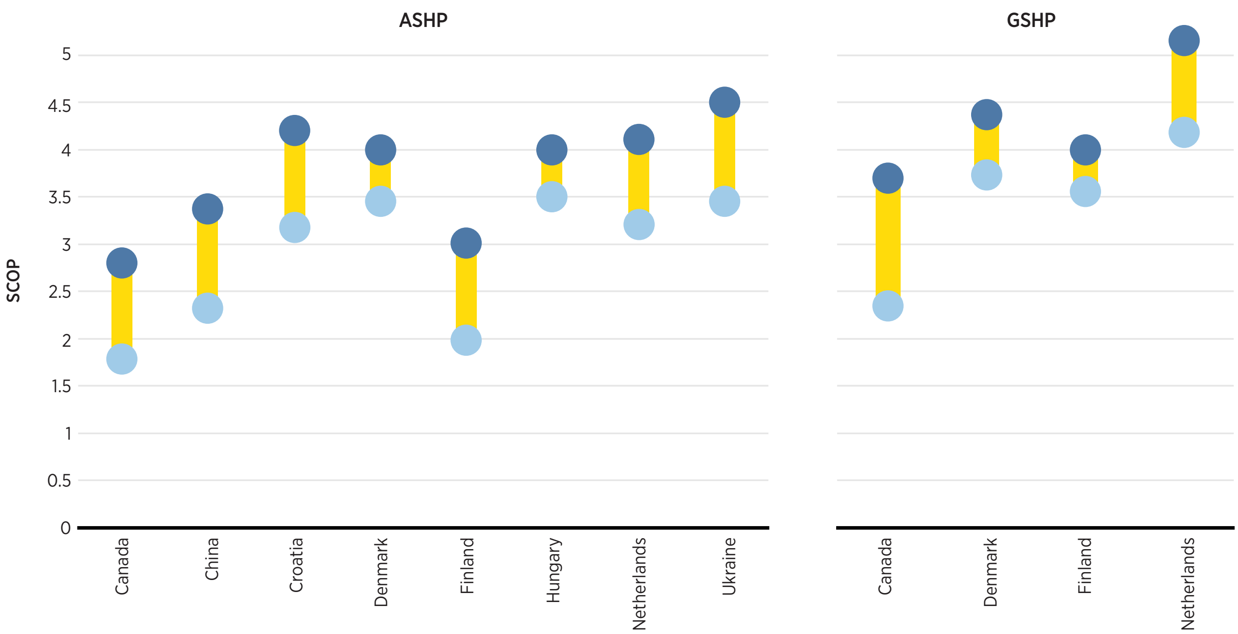
Figure 5.23 Heat pump system cost data range by technology for residential heat pumps by country



Sources: IRENA survey; Danish Energy Agency and Energinet, 2021; Dunsky, 2020; ENOVA, 2020; EHPA, 2015; US DOE EIA, 2018; Finnish Heat Pump Association (SULPU), 2020; Kegel et al., 2015; Liua and Mauzerall, 2020; Niessink, 2019; and Zhang, 2017.

Data for the seasonal coefficient of performance (sCOP) are not always included in the data sources. Figure 5.24 presents the countries for which a range of data for which the sCOP is available, while single point estimates have been excluded. In general, countries with milder climates achieve higher sCOPs, but the technology choice also plays a role. On average, GSHPs, with access to a more stable heat source perform better than ASHPs, but with additional auxiliary loads, the benefit is not always large.

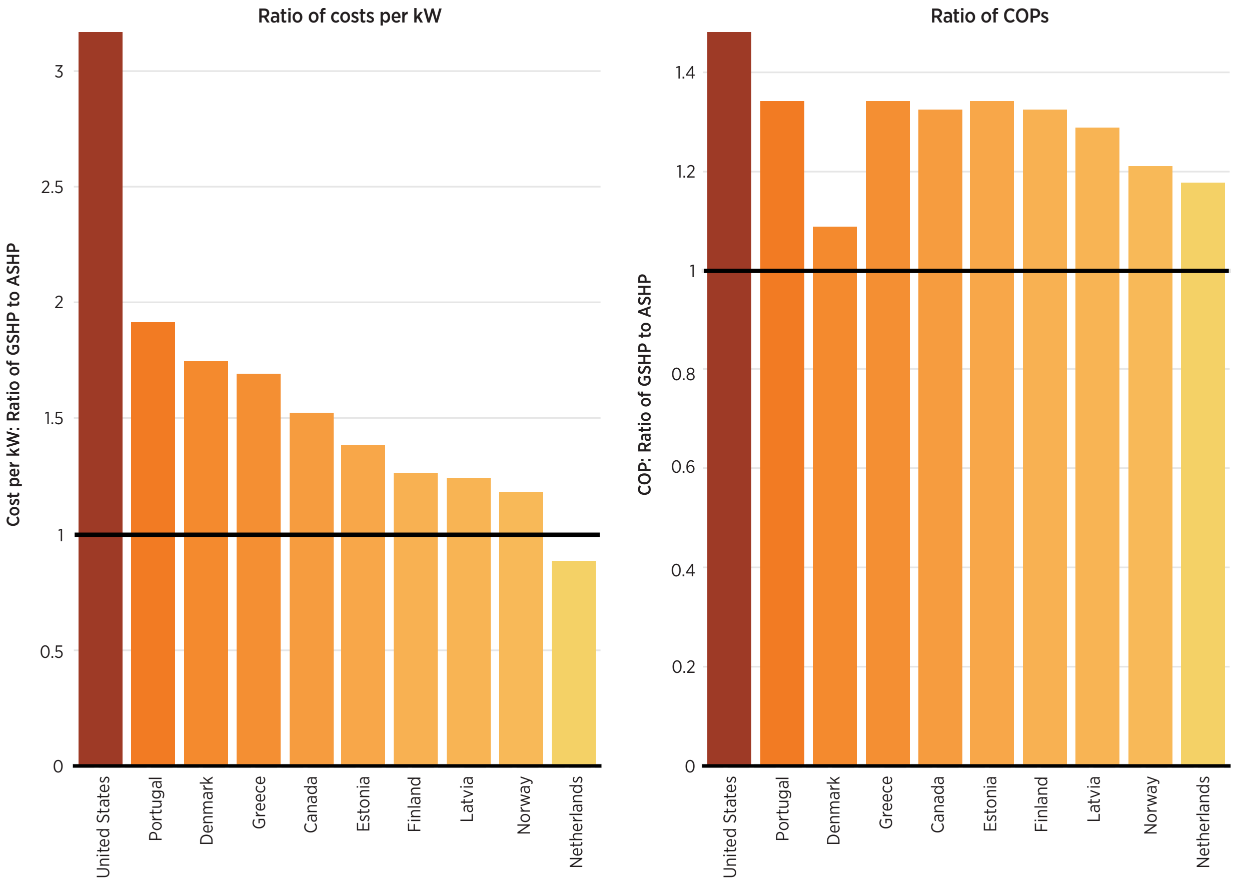
Figure 5.24 Heat pump system sCOP ranges by technology and country for residential heat pumps



Sources: IRENA survey; Danish Energy Agency and Energinet, 2021; Dunsky, 2020; ENOVA, 2020; EHPA, 2015; US DOE EIA, 2018; Finnish Heat Pump Association (SULPU), 2020; Kegel et al., 2015; Liua and Mauzerall, 2020; Niessink, 2019; and Zhang, 2017.

Figure 5.25 shows the ratio of GSHP costs to ASHP's for individual markets and the ratio of the sCOP for the two systems. The United States is a clear outlier, given the very competitive costs of air-air central heat pump systems. However, the significant cost premium of GSHPs over ASHPs and the relatively modest average increased sCOP, explains why GSHP markets are typically smaller than those for ASHPs. This doesn't tell the whole story, however, as in cold climates, the performance improvement of GSHPs over ASHPs can be more pronounced than these representative ranges and avoid the need for back-up heat, particularly in buildings with poorer-performing building envelopes.

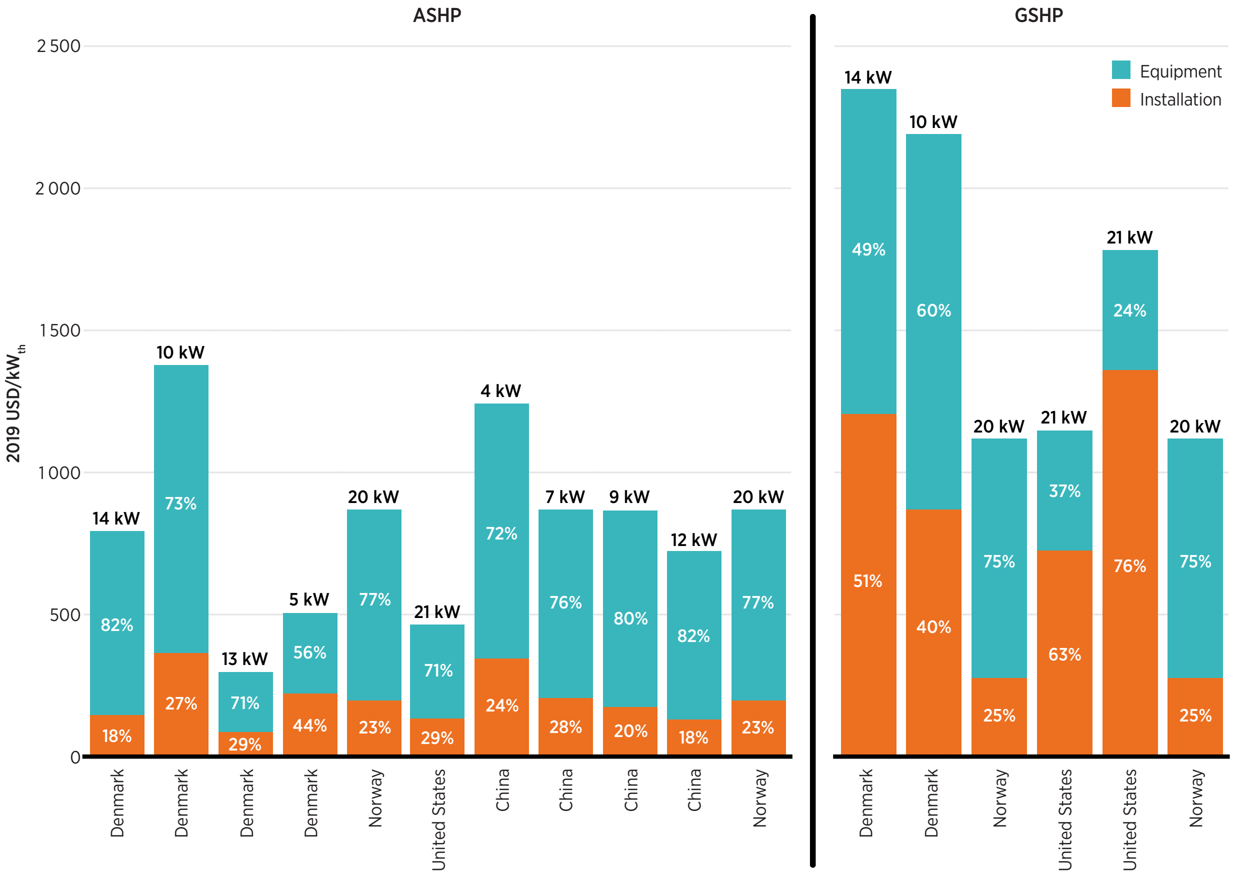
Figure 5.25 GSHP costs and performance relative to ASHP by country



Sources: IRENA survey; Danish Energy Agency and Energinet, 2021; Dunsky, 2020; ENOVA, 2020; EHPA, 2015; US DOE EIA, 2018; Finnish Heat Pump Association (SULPU), 2020; Kegel et al., 2015; Liua and Mauzerall, 2020; Niessink, 2019; and Zhang, 2017.

Figure 5.26 presents data for the cost breakdown where these are available, but only between total equipment costs and installation. Compared to the data available for France, it is noticeable that installation costs are a significantly higher percentage of the total cost for ASHPs in a number of cases. Indeed, only large air-water heat pumps in Denmark (14 kW_{th}) and in China (9-12 kW_{th}) even come close to the top of the range of the share of installation costs for ASHPs in France. For GSHPs, installation costs in Denmark and the United States are significantly higher than in France, with total installed costs also significantly higher in Denmark.

Figure 5.26 ASHP and GSHP cost breakdown by country for China, Denmark, Norway and the United States



Sources: Danish Energy Agency and Energinet, 2021; ENOVA, 2020; US DOE EIA, 2018; Liua and Mauzerall, 2020; Niessink, 2019; and Zhang, 2017.

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ANNEX: SUPPORT SCHEMES CONSIDERED FOR DATA COLLECTION

Support schemes for building renovation and/or heat pump deployment should be a reliable source of high-quality cost and performance data for policy makers, industry, think tanks, research institutions and the public. However, they are rarely designed with this in mind, or if they are, can often be inaccessible to all but the most dedicated researchers.

In Europe, only Germany, Ireland, Italy and the United Kingdom stand out in this respect, in having collected reasonably robust data for the installed costs of the heat pumps supported with public funds. The data for Germany, Ireland and Italy are not easily accessible to the public, while the high-level reporting of the UK data limits somewhat the usefulness of the easily accessible data.

Given the wide variation in costs in Europe, and globally, this lack of detailed, comparable data is a significant barrier to understanding exactly why these costs vary significantly between markets. It is hard not to come to the conclusion that this lack of data transparency is holding back the industry and making policy makers' tasks that much more difficult.

Table A.1 highlights the support schemes identified in Europe from which cost data were sought, but not always received, by IRENA or its partners. The fact cost and performance data were either not collected by the support scheme, or are not available to researchers, for many of these schemes represent a significant gap in our understanding of costs in a substantial number of markets.

Table A.1 European support schemes for heat pumps or building energy efficiency decarbonisation without publicly available cost data

	COUNTRY	SUBSIDY SCHEME NAME
1	Austria	Exit from oil - Raus aus dem Öl (Subsidy for HPs <100kW in commercial, might include MFH owned by companies and public entities).
2	Austria	Renovation Check S&DFH - Sanierungsscheck Ein- und Zweifamilienhäuser.
3	Austria	Renovation Check MFH - Sanierungsscheck Mehrfamilienhäuser
4	Belgium - Brussels	Primes énergie 2018.
5	Belgium - Flanders	Premiums for HPs & DHW HPs - Premies voor een warmtepomp of warmtepompboiler.
6	Belgium - Walloon	Energy Premiums - Primes Énergie.
7	Belgium - Walloon	Aide à l'investissement (Commercial, might include MFH owned by companies or public entities).
8	Belgium - Walloon	Subventions UREBA - Targeting public sector and non-profit, might include social housing.
9	Belgium - Walloon	Ecopack & Rénopack
10	Bulgaria	Bulgarian Energy Efficiency Fund – BGEEF
11	Germany	"Marktanreizprogramm" (Market Incentive Programme).
12	Germany	KfW Renewable Energy Programme Premium.
13	Germany	KfW Renewable Energy Programme – Standard.

14	Denmark	Tax relief.
15	Estonia	Investment support for the renovation of apartment buildings.
16	Estonia	Investment eligibility conditions for the renovation of heating systems
17	Estonia	Investment eligibility conditions for the promotion of energy efficiency and renewable energy use in child day care buildings
18	Finland	Subsidy for the renovation of buildings (from 1 January 2020) and subsidy (EUR 4 000 GSHP, EUR 2 500 AWHP) for getting rid of oil burner (1 June 2020).
19	France	Prime "Habiter mieux".
20	France	Eco-prêt à taux zéro.
21	France	Crédit d'impôt pour la transition énergétique (CITE).
22	France	Prime Energie.
23	Greece	Development Law.
24	Greece	Combined with loan- "Energy Saving at Home II".
25	Greece	Tax regulation mechanism I (Law No. 2238/1994 on the Income Tax).
26	Greece	Tax regulation mechanism II (Development Law).
27	Ireland	Support Scheme Renewable Heat (SSRH).
28	Ireland	Accelerated Capital Allowance scheme.
29	Italy	Conto Termico and 110% Ecobonus, GSE.
30	The Netherlands	Energy Investment Allowance, EIA scheme.
31	The Netherlands	ISDE.
32	Slovenia	Financial Incentives of the Eco Fund.
33	Slovenia	Soft Loan of the Eco Fund
34	Norway	Enova grants for households and commercial entities.
35	Poland	Natural conversation agency.

Note: MFH= multi-family houses; DHW= domestic hot water; S&DFH= single and duplex family house.

COLLECTION OF EXPERT EVIDENCE ON THE PRODUCTION COST SPLIT UP

As to create supporting evidence on the cost structure of heat pumps, individual interviews were executed with manufacturers that were agreeing to disclose cost data anonymously. An air-to-water heat pump was selected, as it is the dominant type of solution in the market today.

The major cost components of heat pumps and their share of cost from these interviews are provided in Table A.2 based on a costs 'Free onboard' from China and from an original equipment manufacturer (OEM) in Europe.

Table A.2 European support schemes for heat pumps or building energy efficiency decarbonisation without publicly available cost data

	OEM CHINA	OEM EUROPE
	EXAMPLE MANUFACTURING COST SPLIT UP FOR 8KW INVERTER (A7/W35)	EXAMPLE MANUFACTURING COST SPLIT UP FOR 8KW INVERTER (A7/W35)
Casing	8%-10%	8%-10%
Compressor	12%-15%	12%-15%
Inverter controller	18%-25%	18%-25%
Heat exchanger (evaporator)	9%-10%	9%-10%
Heat exchanger (condenser)	9%-10%	9%-10%
Water pump	10%-15%	10%-15%
Expansion valve	8%	8%
Refrigerant	5%	5%
Other (sensors, back up element)	9%	9%
Profit margin	Approx. 30%	Approx. 30%
Cost per kW	USD 325 (FOB China)	USD 575 (OEM Europe)

Note: This is for the heat pump only, it excludes balance of plant costs (wiring, piping, *etc.*) and installation.

These data are not directly comparable with the data for sold and installed systems in the main body of this report, excluding as they do balance of plant, transport, wholesaler and installer costs/margins.

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