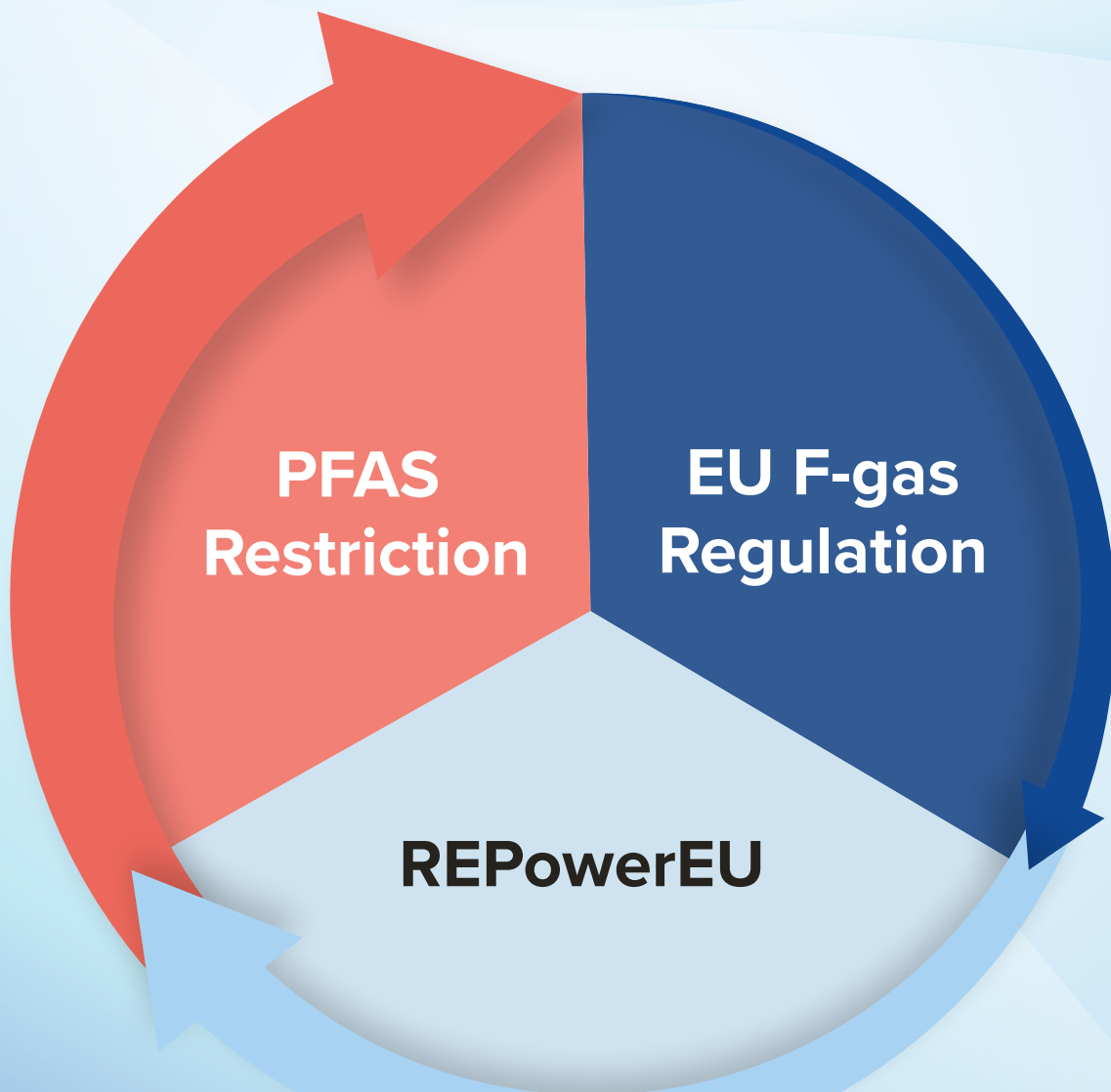


Delivering Today on EU F-gas, REPowerEU and PFAS Restriction with Natural Refrigerant Heat Pumps



2023



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About ATMOsphere

ATMOsphere (formally shecco) is a global and independent market accelerator on a mission to clean up cooling and heating. Its Intelligence Department collaborates with industry stakeholders, policymakers, NGOs and academia to accelerate knowledge on clean cooling and heating in the global RACHP sector.

For more information, visit atmosphere.cool

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Acronyms

ATA: Air-To-Air (heat pump)
ATW: Air-To-Water (heat pump)
CFC: ChloroFluoroCarbon
COP: Co-efficient Of Performance
DG: Directorate-General
EC: European Commission
EEA: European Economic Area
EIA: Environmental Investigation Agency
EHPA: European Heat Pump Association
EU: European Union
F-gas: Fluorinated Gases
GDP: Gross Domestic Product
GHG: GreenHouse Gases
GWP: Global Warming Potential
HCFC: HydroChloroFluoroCarbon
HFC: HydroFluoroCarbon
HFO: HydroFluoroOlefin
HP: Heat Pump
IEA: International Energy Agency
Mt: Metric tons
ODS: Ozone-Depleting Substances
OECD: Organisation for Economic Cooperation and Development
OEM: Original Equipment Manufacturer
PFAS: Per- and polyfluoroalkyl substances
RACHP: Refrigeration, Air-Conditioning and Heat Pumps
RACS: Reversible Air-Conditioning Systems
RMC: Risk Mitigation Concept
SCOP: Seasonal Coefficient Of Performance
SULPU: SUomen Lämpöpumppuyhdistys
TFA: TriFluoroacetic Acid
UNEP: United Nations Environment Programme

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Scope and Methodology

The objective of this research is to provide the most accurate information possible related to the ongoing transition of the European heat pump industry from using fluorinated refrigerants to natural refrigerants.

Consideration is given to both the ambition shown by the European Commission in its proposal for the revision of the EU F-gas Regulation and the objectives of the grand-strategy of REPowerEU to decarbonise European heating systems.

The report seeks to identify drivers and barriers impacting stakeholders in the EU's residential natural refrigerant heat pump sector, framed within the context of decarbonising Europe's heating sector and transitioning towards electrification. No consideration is given to hydrogen as a heating mean in this report.

Regulations in terms of bans on fluorinated greenhouse gases are considered a main driver to this aim, and focus is therefore placed specifically on the EU F-gas Regulation. The unfolding per- and polyfluoroalkyl substances (PFAS) Restriction Intention is also treated in this report as a driver to speed up original equipment manufacturers' transition towards manufacturing heat pumps working with natural refrigerants.

The scope of this research covers heat pumps for space heating and domestic- and sanitary- water heating applications. Combined units are included tangentially in the analysis. It excludes, however, air-to-air and hybrid systems and reversible models. Nevertheless, the most salient progress industry has announced on air-to-air technology are reported for sake of completeness.

The study focuses on heat pumps with a rated capacity of less than 12 kW as this segment is assumed to be relevant for the residential sector. It is also the cut-off point for heat pumps covered under Commission Regulation (EU) No 206/2012 of 6 March 2012 implementing Directive 2009/125/EC of the European Parliament and of the Council with regards to Ecodesign requirements for air conditioners and comfort fans.

It is the report's goal to demonstrate how the climate objectives set by the European Commission can be achieved without locking in marketed appliances with fluorinated refrigerants. It does this by primarily reporting announcements by market players opting to provide heat pump charged with natural refrigerants to the market. ATMOSphere undertook an EU-targeted research effort to investigate both the current and future demand for key natural refrigeration technologies in the EU region (27 countries). To fully understand and analyse these markets, the ATMOSphere team used a combination of qualitative, quantitative, primary and secondary research methods.

Then, via the expansive global ATMOSphere network, global industry experts tested and expanded upon the concepts.

The following methods were used:

DESK-BASED RESEARCH

While preparing this in-depth presentation of the current and future market, ATMOSphere leveraged a combination of external reports and academic, industry and media publications, together with its own articles and reports, to build an understanding of the market and where it is heading and to inform the questions for the subsequent manufacturer interviews.

ATMOSphere is powered by a database of natural refrigerant and clean cooling and heating information, diligently collected over the years by its analysts and journalists.

DATA COLLECTION

The comprehensive desk research was followed and enriched by extensive outreach to relevant original equipment manufacturers and industry stakeholders for primary research. A series of one-on-one interviews was planned to gather information on additional qualitative and quantitative results. Relying on ATMOSphere's database and EHPA's member section, an initial email outreach and briefing on the objective of this project was sent to manufacturers already producing heat pumps with natural refrigerants or announcing their future placing on the market. In cases where no answers were received from relevant representatives of stakeholders of the EU heat pump industry, an email was sent to the official company's email address as found on their main website.

A second-step of selection identified a target of 29 heat pump OEMs that were invited to take part in a conversation with ATMOSphere experts via a structured interview or alternatively submitting inputs through a fill-in survey.

Additional testimonials and information from stakeholders were gathered at conferences and trade fairs, as ISH 2023 in Frankfurt.

Executive Summary

Heat pumps are a key technology to support the climate alignment of global heating and cooling systems. Heat pumps can deliver both cooling and heating effects, and multiple technologies are available according to different installations' settings and buildings.

To provide heating and cooling, heat pumps rely on refrigerants – substances that deliver heat and cold where needed, generally either directly or by changing the temperature of a secondary fluid. In Europe, primarily two kinds of air-source heat pumps are being deployed. The first, air-to-water systems, have mostly been installed containing the refrigerant HFC-410a, a fluorinated greenhouse gas with a global warming potential thousands of times higher than that of carbon dioxide. The second, air-to-air systems, are rapidly being switched to HFC-32, a refrigerant that traps hundreds of times more heat than carbon dioxide.

The recently released summary of the 6th Assessment Report of the International Panel on Climate Change (IPCC) clearly states that “human activities, principally through emissions of greenhouse gases, have unequivocally caused global warming.” Fluorinated greenhouse gases are exclusively man-made substances that are emitted to the atmosphere during production, while leaking during operation of systems or at the end of life of the equipment in which they are contained.

The UN Secretary-General António Guterres stated at the release of the summary: “Our world needs climate action on all fronts – everything, everywhere, all at once.” By allowing the continuous use of fluorinated greenhouse gases with global warming potential, we would fail to deliver European climate leadership, especially considering the solid industrial ecosystems of European companies that can deliver without relying on these problematic fluorinated substances.

Heat pumps are based on the vapour compression technology applied to the refrigerant. This technology does not require fluorinated greenhouse gases, from a technical perspective. The proof of this is the availability of natural refrigerants such as hydrocarbons, carbon dioxide and ammonia across the spectrum of capacities and technologies included in heat pumps, as well as in most other applications used to mechanically control temperatures.

Policymakers designing the speedy rollout of heat pumps under REPowerEU, consisting of millions of units to be installed, must take into account the refrigerant used to avoid additional burdens on the climate and the environment caused by fluorinated greenhouse gases.

In fact, not only some widely used fluorinated greenhouse gases have high global warming potential, but are also labelled per- and polyfluoroalkyl substances, known as “forever chemicals” due to their persistent chemical structure. Fluorinated refrigerants can therefore be a concern from the perspectives of climate, environment and health. The report also finds that little production of these substances is taking place in Europe, whereas imports, both legal and illegal, are substantial.

Avoiding locking-in fluorinated greenhouse gases and PFAS in the deployment of heat pumps under REPowerEU is therefore an imperative. Not only are these fluorinated substances commonly more expensive than natural refrigerants, but they also do not ensure better energy performance. Heat pumps with natural refrigerants are available on the market today from multiple manufacturers across Europe without substantive cost increases over their fluorinated counterparts. This is especially the case for air-to-water heat pumps, which count for a significant part of the units sold across European countries each year.

Industry is evidently setting its focus on these natural working fluids, avoiding burdensome changes in refrigerants and system components under the ever-lowering of the global warming potential of these substances. Most companies interviewed find natural refrigerant heat pumps to be a solid investment from the perspective of the revision of the EU F-gas Regulation.

Driven by clear regulatory measures on fluorinated substances, interviewed industry stakeholders have reported their committal to scale up production to meet the targets set by policy. Small and medium companies are leapfrogging to natural refrigerants in heat pumps to avoid continuous refrigerant changes, and market leaders are converting their sales portfolio to fully natural by 2027. Companies specialised in other heating applications are also crowding into the heat pump space, seeing the market opportunity in providing systems with natural refrigerants.

Most companies want to avoid the uncertainty related to fluorinated refrigerants that are PFAS by directly investing in natural refrigerants, providing customers with systems that have no ozone depletion potential, negligible effect on global warming and no PFAS or PFAS-forming substances.

Finally, most of the companies interviewed report the feasibility of converting production lines from fluorinated refrigerants to natural refrigerants in roughly three years, with few concerned about the aspect of flammability, arguing a training upgrade to the EU F-gas certification could be achieved in two days.

Brief technology overview

Heat pumps are installations that take advantage of the heat sources present in the surrounding environment to provide a heating or cooling effect to a sink. These heat sources, which may originate from energy in the air, water or ground, are displaced by electricity with the help of a refrigerant, also called a heat medium.¹

Heat pumps are technologies used to mechanically control temperatures in accordance with human needs. They belong to the same category as fridges, freezers, chillers and air-conditioning because the technology and its functioning are closely related, i.e., they rely on the vapour compression cycle. This is why the industry jargon often groups these applications into the acronym RACHP: refrigeration, air-conditioning and heat pumps.

All RACHP technologies can be differentiated between direct or indirect when delivering the heating or cooling effect to the sink. When a refrigerant enters the space where the heating or cooling effect is required, the system is direct. When the refrigerant warms or cools another heat medium, such as water or glycol which will be charged with the required temperature to be delivered, the application is considered indirect.²

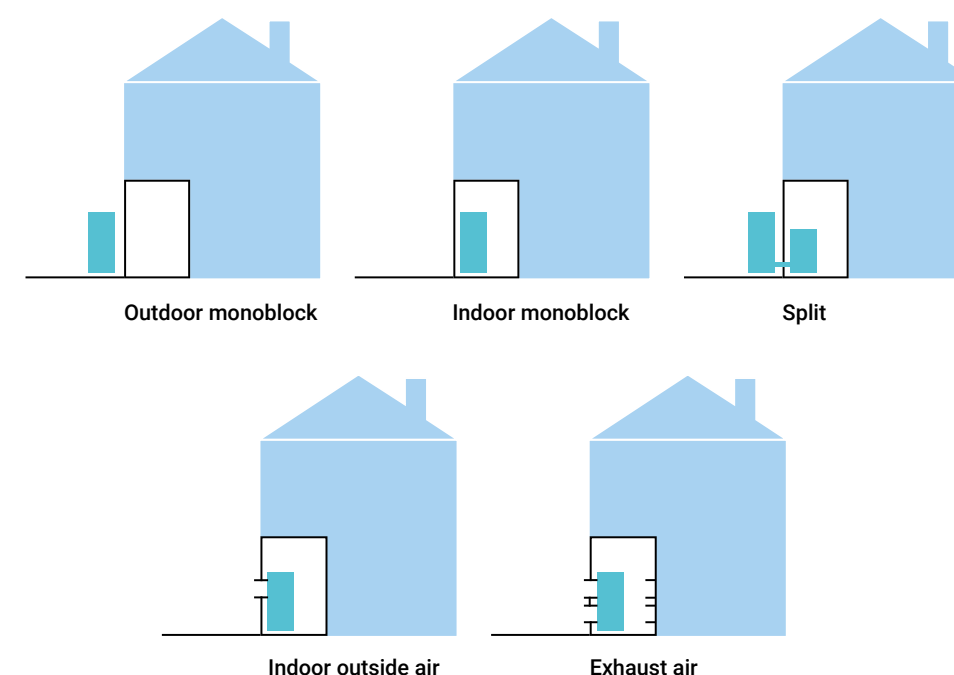
In the context of heat pumps charged with natural refrigerants that are flammable, such as R-290, an A3 refrigerant, this distinction is pivotal. Indirect systems normally place the refrigerant outside the building, or in dedicated spaces, away from where the heating or cooling effect is required and let the secondary fluid run through the building through pipes connected to underfloor systems or radiators, alleviating flammability concerns.

Indirect systems such as heat pumps that keep the refrigerant outside the building and deliver heating or cooling effects in buildings through secondary media are steadily being marketed in Europe due to the maturity of the technology. Hydronic systems can be further divided into monobloc or split systems, which maintain the refrigerant completely outside the building or in a dedicated space within the building where the temperature lift is performed, respectively. Both systems can be designed with flammable refrigerants such as R-290, with the monobloc architecture's being an excellent option for welcoming R-290.

Direct expansion systems – applications that deliver heating and cooling relying on the refrigerant entering the building and running through it – have historically been less prone to adopt flammable refrigerants such as R-290 due to the perceived risk, although HFC-32, an A2L (i.e., mildly flammable) is being widely adopted by the market.

Standards and building codes are often considered to be hindrances to the adoption of flammable refrigerants in these applications, even if other flammable substances, such as natural gas, are already running through buildings for heating and cooking purposes.³

Figure 1: Different heat pumps set up



Source: Colbourne (2022). Can refrigerants below 150 GWP be used in heat pumps in Europe? GIZ Proklima.

Direct expansion systems with natural refrigerants are developing faster than you think

The flammability hazard related to refrigerants such as R-290 has posed a barrier to the adoption of this heat carrier in the RACHP sector.

However, natural gas is already running through the walls of European buildings to serve heating and cooking needs, igniting in open flames in boilers and cooking stations. This fact makes some of the restrictions applied to flammable refrigerants seem inconsistent and outdated.

Different companies are already producing direct systems relying on R-290 and are marketing them in Europe today or intend to launch them in 2023. Clivet, Haier, Godrej and Midea are the most well-known examples of OEMs working with these systems and actively promoting them, although more OEMs are about to start this line of production as this report is being drafted.⁴

Due to the relation between the refrigerant charge and the capacity, these systems are normally marketed with small capacities up to 4 kW, as a function of the limited charge of refrigerant allowed in the system.

However, two notable developments in 2022 are opening the door for greater adoption of flammable refrigerants such as R-290, extending the capacity range of direct systems while preserving safety.

First, the standard IEC 60335-2-40 has been unanimously adopted in its seventh edition. The standard covers household air conditioners, heat pumps and dehumidifiers, and the revised edition allows for greater charge of R-290 up to 988 grams once safety measures are in place in the system design.⁵ Greater charges allow for greater capacities, and by deploying the updated standard, OEMs can already begin production of these systems.

Second, heat pump technology based on R-290 is evolving, allowing higher capacities of the systems with reduced charges. This is the result of a project conducted by the Fraunhofer Institute for Solar Energy Systems (ISE) called LC150, or Low Charge 150. The researchers have achieved a new efficiency record of 12.8 kW heating capacity with only 124 g of propane (R-290) – or 9.7 g/kW – in a heat pump. The results were reached by optimising the system components and improving the compressor. The system was showcased at the Chillventa trade show in Nuremberg, Germany.⁶

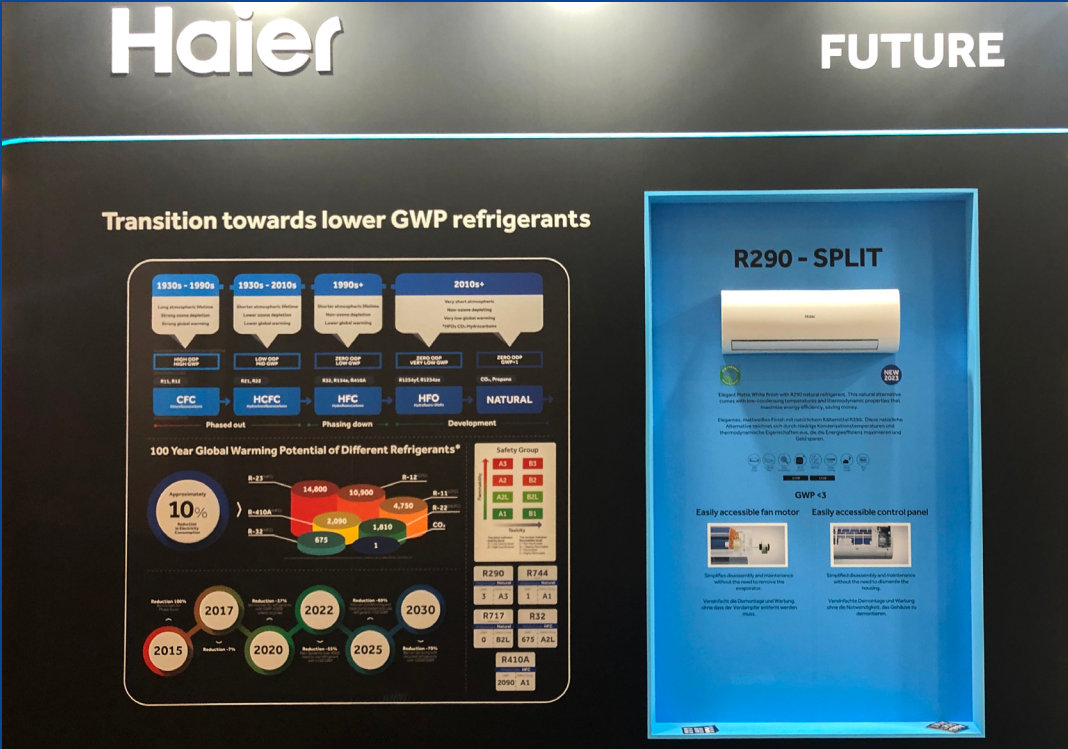
Analysis by the Gesellschaft für Internationale Zusammenarbeit (GIZ), the German government agency for implementing international cooperation projects, has debunked myths related to the burdens of switching production lines from HFCs to low-GWP refrigerants such as hydrocarbons in split air conditioners. The study focuses on split ACs below 12 kW and investigated models already available on the market listed on the Eurovent and Keymark databases.⁷ Some of the study's key findings related to cost for reversible

air-conditioning systems (RACS) for domestic use employing low-GWP refrigerants are:

- A switch from HFC-410A to propylene (R-1270), another natural refrigerant, is likely to be cost-neutral.
- A switch from HFC-32 to R-290 would likely incur a small incremental material cost (less than €10/US\$10.05).
- A switch from HFC-410A to propylene (R-1270), another natural refrigerant, is likely to result in a cost benefit.
- A switch from HFC-32 to R-1270 would likely incur a negligible incremental material cost (less than €5/US\$5.03).

The study specifies that “in all cases, the variation would be less than 1% of the RACS retail price ... These also neglect the lifetime costs associated with re-charging or [topping-up] systems, which if accounted for, would yield further cost advantages for R-290 and R-1270 RACS.”⁸

Picture 1: Haier single split unit charged with R-290 showcased at Chillventa 2022



Source: [Hydrocarbons21.com](https://hydrocarbons21.com), Haier

Policy Landscape

The alignment between REPowerEU and the stricter EU F-gas Regulation

REPowerEU is an overarching strategy that lists multiple efforts in the short and medium term to decouple EU economies from reliance on imported fossil fuels from Russia.⁹ The plan is a reaction to the geopolitical turmoil caused by Russia’s waging war on Ukraine’s soil, triggering extreme volatility in global energy markets. The European Union has relied on Russia’s abundant oil and gas resources to satisfy its energy-demanding industry and, most relevant for this report, heating needs.

Heat pumps are considered a source of renewable heating and cooling, using the surrounding environment as a heat source and electricity to deliver the needed temperature. Heat pumps are therefore a key piece of this grand strategy. The Commission reports that there were almost 17 million heat pumps installed in Europe at the end of 2021.¹⁰

The Commission’s REPowerEU plan includes the speedy deployment of heat pumps to reduce the need to import natural gas from Russia, used widely in Europe to meet the heating needs of building owners and decarbonise the heating infrastructure across Europe.

The strategy envisages a doubling of the pace of deployment to install hydronic heat pumps in an additional 10 million buildings in the next five years and 30 million by 2030.

Hydronic heat pumps are a relatively easy switch from fossil fuel-powered boilers for buildings with radiators or underfloor heating systems. In Europe, hydronic systems for domestic uses are normally below 12 kW of heating capacity, in accordance with the relevant Ecodesign provisions, and are charged frequently with the refrigerants listed in the table 1. This technology has a usual leakage rate around 3.5% per unit over one year of operation, on top of a 0.5% leakage rate during the first fill of the refrigerant,¹¹ exacerbating potentially both global warming by emitting high- and medium-GWP refrigerants as well as PFAS and TFA-forming fluorinated refrigerants when they are used.

According to industry analysis in 2019, the great majority of heat pumps installed and sold in Europe rely on HFC-410A, a high-GWP blended refrigerant which is also composed of fluorinated substances labelled as PFAS.¹³

However, as table 1 shows, industry is already installing heating systems relying on lower-GWP refrigerants, such as R-290, HFC-32 and HFO-513, in European homes. This is reducing the need to secure quotas from the EU F-gas HFC phase-down system and allowing lawmakers to introduce stricter bans on the GWP of refrigerants to yield climate benefits.

Table 1: Refrigerants most frequently used in hydronic systems (air-to-water) in Europe

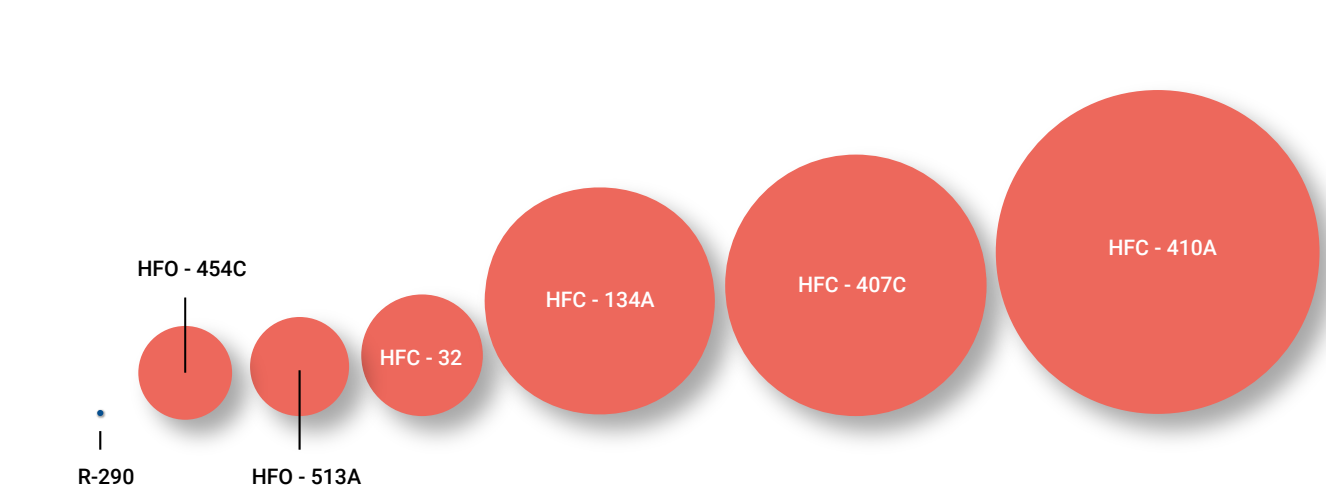
Refrigerants	Composition	GWP 20 years	GWP 100 years	PFAS - OECD/ECHA definition	TFA creation ¹²
R-290	Pure refrigerant	0.072	0.02	no	no
HFO-454C (*)	21.5% HFC-32 78.5% HFO-1234yf	579	166	yes, due to HFO-1234yf	HFO-1234yf up to 100%
HFO-513A (*)	56% HFO-1234yf 44% HFC-134a	1,700	600	yes, due to HFO-1234yf and HFC-134a	HFO-1234yf up to 100% HFC-134a up to 20%
HFC-32	Pure refrigerant	2,690	771	no	No
HFC-134a	Pure refrigerant	4,140	1,530	yes	HFC-134a up to 20%
HFC-407C (*)	53% HFC-134a 25% HFC-125 23% HFC-32	4,100	1,700	yes, due to HFC-134a and HFC-125	HFC-134a up to 20%
HFC-410A (*)	50% HFC-32 50% HFC-125	4,400	2,100	yes, due to HFC-125	No

Notes to the table:

- Single component refrigerants GWP values are sourced from Smith, C. et al. (2021). The Earth’s Energy Budget, Climate Feedbacks, and Climate Sensitivity Supplementary Material. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR6). Available online at: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter07_SM.pdf
- Blended refrigerants are indicated with (*) and their corresponding GWP values are sourced from ATMOSphere X FGN, 2021. Impact of Refrigerants Fact Sheet #1 (V.1.1.) - Real GWP: 20 years vs. 100 years. Available online at: https://atmosphere.cool/fact_sheets/impact-of-refrigerants-fact-sheet-1-v-1-1/
- Refrigerants are defined as PFAS when they meet the definition proposed by the Organisation of Economic Cooperation and Development and the one proposed by the five European chemical agencies submitting the PFAS Universal Restriction Proposal. The definitions are available online at: <https://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/terminology-perand-polyfluoroalkyl-substances.pdf> and <https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e18663449b>
- TFA-forming values are sourced from Table A.7 in Behringer, D. et al. (2021). UBA study 73/2021 Persistent degradation products of halogenated refrigerants and blowing agents in the environment: type, environmental concentrations, and fate with particular regard to new halogenated substitutes with low global warming potential. Available online at: https://www.umweltbundesamt.de/sites/default/files/medien/5750/publikationen/2021-05-06_texte_73-2021_persistent_degradation_products.pdf
- (*) GWP values identified according to the formula present in Annex VI of the EU F-gas Regulation proposal. Available online at: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022PC0150> . Pure refrigerant values are sourced from the IPCC AR6 as reported above.

Source: European Commission EU F-gas Revision Impact Assessment Analysis, own analysis

Figure 2: GWP 100 year of refrigerants most frequently used in hydronic systems (air-to-water) in Europe



Source: IPCC AR6 (2022), own analysis

Following this market development, the European Commission has strengthened the HFC phase down and introduced targeted bans in their proposed revision to provide the industry with market clarity on the need to serve the market with low-GWP refrigerants. As shown in figure 2, the European Commission-proposed HFC phase down, labelled “proportionate action” due to its mild costs and potentially greater benefits for industry and society, plans a remaining 23.6% permitted HFC quota on the market as of the entry into force of the revised regulation, estimated for 2024. A reduction down to 10% is then proposed as of 2027, reaching an available amount of about 3% as of 2048.

In addition, the European Commission’s proposal includes the addition of bans targeting the heat pump and air-conditioning sector, relying, once again, on the market maturity of systems using low GWP. More specifically, the Commission support the following restrictions:

As of 1 January 2025, plug-in room and other self-contained air-conditioning and heat pump equipment are restricted if they contain any fluorinated GHG above 150, and single split systems containing less than 3 kg are restricted if they contain any of the fluorinated greenhouse gases listed in Annex I with a GWP above 750.

Two years later, other capacities in the split sub-sector will be addressed: as of 1 January 2027, new systems with a rated capacity of up to 12 kW are prevented from accessing the common market if charged with a refrigerant above 150.

Similarly, the same systems delivering capacities higher than 12 kW are barred from the market if charged with fluorinated GHG refrigerants with a GWP above 750.

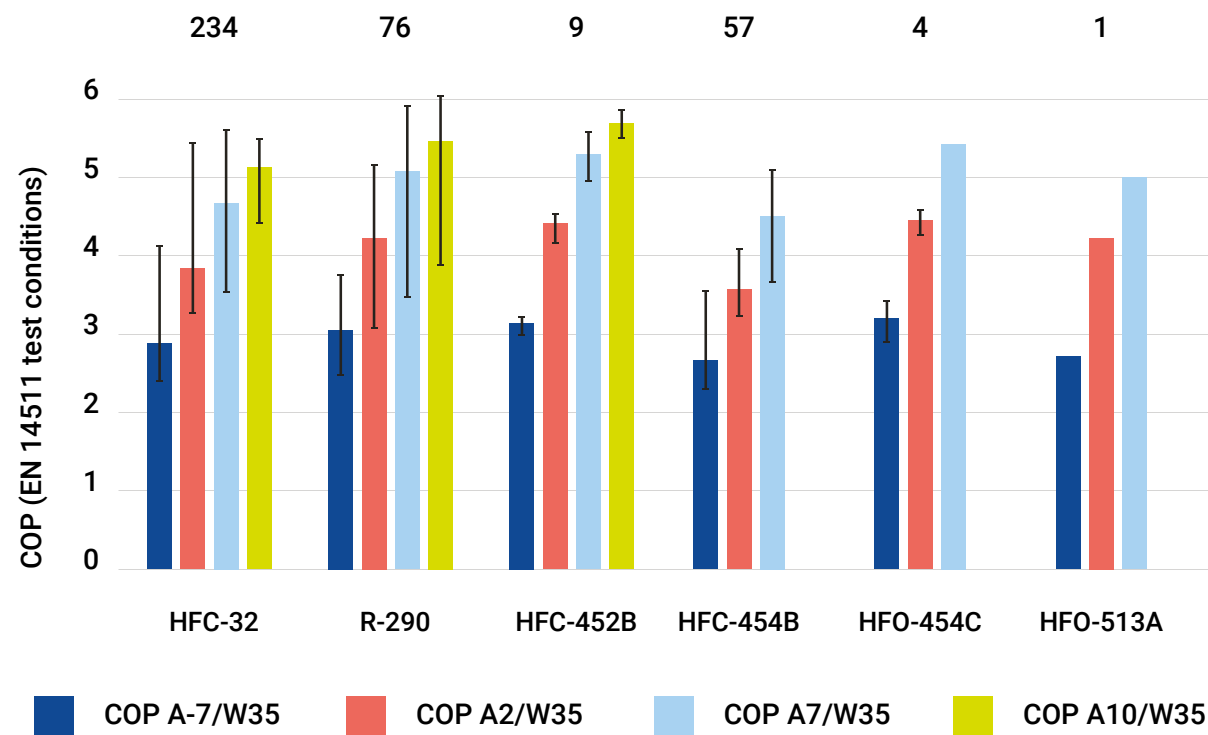
These measures, alongside the general decoupling from high GWP fluorinated greenhouse gases of the European RACHP sector, will lead to a reduced lock-in of f-gases into European heating systems, ensuring their deployment with alternatives.

In its analysis, the Commission’s Directorate- General for Climate Action argues that these measures are synergistic with the objectives of REPowerEU. It says that demand for HFCs for different heat pumps is already declining, with models estimating a reduction in 2030 down to 25% of 2020.¹⁴

This is in relation to the marketing of low GWP solutions, among which R-290 ensures compliance and is the least costly option for a refrigerant in light of more stringent requirements from the revised EU F-gas Regulation.

As reported in figure 3 from the International Energy Agency Heat Pump Annex 54 Working group, efficiencies are similar among medium and low GWP-charged heat pumps already present on the German market. Besides R-290 and HFC-32, with a GWP 100 years (AR6) of 0.02 and 771, respectively, other marketed options in Germany are HFC-452B, HFC-454B, HFO-454C and HFO-513A, with a GWP 100 years of 710, 490, 148 and 600, respectively.¹⁶

Figure 3: BAFA listed air-to-water heat pumps, COP and GWP of refrigerants

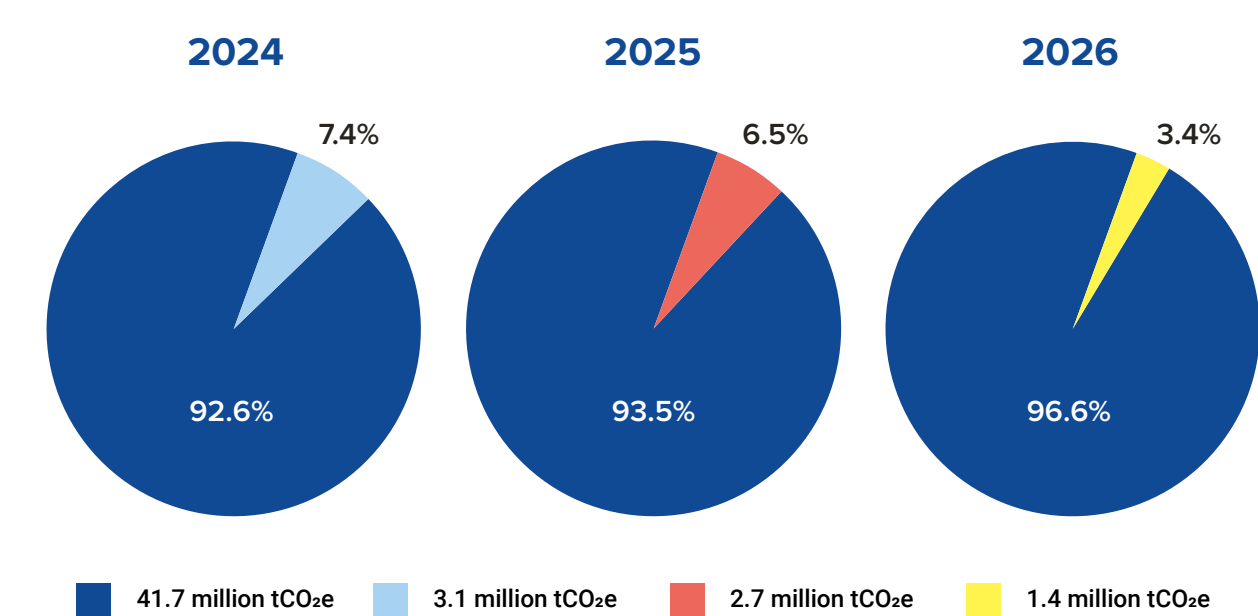


Note to infographic: numbers on top refer to the number of models with the given refrigerant present in the BAFA database. Values calculated for these air-source heat pumps with incoming air at -7°C, 2°C, 7°C and 10°C and the flow out to the heating system is 35°C. Source: Heat Pumping Technology Collaboration Programme IEA (2022)

The Commission has stress-tested the HFC quota system as proposed in the proportionate action scenario against the objectives of REPowerEU. It found that the additional amount of HFCs can be displaced by the higher penetration rate of systems with medium and low GWP refrigerants, such as R-290, requiring less quotas from the system. The Commission notes that the demanded amount of HFC for heat pumps is small compared to the overall built-in buffer of available quotas (about 12% in 2030 and 5% in 2040),¹⁷ further

reporting that, even if considering a delay of the entry into force of the relevant ban at 150 GWP in 2027, the growth spurred by REPowerEU would require an additional annual demand for HFCs by around 3.1, 2.7 and 1.4 million tCO₂e in 2024–2026.¹⁸ This is a small amount compared to the quota available under the HFC phase down proposed by the Commission which makes 41.7 million tCO₂e available for each year between 2024 and 2026.

Figure 4: Additional quotas required for heat pumps to meet targets of REPowerEU



Assumptions of the infographics: Prohibition for stationary heat pumps with a rated capacity of up to 12 kW with F-gases with a GWP of 150 or more would start in 2027. Under this scenario, additional growth needed would increase the estimated annual demand for F-gases by around 3.1, 2.7 and 1.4 million tCO₂e in the years 2024-2026. Source: European Commission (2022)

On the other hand, direct systems such as some kinds of air-to-air systems, are also experiencing growth in Europe as they show high efficiency and are normally cheaper to purchase than indirect systems. Market data from 2021 shows that the adoption of this type of technology is high in Nordic countries as well as in Southern Europe, where these systems are mainly used in cooling mode.²⁰ Air-to-air systems are therefore a growing segment within the heat pump market, and their transition to medium or low GWP refrigerants is well underway, with both HFC-32 and R-290 candidates to replace HFC-410A in the near future. HFC-32 has become the preferred choice for this kind of system in roughly six years since its initial marketing in 2013, reaching over 80% of the market share in some European countries in 2019.²¹

Although HFC-32 is becoming the preferred option for air-to-air systems, a global switch to R-290-charged split air-to-air systems could prevent up to 1.2°C of global warming by the end of this century. In addition, a global switch to R-290 in this technology would palliate the estimated leakage factor for this kind of systems, amounting to 5% during yearly operation and 3.5% during the first filling.²²

Table 2: Refrigerants frequently used in direct expansion systems in Europe

Refrigerant	GWP_20 years	GWP_100 years	PFAS - OECD/ECHA definition	Composition	TFA creation ²³
R-290	0.072	0.02	no	Pure refrigerant	no
HFC-32	2,690	771	no	Pure refrigerant	no
HFC-410A (^)	4,400	2,100	yes, due to HFC-125	50% HFC-32 50% HFC-125	no

Notes to the table:

- Single component refrigerants GWP values are sourced from Smith, C. et al. (2021). The Earth’s Energy Budget, Climate Feedbacks, and Climate Sensitivity Supplementary Material. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR6). Available online at: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter07_SM.pdf
- Blended refrigerants are indicated with (^) and their corresponding GWP values are sourced from ATMOSphere X FGN, 2021. Impact of Refrigerants Fact Sheet #1 (V.1.1.) - Real GWP: 20 years vs. 100 years. Available online at: https://atmosphere.cool/fact_sheets/impact-of-refrigerants-fact-sheet-1-v-1-1/
- Refrigerants are defined as PFAS when they meet the definition proposed by the Organisation of Economic Cooperation and Development and the one proposed by the five European chemical agencies submitting the PFAS Universal Restriction Proposal. The definitions are available online at: <https://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/terminology-perand-polyfluoroalkyl-substances.pdf> and <https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e18663449b>
- TFA-forming values are sourced from Table A.7 in Behringer, D. et al. (2021). UBA study 73/2021 Persistent degradation products of halogenated refrigerants and blowing agents in the environment: type, environmental concentrations, and fate with particular regard to new halogenated substitutes with low global warming potential. Available online at: https://www.umweltbundesamt.de/sites/default/files/medien/5750/publikationen/2021-05-06_texte_73-2021_persistent_degradation_products.pdf

Source: European Commission EU F-gas Revision Impact Assessment Analysis, own analysis

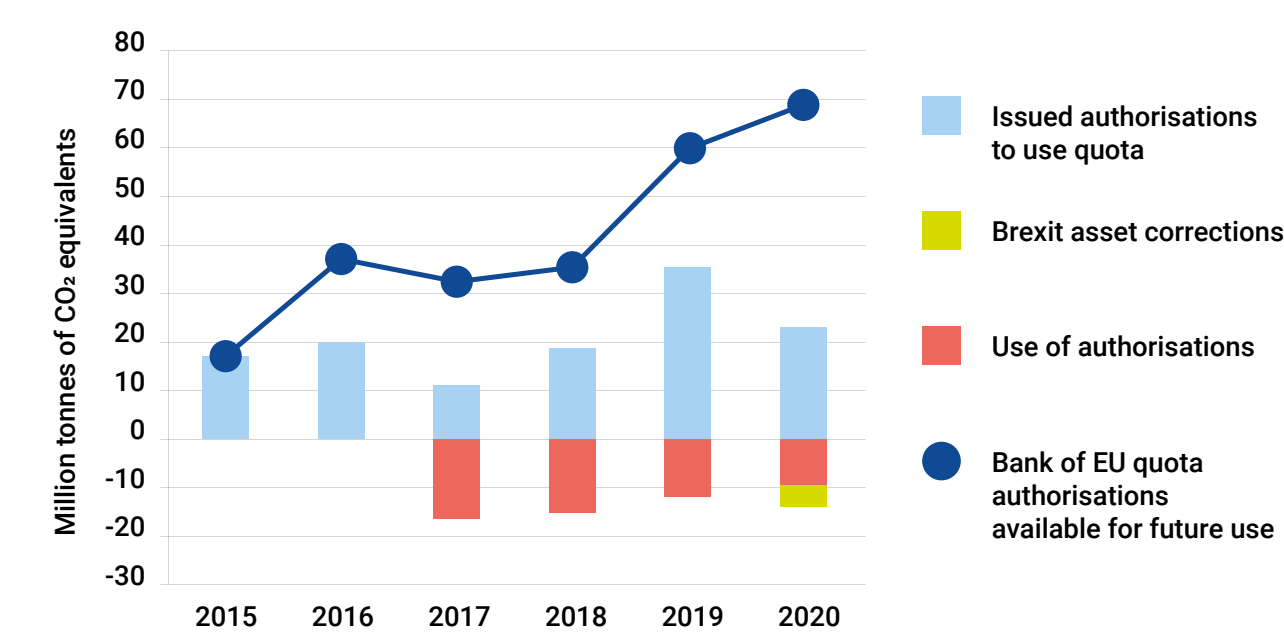
Fears of lack of availability of quota seem unfounded in heat pumps, as the GWP of the main refrigerant HFC-32 is a quarter of the previously used HFC-410A, thereby requiring a proportionally three-quarter smaller quota from the system. The growing penetration of R-290 in this sector, as well as other non-HFC refrigerants in others, will not consume any quota.

These fears can further be assuaged by the large quantity of banked authorisations for imports of HFC-containing equipment available, with stakeholders holding unused quota for a value of about 70 million tCO₂.

According to the latest report by the European Environmental Agency, the amount of banked EU quota authorisations has decreased in 2021 to 60 MtCO₂.²⁴ This underlines the constant difference between the used authorisations (a bit more than 10 million) and the banked amount.

In the unlikely event of market disruption or a lack of available refrigerants – something that has not occurred in the past eight years – the EU F-gas Regulation has built in flexibility which enables exemptions for specific applications from the phase down and grant delays before the entry into force of bans under Articles 15(4) and 11(3), respectively.²⁵

Figure 5: Bank of authorisations for RACHP equipment imports



Source: European Environmental Agency (2021)

The EU F-gas Regulation revision: decoupling the RACHP from fluorinated greenhouse gases.

Eliminating HFC emissions has long been considered a low-hanging fruit for climate action with national, regional and international phasedowns being introduced over the past decade.

In that time, the use of natural refrigerants has grown and expanded to more applications. This has been attested to on multiple occasions. For instance, Professor Armin Hafner from the Norwegian University of Science and Technology provides a clear overview of the natural alternatives in different applications, listing applications not requiring f-gases in figure 6.²⁶

The same findings are highlighted by the European Commission’s consultants working on the revision of the EU F-gas Regulation, listing 30 RACHP specific applications that can be deployed today with alternatives to fluorinated substances.²⁷ The same results are reached by the Norwegian Chemical Agency working on the PFAS Universal Restriction Intention.²⁸

The technology to decouple RACHP sectors from f-gas refrigerants is advanced and has proven efficient, safe and cost effective.

The opinion drafted by the Rapporteur for the European Parliament MEP Bas Eickhout (the Greens/EFA) is based on these premises.²⁹ It aims to further reduce the global warming level of acceptable refrigerants and directly leapfrog to non-f-gas refrigerants in applications where this is technically and economically feasible.

As the rapporteur for this legislation, Eickhout is planning to completely eliminate HFC quotas as of 2050 in line with Europe’s climate neutrality objectives.³⁰

Figure 6: Where are natural alternatives to F-gases used today?

	CO ₂ / R744	NH ₃ / R717	HC	H ₂ O / R718	Air / R729
Domestic applications	★		★	★	
Commercial refrigeration	★	★	★	★	
Industrial refrigeration and heat pump systems	★	★	★	★	★
Water and space heating heat pumps	★	★	★		
Chillers	★	★	★	★	
Vehicle air conditioning	★		★		★

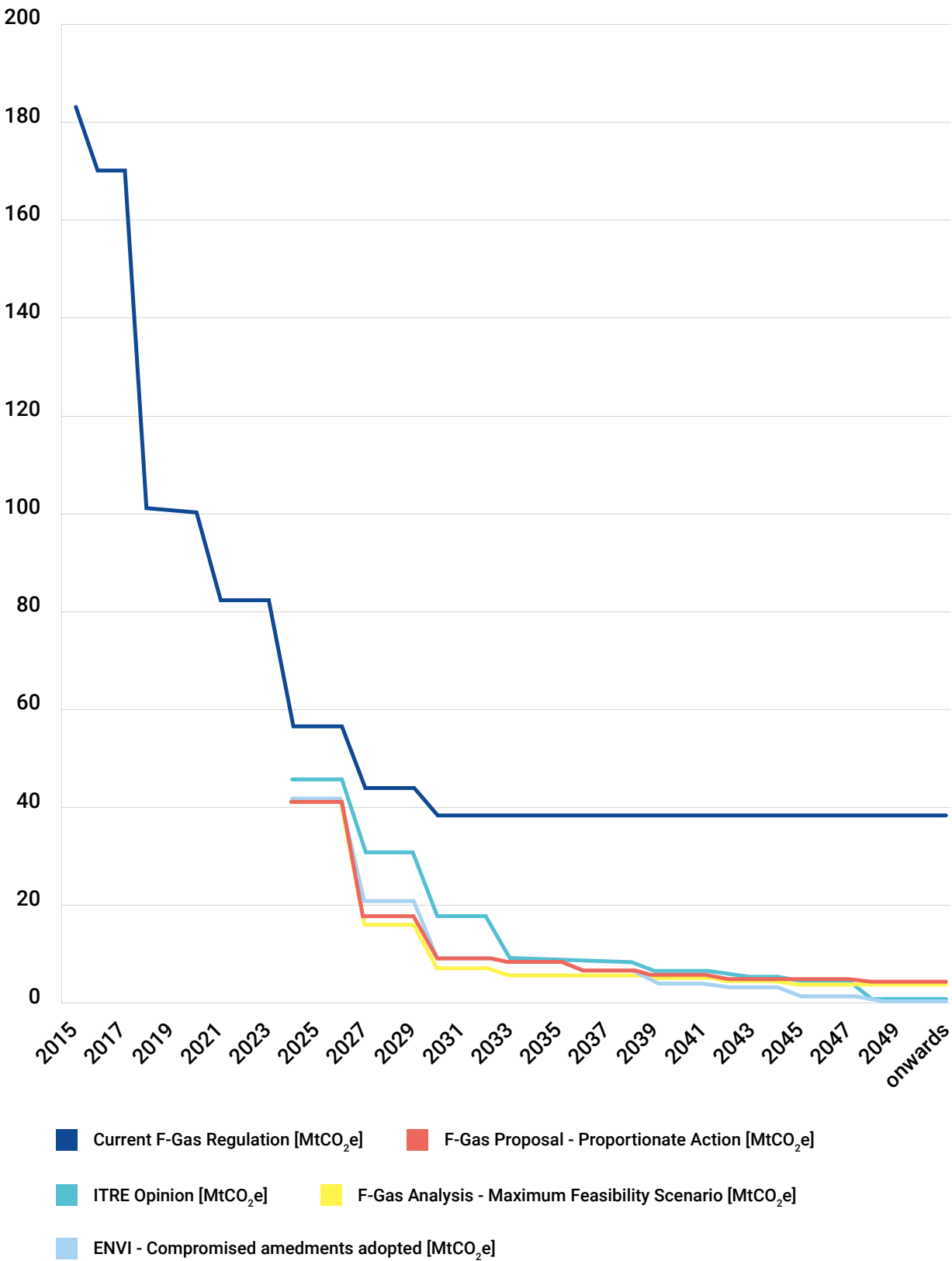
Source: Hafner, A., Ciconkov, R. (2021). Current state and market trends in technologies with natural refrigerants. 9th IIR Conference: Ammonia and CO₂ Refrigeration Technologies, Ohrid, 2021; European Commission (2022) EU F-gas Technical Annexes to the Revision; Norwegian Chemical Agency (2022) Report Summary F-gas Uses.

He is also looking ahead to the upcoming Universal Restriction Intention on per- and polyfluoroalkyl substances, or PFAS, which affects fluorinated substances used as refrigerants, whether of high, medium or low GWPs, according to their chemical composition.³¹

“In order not to repeat mistakes from the past, the rapporteur proposes to move several (sub)sectors, such as refrigeration, air conditioning, heat pumps and switch-gear, to F-gas free alternatives”, writes Eickhout in its opinion. He has proposed a ban on plug-in and self-contained heat pumps and air-conditioning applications that rely on fluorinated substances as of 2025. For split systems, he precludes fluorinated substances in systems with up to 3 kg of refrigerant charge and below 12 kW capacity as of 2025 and above 200 kW as of 2027.³²

In the recently adopted text by the Environment, Public Health and Food Safety Committee (ENVI), Eickhout managed to maintain most of the proposed measures targeting heat pumps, reaching a political agreement on a ban on fluorinated greenhouse gases contained in plug-in room, monoblock and other self-contained air conditioning and heat pump equipment as of 1 January 2026, as well as stationary split air-conditioning and split heat pump equipment containing fluorinated greenhouse gases as of 1 January 2027 and 2028, except for systems with a capacity between 12 kW and 200 kW allowed to used fluorinated refrigerants up to 750 GWP.³³

Figure 7: Different HFC phase down proposed during negotiations



Notes to the figure 7 infographics: Y-axis: MtCO₂e, X-axis: timeline
Sources: European Commission, European Parliament. Own analysis.

What is the cost difference between a natural refrigerant-based heat pump and one with fluorinated refrigerants?

Comparative analysis from the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) focuses on the cost difference of systems and components of hydronic heat pumps charged with hydrocarbons and other low-GWP refrigerants against high- and medium-GWP fluorinated greenhouse gases.³⁴

Compared to HFC-410A domestic heat pumps, the quantity of material for systems relying on R-290 and R-1270 is similar, with differences of a few additional euros (mainly due to the heat exchanger). For heat pumps located outdoors, the study finds that there is no cost difference in terms of systems, debunking an industry myth of increased costs to meet safety standards. On the other hand, applying risk mitigation concepts (RMCs) to indoor heat pumps can increase an installations' cost from a few euros to several tens of euros. The cost effectiveness of switching to R-290 and R-1270 can still be favourable, depending on the RMC deployed and the time assessment used. These two refrigerants allow for emissions reductions achieved in parallel with lifetime cost reductions, particularly when the cost of refrigerant is taken into account. Use of HFO-1234yf normally results in a cost increase, and cost-effectiveness of R-290 and R-1270 is usually around €20 – 30 per tCO₂e.

The study also addresses the viability of using refrigerants below 150 GWP in domestic heat pumps across Europe. It highlights that for the entire capacity range of domestic heat pumps, natural refrigerants such as R-290 and R-1270 can provide at least a SCOP of 6.5 and a supply temperature of 35°C – parameters included in Ecodesign and Energy Labelling measurements. These results can be reached within the refrigerant charge limits imposed by the updated standard IEC 60335-2-40: 2022 for capacities of a few kilowatts. For those with greater capacities, RMCs need to be designed, although these would also be needed for systems charged with other flammable refrigerants including HFC-32, depending on the location of the system.

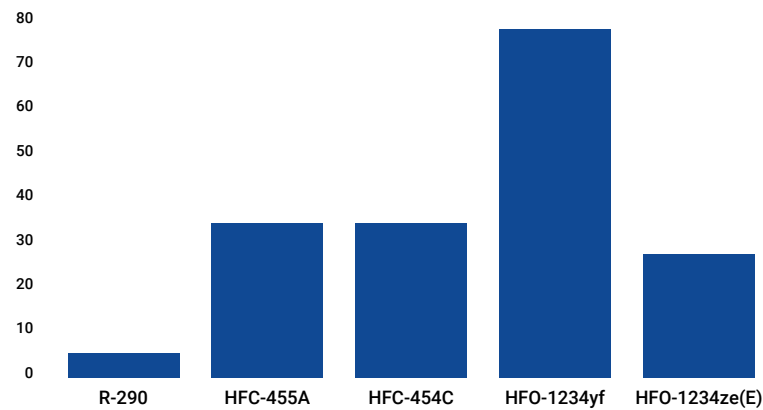
The report also underlines that any additional emissions related to increased material used to switch to low-GWP refrigerants is negligible compared to emissions caused by the use of refrigerants above 150 GWP. The study includes industry stakeholder information on current developments in the design of systems, especially on R-290 systems which are showing higher capacities with reduced refrigerant charges thanks to component efficiencies.

The findings of this report are confirmed by the data gathered during the outreach phase of this report: the OEMs approached for this report have indicated slight cost differences for components used in systems relying on fluorinated refrigerants and R-290. Twenty percent of respondents pointed to still low and non-standardized production and a limited number of suppliers as the cause of slightly higher cost for certain components.

However, industry reports that with the mass production of systems and components relying on natural refrigerants, these cost premiums are bound to disappear. Cost increase can also be leveraged by industry through dedicated long-term contracts.³⁵ These current additional costs, however, are likely to be counterbalanced by the continuous reliance on HFCs, whose cost is to increase due to the phase down in force at European and global level.

On the other hand, the price of natural refrigerants is considered stable and lower than that of HFCs. In 2020, the price of propane was approximately equal to 5 €/kg. The price of HFO refrigerant blends such as HFC-455A or HFC-454C was about 34 €/kg. In the case of pure HFO, the price varies considerably: for example, the price of HFO-1234yf was about 77 €/kg and the price of HFO-1234ze(E) was about 27 €/kg. These differences in prices can have a significant impact on the cost of a heat pump, taking into account the quantity of refrigerant used in all the units of one series.³⁶

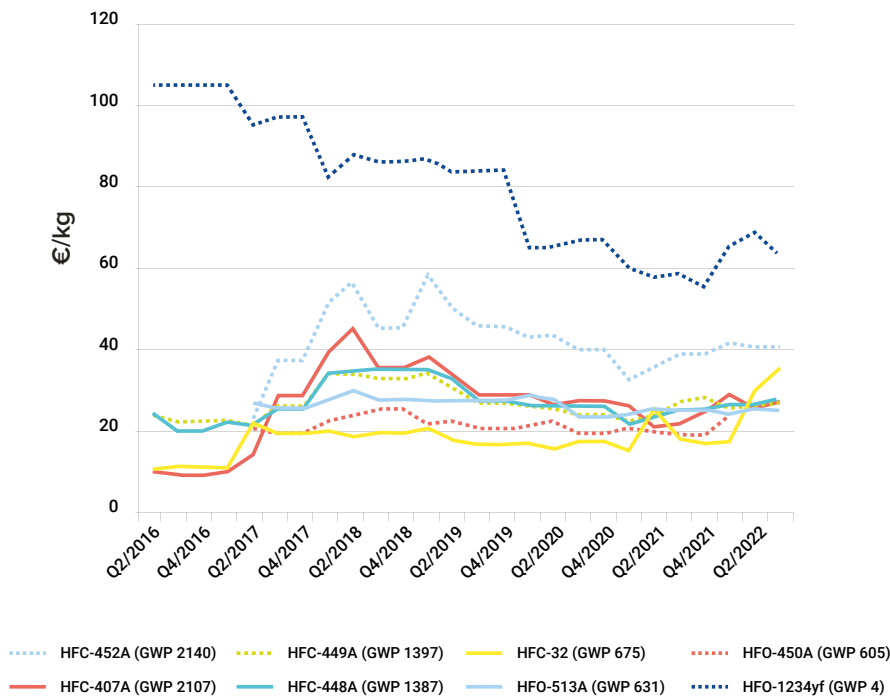
Figure 8: Refrigerants' price - €/kg



Source: Carel (2020)

Figure 9 shows the development of purchase prices for some fluorinated and blended refrigerants up to the second quarter of 2022.³⁷ Compared to Q2/2022, the Q3 purchase price for HFC-32 increased by 18% on the service company level.

Figure 9: Development of purchase prices of some fluorinated refrigerants



Source: Öko-Recherche (2022)

Using natural refrigerants to future-proof Europe’s heat pump industry

The production of fluorinated gases has been steadily decreasing in the European Union since 2007, according to data from the European Environmental Agency.³⁸ While production of HCFOs and HFOs was not reported, figure 10 below clearly shows that the European production of all f-gases is declining, both in terms of weight and MtCO₂e, regardless of saturated or unsaturated fluorinated substances.

The raw material used to manufacture fluorinated gases, fluorspar, has been listed as a critical raw material by the Joint Research Centre since 2020. It is reported that China provides around 65% of the global market. Fluorspar is a key precursor for the production of fluorinated gases. 25% of the fluorspar used in the EU is sourced from Mexico, with very little internal production in the European Union.³⁹

It comes, therefore, as no surprise that most of the bulk imports of HFCs are sourced from China, as Figure 11 shows. The EU’s dependence on foreign supply chains could possibly undermine the availability of fluorinated gases especially as global availability of HFCs is reduced under the Kigali Amendment. Continued reliance on F-gases risks locking the entire RACHP industry into unstable and increasingly strained supply chains.

The European Commission report assessing the risk in the supply chains of critical technologies such as heat pumps, includes reference to refrigerants for the first time in the 2022 edition. The report shows that most fluorinated refrigerants are marketed by Chinese companies, such as Dingyue and Sinochem, and from American ones, such as Chemours, DowDupont and Honeywell. Other companies producing f-gases are Asahi Glass and Daikin, headquartered in Japan; SRF from India; and Koura, a Mexican company.⁴⁰

High GWP refrigerants have experienced price hikes in recent years, due to restrictions put on their marketing in Europe and at global level. This has especially proved true on the European market, due to the HFC Phase down introduced by the EU F-gas Regulation.⁴¹ In addition, new refrigerants such as most HFOs are still protected by patents in legislation across the world, hence becoming more difficult to rely upon by end-users and eventually costing more.⁴²

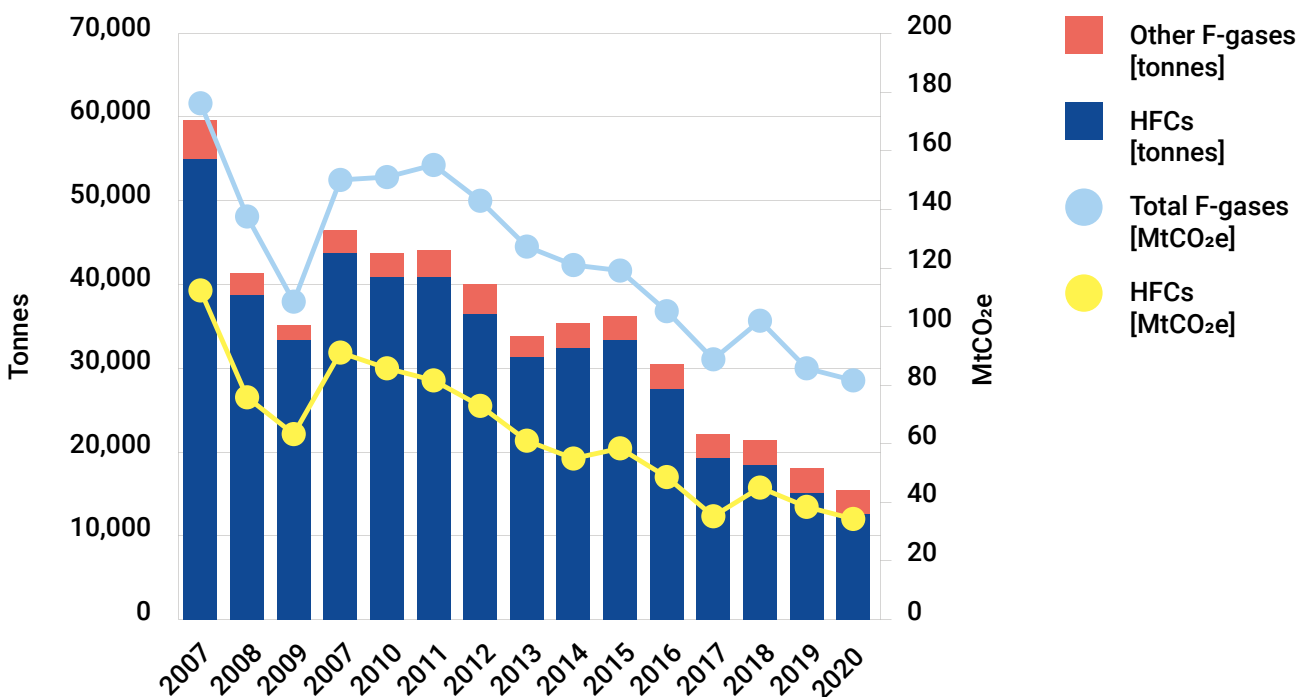
Natural alternatives, on the other hand, being in most part by-products of other industrial activities operating in Europe, have been widely available on the European market.⁴³ As unpatented industrial gases, their prices are usually low compared to fluorinated gases.⁴⁴

According to the European Commission’s Impact Assessment, higher ambition in the EU F-gas Regulation would have positive economic implications, result in a GDP increase, reduce electricity use and trigger higher consumption in the EU27, as savings from energy bills are invested in other goods and services.⁴⁵ Other positive spillovers would include greater investments in

R&D and increased innovation by EU companies. This will support European competitiveness against other countries in light of the global HFC phase down taking place under the Kigali Amendment.⁴⁶ Moreover, the Commission estimates that higher ambition would not create strong regional differences (between EU North and South) nor significant cost for private consumers, sustaining the long term job creation of the sectors involved in this transition.

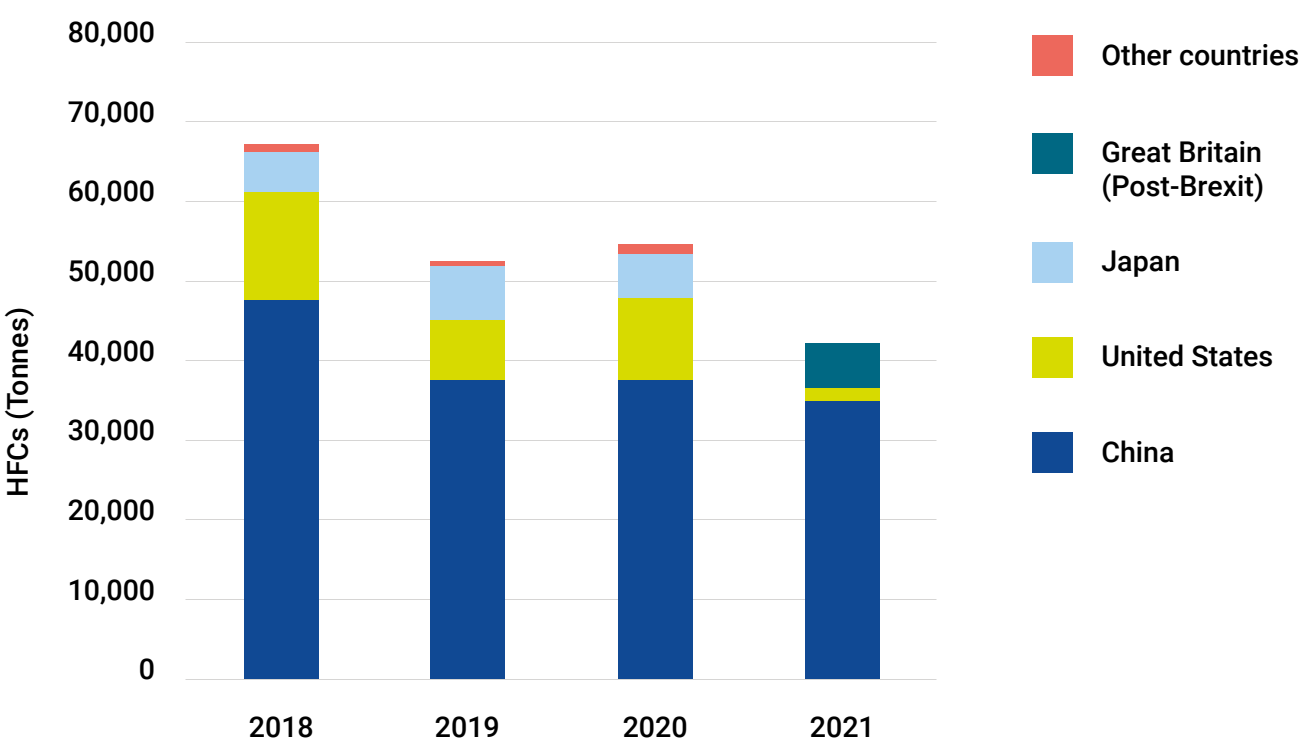
Another department within the Commission services has highlighted the same messaging regarding heat pumps. The Joint Research Centre, working with the Clean Energy Observatory and DG Energy, have come to the conclusion that “the transition to greater use of natural refrigerants can be an opportunity for the sector to differentiate itself with respect to non-EU competitors and to reduce dependence on non-EU suppliers”,⁴⁷ mainly due to the swifter-than-global action of the European Union in tackling these climate-altering substances and steering industry transition towards more climate- and environment-aligned harbours.

Figure 10: EU production of fluorinated gases



Source: European Environment Agency (2022)

Figure 11: Origin of bulk HFC imports (tonnes)



Source: European Environment Agency (2022)

More and more refrigerants are coming onto the market, in particular a multitude of mixtures with HFOs as one of the components.

These aim to replace specific refrigerants and applications with lower GWP versions to meet ever-decreasing legal thresholds. There are currently over 60 different refrigerants and mixtures available on the market, but the range is constantly changing.⁴⁸ Any attempt to list them would provide an incomplete picture. Industry has long reported that the ever-changing mix of synthetic fluorinated refrigerants is translating into time, R&D and financial burdens, hindering the clarity of the market.

The scientific community is also supporting this transition away from fluorinated greenhouse gases and PFAS, by standing firmly with the adoption of hydrocarbons in heat pumps. 46 professors from 29 different Universities and engineering departments have recently released a position paper supporting the safe uptake of hydrocarbons in heat pumps, envisioning a transition of 3 to 5 years for air-to-water technologies and 3 to 8 years for indoor heat pumps across the industry.⁴⁹

The issue of HFO and TFA has been discussed for some years and is recently becoming more and more urgent.⁵⁰ It does not only involve HFO-1234yf, which turns 100% into TFA,⁵¹ but also HFO-1234ze, a refrigerant that is under increasing scientific scrutiny for its molar yield of HFC-23 (CF₃CHO),⁵² an f-gas with a GWP 100 year of 14,800,⁵³ whose emissions have reached unexpectedly high levels in recent years.⁵⁴

A comprehensive view of different fluorinated refrigerant’s TFA-forming properties can be found in the table 3 below. TFA has come in the spotlight following multiple reports of increased concentrations in water bodies and rainfall. The NGO Deutsche Umwelthilfe has recently filed a lawsuit recently against the northern German State of Schleswig-Holstein for alleged lack of monitoring of TFA in the Eider river basin.⁵⁵

Further pressure is placed on fluorinated refrigerants, and their degradation products, that match the definition of PFAS⁵⁶ as proposed by the five European chemical agencies submitting the restriction dossier. The proposal⁵⁷ calls for a complete phase out of these substances, derogations provided, eighteen months after the adoption of the restriction. Due to their chemical structure and potential health and environmental impacts, the following refrigerants are included in the proposal restriction: HFC-125, HFC-134a, HFC-143a, HFO-1234yf, HFO-1234ze(E), HFO-1336mzz(E), HFO-1336mzz(Z) and blends containing these gases.⁵⁸

A further investigation into the level of PFAS contamination in Europe has exposed more-than-assumed contamination hotspots across the continent, with Germany and Belgium particularly affected.⁵⁹ Professor Ian Cousins, environmental scientist at Stockholm University compares PFAS pollution to plastic, “in that these chemicals are not degradable, [but] in the case of PFAS it is invisible.”⁶⁰

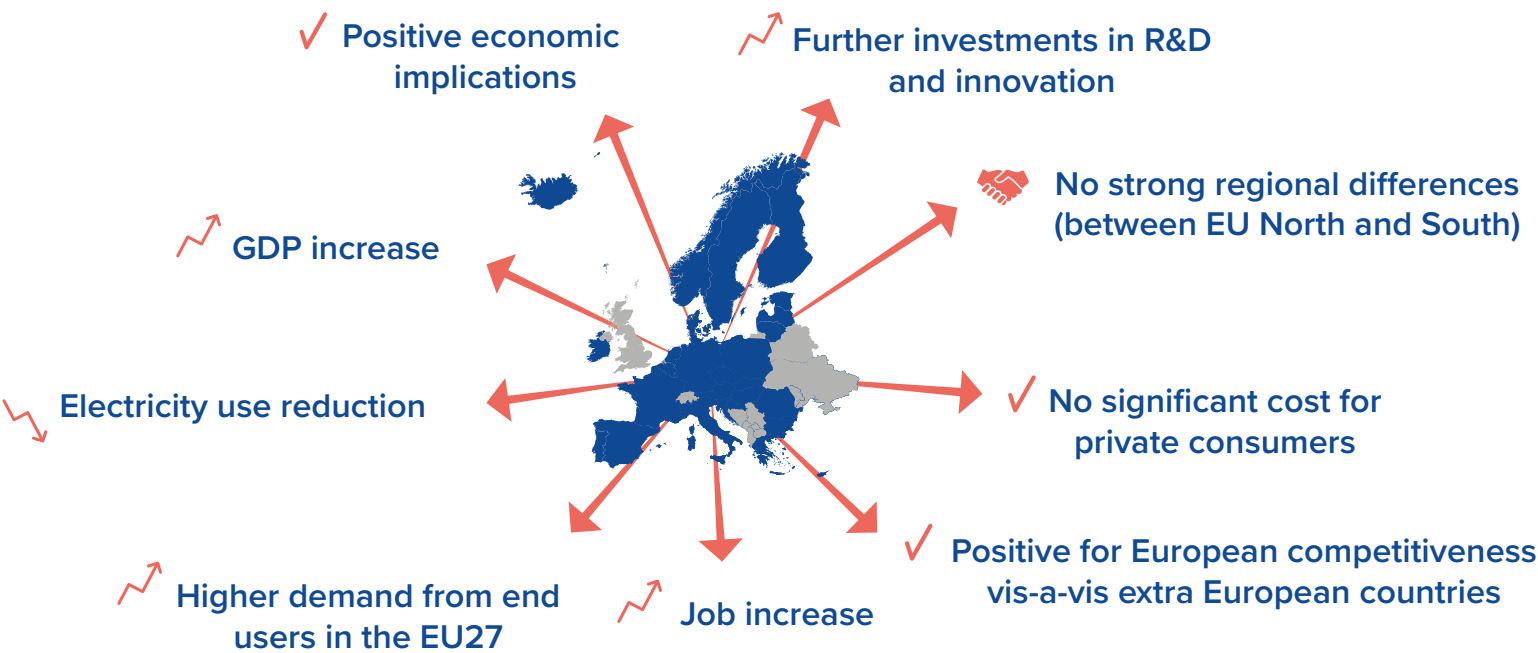
TFA is also included in the proposed restriction due to its chemical formula consisting of a fully fluorinated carbon atom bonded to another one, i.e., CF₃CO₂H.

Table 3: TFA forming fluorinated refrigerants and substances

Substance	TFA molar yield	Source
HFC-234fa	<10%	WMO (2010)
HFC-134a	7–20%	Wallington et al. (1996)
HFC-143a	<10%	Author estimates
HFC-365mfc	<10%	WMO (2010)
HFC-227ea	100%	WMO (2010)
HFO-1234yf	100%	Hurley et al. (2008)
HFO-1234ze(E)	<10%	WMO (2010)
HFO-1336mzz(Z)	<20%	Qing et al. (2018)
HFO-1225ye (E and Z)	100%	Author estimates
HCFO-1233zd(E)	2%	Sulbaek Andersen et al. (2018)
HCFC-1224yd(Z)	100%	Author estimates

Source: Behringer, D. et al. (2021). UBA study 73/2021 Persistent degradation products of halogenated refrigerants and blowing agents in the environment: type, environmental concentrations, and fate with particular regard to new halogenated substitutes with low global warming potential

Figure 12: Some of the macroeconomic effects triggered by higher ambition under the EU Fgas Regulation



Source: European Commission (2022)

Market size today and forecasts to 2030

Heat pumps are expected to contribute significantly to the decarbonisation of heating across a range of different applications, from households to industry.

Making existing buildings more energy-efficient, phasing out fossil fuel-based equipment such as oil and gas boilers and expanding and decarbonising heating networks through district heating are only a few of the goals that heat pumps could support. However, the risk of relying on f-gases in the deployment of millions of these systems world wide risk locking in high- and mid-GWP f-gases that are also PFAS.

Global Market

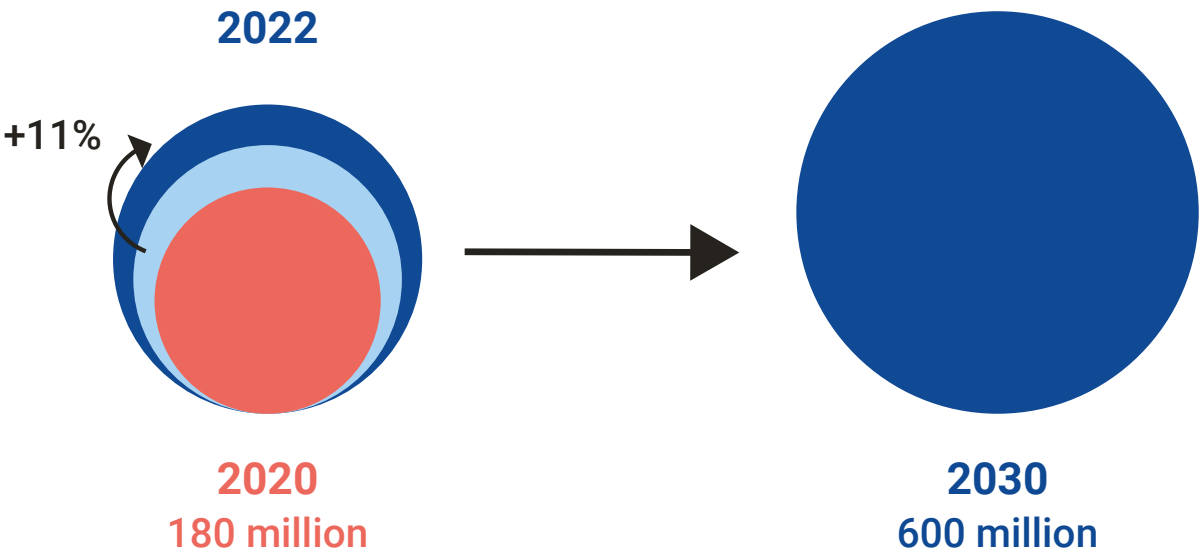
There were 180 million heat pump units used for mainly heating purposes in operation worldwide in 2020.⁶¹ Estimates from the International Energy Agency require this number to rise to 600 million by 2030 to be on track to meet the goal of net-zero emissions by 2050.⁶²

Heat pumps are growing at global level. According to the latest IEA analysis,⁶³ in 2022 the global sales of heat pumps grew by 11%, marking a second year of double-digit growth.

According to JARN's database, the global ATW market in 2021 increased by 19.3% year on year by an additional 4.1 million units.⁶⁴

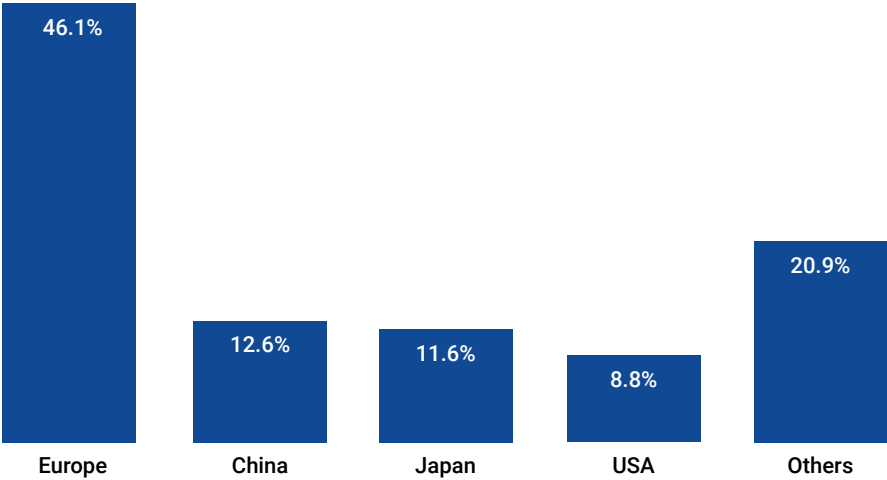
Europe, China and Japan's markets continue to expand; among them, the European one has the most significant growth rate. JARN estimates that Europe, Japan and the United States increased by 46.1%, 11.6% and 8.8%, respectively, in 2021, while China increased by 12.6%. The US market is driven mainly by policy support and incentives, while the Asia-Pacific market is driven by policy and rapid growth in the construction sector. The European market is driven by a mix of policy and market drivers.

Figure 13: Heat Pumps units - global market size



Source: Own elaboration based on EIA data

Figure 14: Estimated market growth rate in different Regions (2021)



Source: Own elaboration based on JARN data (2022)

The impact of supply chain difficulties on the global RACHP market

Heat pumps have few specific material vulnerabilities, regardless of refrigerants. As most clean technologies, they are vulnerable to broader trends such as volatility in metal prices and semiconductor supply.

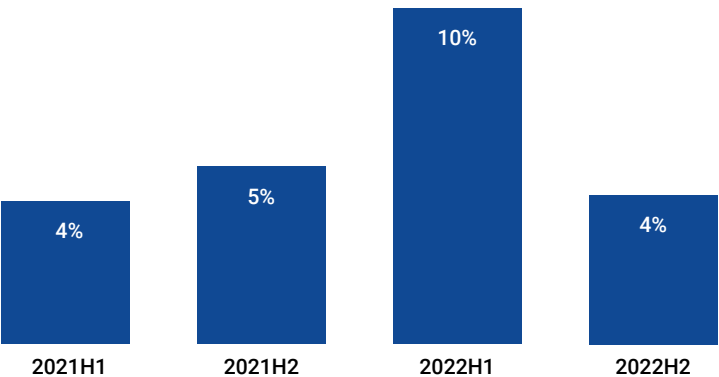
The ecosystem of companies supplying products dedicated to natural refrigerant heat pumps is already well in place. One example is the German manufacturer Rheinmetall which won a €770 million long-term supply contract for propane-based compressors in 2022.⁶⁸

An increase in prices has been observed in the last two years for a large range of products:⁶⁵ from 4% in the first six months of 2021 up to 10% in the same period of 2022.⁶⁶

Manufacturers, who responded to the 2023 Eurovent Market Intelligence's survey, expect that this increase will decelerate in the second part of the year as a sign of stabilisation of the market.

Higher increases ($\geq 10\%$) were found in more technological products such as IT cooling, chillers and heat exchangers compared to others like domestic heat pumps, air filters and chilled beams ($< 10\%$).⁶⁷

Figure 15: Average price increase in Global RACHP



Source: Eurovent Market Intelligence (2023)

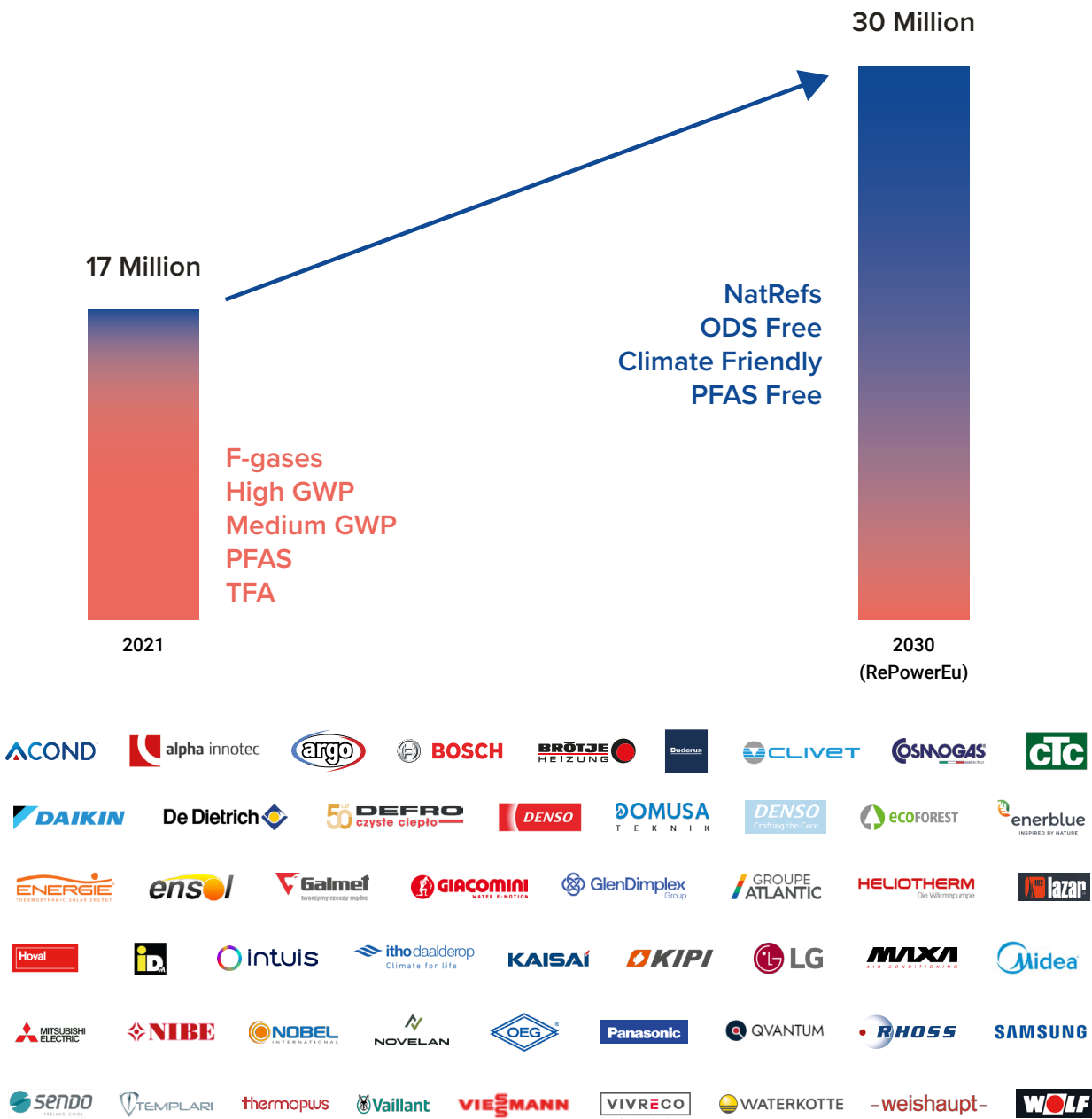
European Market

The European Heat Pump Association (EHPA)⁶⁹ reported a growth in European heat pump sales – hydronic, air-to-air and sanitary hot water – of 38% in 2022: 3 million heat pump units were estimated to be sold⁷⁰ compared with 2.18 million units sold in 2021.⁷¹

The total number of installed heat pumps in the EU was 16.98 million at the end of 2021, covering 21.5% of the heating market.

The REPowerEU measure aims to have 30 million hydronic heat pumps by 2030.⁷² If the average annual sales growth in Europe between 2019 and 2021 of all types of heat pump used for heating (20% per year) is maintained, this target could be achieved.⁷³ The heat pumps now installed in the EU avoid over 44 million tonnes of CO₂ – slightly more than the annual emissions of Ireland⁷⁴ – with the heating sector producing around 1,000 Mt overall.⁷⁵

Figure 16: Air-to-water heat pumps installations in Europe, and companies having natural refrigerants heat pumps in their portfolio



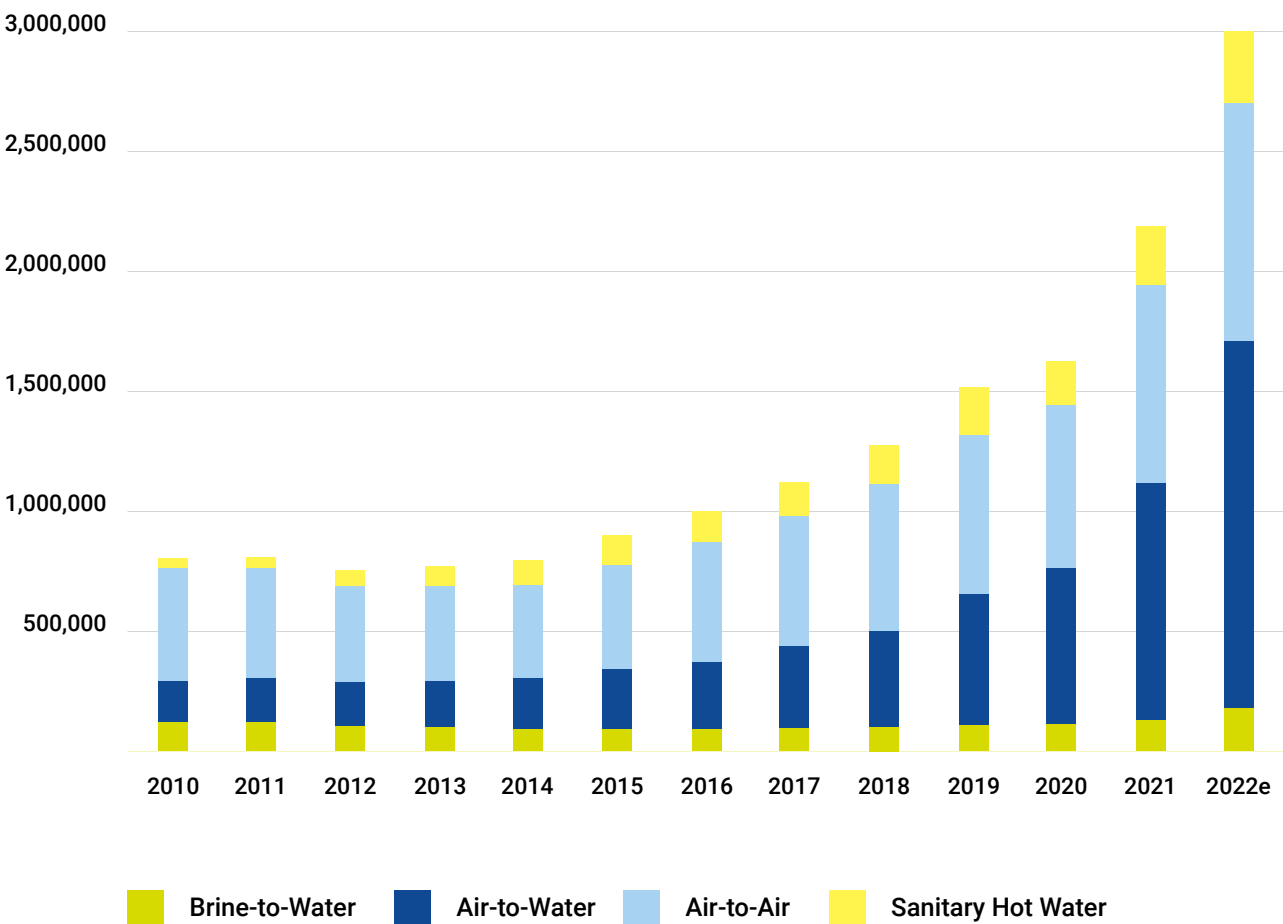
Own elaboration based on European Commission and EHPA data

Analysing the data per type of heat pump, the hydronic sector, whose models are compatible with typical radiators and underfloor heating systems, shows - in the latest IEA analysis - the greatest growth in terms of sales for both 2021 and 2022, jumping by almost 50%.

JARN estimated that the European ATW heat pump market increased by 46% year-on-year in 2021, reaching 1.09 million units.⁷⁶ Of this total, France, the largest ATW heat pump market in Europe, accounted for 35.5%, followed by Italy and Germany.⁷⁷

This technology, which is mainly used for heating, grew particularly fast in Poland (120% growth), Denmark and the Czech Republic (50%), Germany (44%), Belgium (36%) and Sweden (34%). In Hungary, the ATW heat pump market exploded from virtually non-existent to more than 5,000 units sold in 2020.⁷⁸

Figure 17: Heat Pump sales in 21 European markets per type of technology



Source: EHPA (2023)

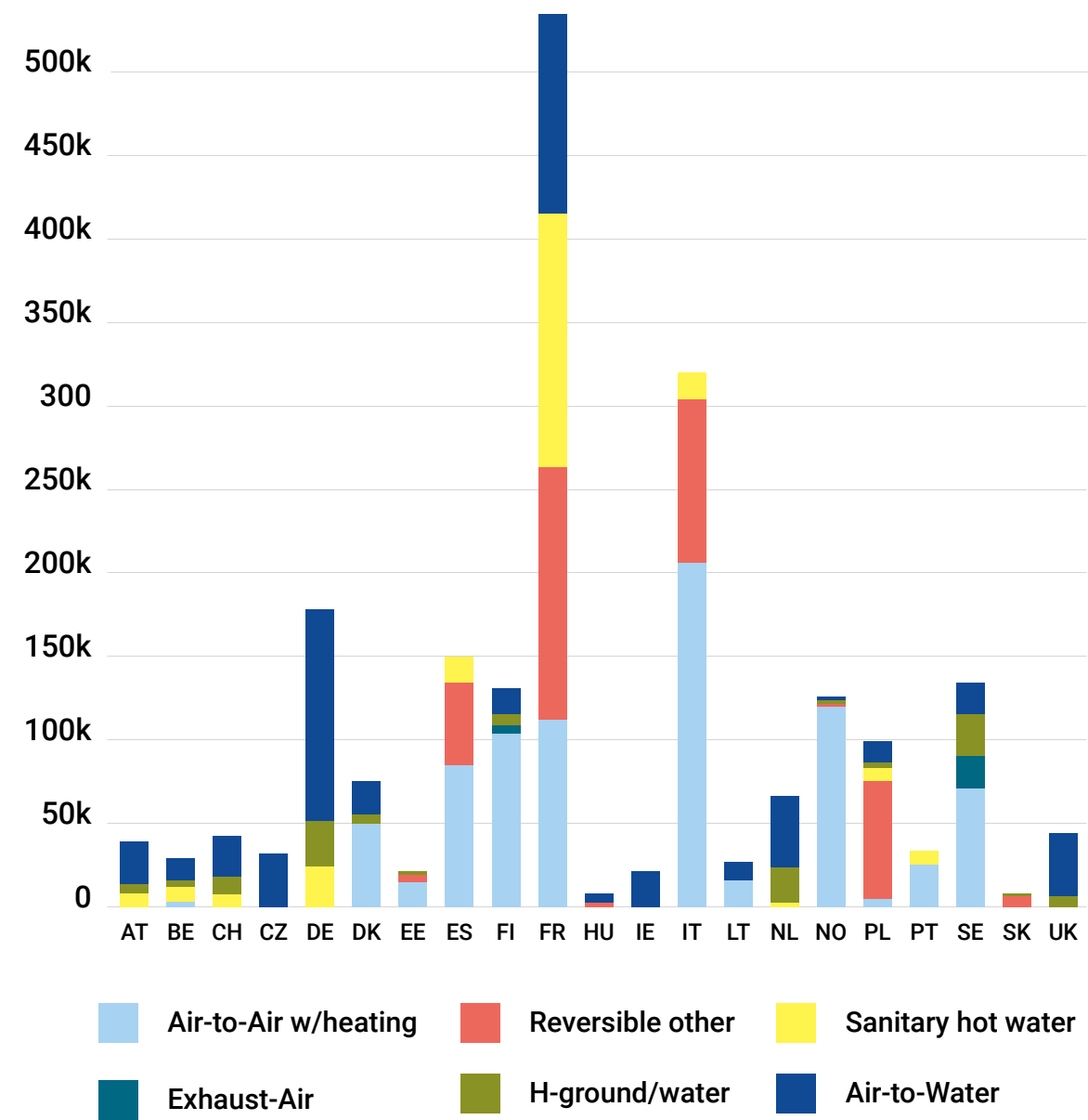
86.5% of the European market volume was sold in only ten countries (France, Italy, Germany, Spain, Sweden, Finland, Norway, Poland, Denmark, and the Netherlands). The top three countries, France, Germany, and Italy, accounted for at least half of the annual sales, according to multiple sources.

The five biggest European heat pump markets in terms of units sold (heat pumps and hot water units) in 2021 were France (537,000 units sold, +36%), Italy (382,000 units, +64%), Germany (177,000 units, +26%), Spain (148,000 units, +16%), and Sweden (135,000 units, +19%).⁷⁹

The growth of heat pump sales in the eight European countries with higher volume is presented in figure 19. France shows a consistent and positive development in the last decade, with growth spurts between 2018 and 2019 and after 2020. Italy also registers a steep rise. The other countries with accelerating development are Finland, Germany, Norway, Poland, Spain and Sweden.

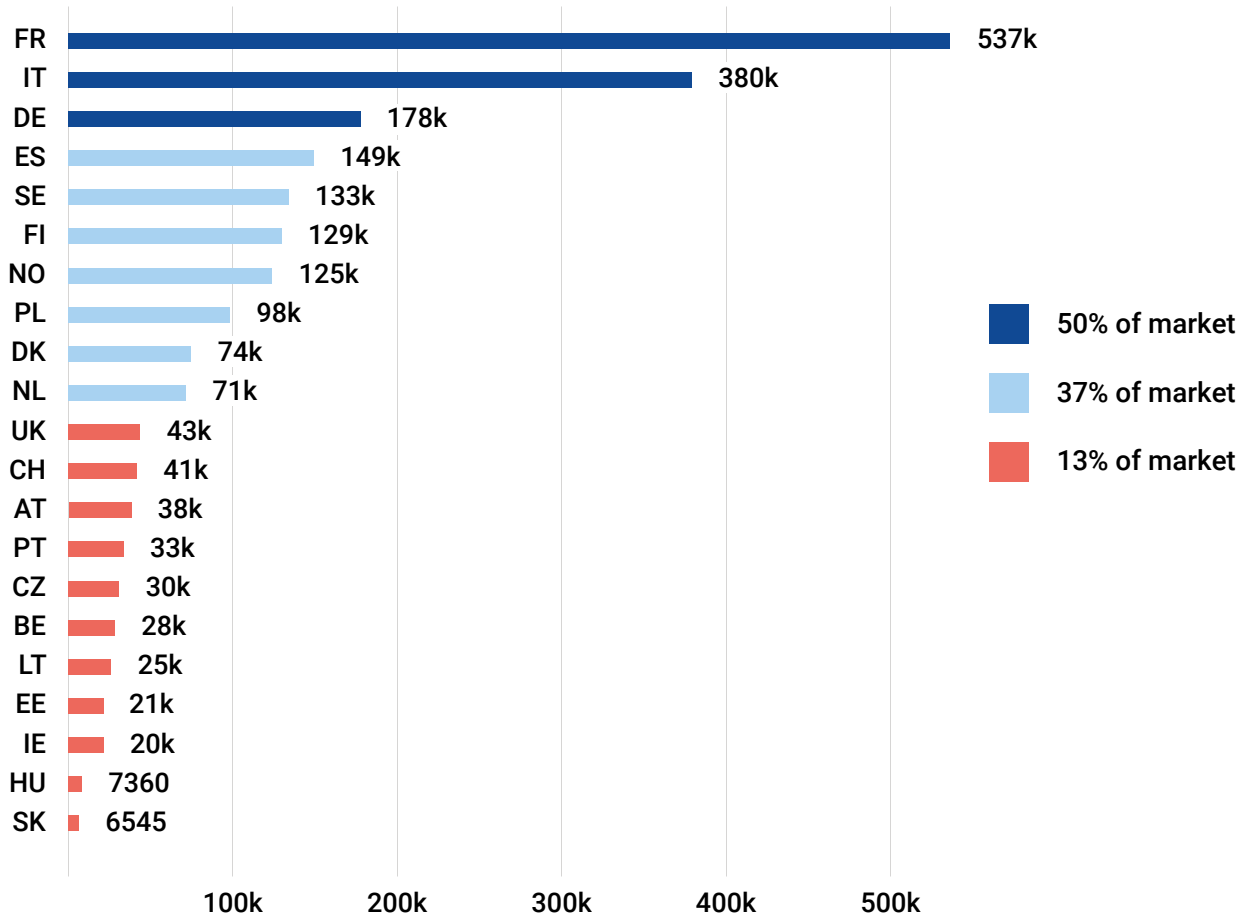
The biggest markets for air-to-air heat pumps are still France, Italy and Spain. For ground-source heat pumps, Germany became the largest market in 2021 in terms of units sold (27,000), with a 32% increase compared to 2020.⁸⁰

Figure 18: Unit sold by country and by type (2021)



Source: EHPA (2021)

Figure 19: Heat Pump sales per Country (2021)



Source: EHPA (2021)

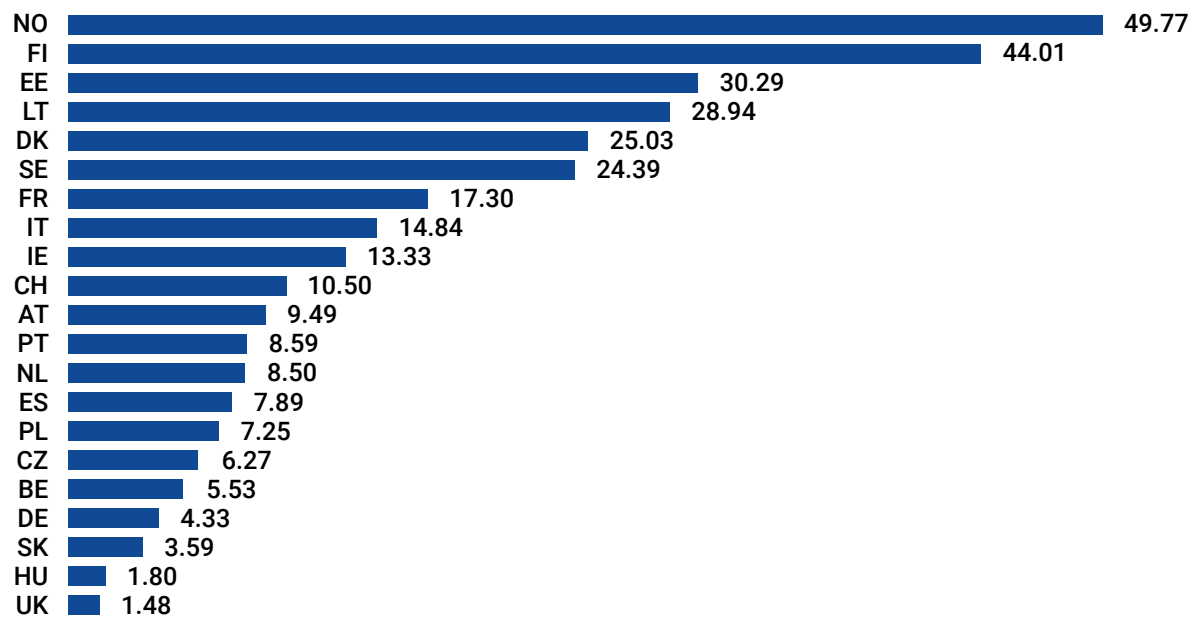
Heat pumps in the European building stock

Figure 20 shows the number of heat pumps per 1,000 households in Europe. This can be a good indicator to estimate the market penetration of heat pumps in the building sector. The higher the percentage, the more mature the market is.

Northern countries represent the top group, showing the highest penetration rates. This dispels the myth that heat pumps don't work well in cold climates.⁸¹ Thanks to a huge jump in sales, Lithuania joined this top group. Low market penetration can be also seen as an indicator for development potential and sales to be realised. The two potentially biggest markets are Germany and the UK, especially for air-to-water systems, with 4.3 and 1.5 heat pumps sold per 1,000 households, respectively.

In Norway and Finland, over 10 times more heat pumps per 1,000 households were installed in 2021 than in Germany. Norway is the country with the coldest climate in Europe, and about two-thirds of households now have a heat pump. It has seen a 25% increase in their sales. Almost all new heating systems in 2022 are powered by heat pumps. In Sweden, the market share of heat pumps is around 90%,⁸² and more than half of single-family homes have a heat pump installed.⁸³

Figure 20: Heat pump sales per 1,000 households in European comparison (2021)



Source: Agora Energiewende based on market data from EHPA (2022)
Note to the figure: X-axis: Heat pumps sold per 1,000 households (2021)

Natural refrigerant alternatives and their market penetration estimates

Suitable natural refrigerants are a market reality today for the domestic sector, with both air-to-water and air-to-air technologies able to deliver cooling and heating effects relying on alternatives to fluorinated gases.

Some recent M&As in the market and products displayed at Chillventa 2022 and ISH 2023 indicate that many companies are increasingly focusing their attention on the production of systems for natural refrigerants or are entering this growing domain through other means, such as acquiring companies manufacturing heat pumps charged with natural refrigerants.

The Cool Technologies database, run by the Environmental Investigation Agency and Greenpeace, provides an abundant but non-exhaustive list of natural refrigerant heat pump, and other RACHP, technologies readily available on the market.⁸⁴

Natural refrigerants have a very low climate impact (less direct and manufacturing emissions), low environmental impact (they are not considered PFAS) and perform comparably to or better than synthetic alternatives (less indirect emissions), with acceptable system costs.⁸⁵

In addition, Germany is providing targeted support for heat pumps based on natural refrigerants, where subsidies for heat pumps cover up to 40% of their cost as of 1 January 2023. Heat pumps using natural refrigerants like propane are favoured, sending a first-of-its-kind signal to the market and making Germany the first country to specifically subsidise the switch to natural refrigerant-based heat pumps from other fossil fuel-based systems.

An additional bonus of 5% is planned in the federal subsidy for efficient buildings for end customers purchasing a heat pump with natural refrigerant from 1 January 2023.⁸⁶ From 2028 only natural refrigerant heat pumps will be subsidised.⁸⁷

The technology for domestic space heating units with capacities below 12 kW is available and in use on the market with propane, isobutane and carbon dioxide. Nevertheless, HFC-410A still accounts for the large majority of air-to-water heat pump sales in Europe, while most air-to-air heat pumps on the market use HFC-32.⁸⁸ End-users are therefore locking in unnecessary emissions of climate damaging refrigerants where climate and environmentally sustainable alternatives exist. In addition, as table 3 reports multiple commonly used low-GWP fluorinated refrigerants decompose into TFA, a substance of growing concern and increasing presence in the European environment.⁸⁹

Heat pumps that use R-290 have been available on the European market since 2017 from manufacturers such as Alpha Innotec, Glen Dimplex, Heliotherm, NIBE and others.

The trend of actively adopting R-290 in monobloc systems has begun to pick up speed in Europe, specifically in Germany. This process seems to have speed up notably in the recent months, with the amount of R-290 charged heat pumps that were on display at ISH 2023. As a result, there are increasing numbers of manufacturers applying R-290 in monobloc-type air-to-water heat pumps.⁹⁰ A non-exhaustive list of EU-based original equipment manufacturers working with natural refrigerants for heat pumps targeting domestic capacities is provided in Figure 21.

Figure 21: List of Europe-based OEMs having, or that have announced to include, natural refrigerants heat pumps in their portfolio



Source: EHPA, ATMosphere, own visualisation. Market research performed in January 2023.
Note to the figure: Non-exhaustive and limited to domestic capacities. It includes direct and indirect systems.

Are R-290-charged split HPs/ACs factually any riskier than other hydrocarbons-charged applications?

Different analyses have been performed to assess the actual flammability risk of split air-conditioning units charged with natural refrigerant R-290.

In particular, Colbourne and Suen found in their pivotal 2015 study, "Comparative evaluation of risk of a split air conditioner and refrigerator using hydrocarbon refrigerants", that the risk of ignition frequency for split air-conditioning (SAC) is less than one event per 100 million split air conditioners in 10 years. Additionally, the authors also report that the frequency of secondary fire events was much lower: $2 \times 10^{-5} \text{ y}^{-1}$ in the USA. These results are due to (a) the use of an indoor unit fan which helps to disperse the leaked refrigerant in an effective manner, (b) that a release occurs at a high level enables it to disperse to below the flammable limits easily, and (c) the high density of the refrigerant layer formed on the room floor, which makes the persistence much longer.⁹¹

Similar results from a production line reconversion project of split air-conditioners in China suggest hydrocarbon systems' flammability risk is highly inflated due to hidden agendas of stakeholders trying to steer negotiation processes at the European and international levels. In fact, in the project financed by the Multilateral Fund under the Montreal Protocol, a firefighting research institute performed analysis on the flammability of R-290 in a common use scenario, installing air conditioners in rooms of various sizes, performing refrigerant leaks and burning tests in different conditions.

The experiments and assessments showed that the possibility of fire and explosion for a wall-mounted R-290 air-conditioner is 10^{-8} - 10^{-9} per year under household use conditions, which is 1/10 the risk of a domestic refrigerator with hydrocarbons.⁹²

Split systems charged with R-290 are not new, and work efficiently without reported issues - for instance, as of July 2019 there were around 650,000 units sold in India by Godrej.⁹³

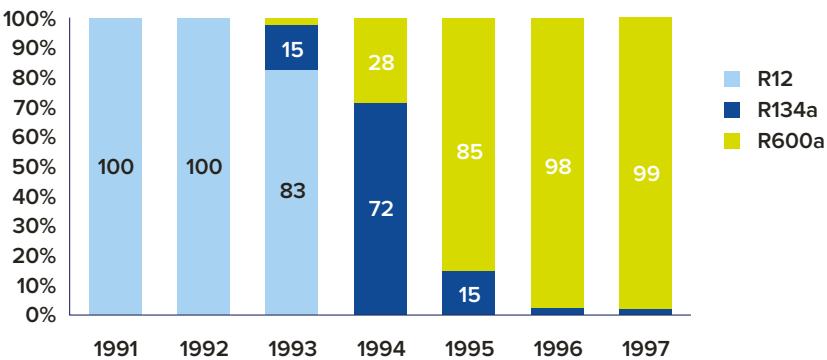
- Taking into account the EU market penetration rates published by Öko-Recherche in the context of the revision of the EU F-gas Regulation, some common trends can be drawn:⁹⁴
- In 2024–2036 hydrocarbons penetration grows to 56% in the Baseline Scenario, 36% in the Montreal Protocol Scenario and 97% in the Proportionate Action and Maximum Feasibility Scenarios for new installations of small heat pumps.
 - HFC-410a can still count on a modest 3.4% market share in the Baseline Scenario and 8% in the Montreal Protocol Scenario for 2024–2036 but will in any case disappear from new installations in the following years.
 - For 2050, hydrocarbons penetration percentages vary from 70–80% and up to 100% between the most conservative and most progressive scenarios.
- Öko-Recherche has done this market research for the European Commission in view of the revision of the Regulation and modelled feasible uptake. The consortium of consultants have therefore concluded that these high penetration rates of propane are feasible with cost effective and safe in this application.
- The expected steady growth in the use of all natural refrigerants will not lead to supply problems in the future.⁹⁵ The stable market expansion of systems working with natural refrigerants will be a benefit as the progressive reduction of HFCs and HFOs in equipment takes place.

Table 4: Market penetration rates for small heat pumps (<12 kW) – new installations (different EU F-gas Regulation's policy scenarios)

Refrigerants in heat pumps	Baseline Scenario		Montreal Protocol Scenario		Proportionate Action Scenario		Maximum Feasibility Scenario	
	2024–2036 average	2050	2024–2036 average	2050	2024–2036 average	2050	2024–2036 average	2050
HCS	56.1%	70%	35.9%	80%	97%	100%	97%	100%
HFC-410A	3.4%	-	8.2%	-	0.7%	-	0.7%	-
HFC-407C	-	-	-	-	-	-	-	-
HFC-134A	0.1%	-	0.6%	-	0.1%	-	0.1%	-
HFC-32	38.9%	30%	51.1%	20%	2.0%	-	2.0%	-
HFC-513A	1.5%	-	4.2%	-	0.2%	-	0.2%	-

Note to the table. Baseline Scenario reflects the application of the EU F-gas Regulation without revised measures; the Montreal Protocol Scenario involves only measures that would ensure compliance the EU compliance with the Montreal Protocol; the Proportionate Action Scenario support proportionate action across the revision of the EU F-gas Regulation, and the Maximum Feasibility Scenario portrait what is deemed technically feasible by European companies. More information can be sourced in the link to the document in the List of References.

Figure 22: Hydrocarbons in Domestic Refrigerators/Freezers in Germany



Source: Kauffeld, M.: Trends og status for kølemedier. [Trends and status of refrigerants] Danske Køledage, Odense, Denmark (9–10 March 2000)

Leapfrogging examples in RACHP sectors

The RACHP sector has shown its ingenuity through the multiple refrigerant changes that it has undergone in the past decades at different application levels.

Domestic refrigerators are a good example of this transition and of an application where a natural refrigerant is widely and successfully used due to several advantages offered by the hydrocarbon isobutane (R-600a).

The following figure shows the transition in the refrigerator/freezer sector in Germany during the 1990s. While in 1991, 100% of products were filled with CFC-12, in less of a decade the same amount (almost the totality) has R-600a as refrigerant, leapfrogging HFC-134a.

Advantages of R-600a are higher COP and energy efficiency.⁹⁶ The main obstacle for the wide use of hydrocarbons such as R-600a (and R-290) is the perceived risk of flammability. However, international standards have been established for safety testing for household refrigerators and similar applications and refrigerated

appliances that use hydrocarbons as refrigerants have received approval according to the procedures of these standards since 1994.

In the early 1990s, Greenpeace developed Green-Freeze refrigeration technology to show that climate-friendly alternatives exist. This was in response to claims by chemical companies that Greenpeace's fight against f-gases would interrupt the cold-chain with drastic consequences for users and that "Greenpeace criticises but offers no solutions."

Greenpeace assembled a team of engineers, and developed a refrigerator prototype that was efficient and good for the environment, the ozone layer and the climate, using hydrocarbons as the refrigerant. Greenpeace worked with a small East German company, Foron, and together they designed GreenFreeze refrigerators. Within a year, almost all European companies had adopted Greenfreeze technology. And thus, the environmentally-friendly fridge was born.⁹⁷

As CO₂ (R-744) is recognised across the world as the most promising working fluid for supermarket applications, commercial transcritical R-744 refrigeration systems have emerged as a leading fluorinated gas-free technology, alongside hydrocarbons in self-contained equipment.

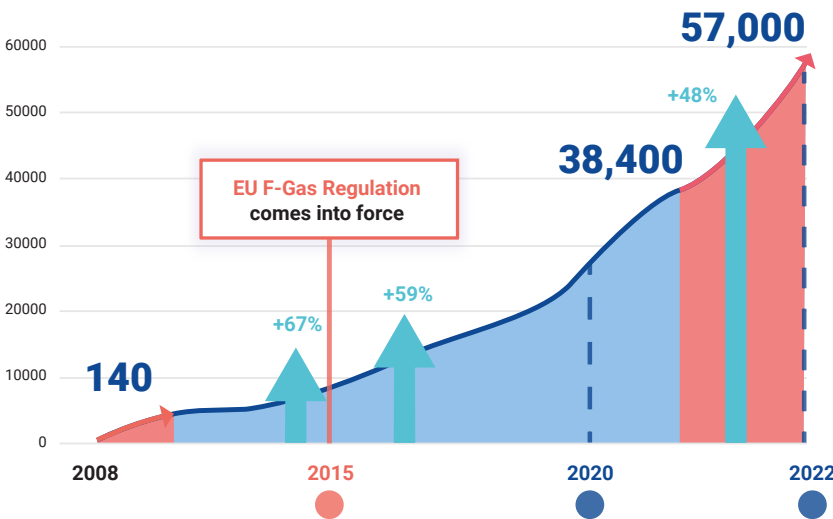
The fast transition in this sector is a good example of policy-driven scale-up. Even before the product bans and phasedown under the EU F-gas Regulation officially came into play, the industry started readying itself for the upcoming changes. Rather than simply lowering the GWP of the refrigerant in their systems, remaining susceptible to possible future lowering thresholds, a great number of OEMs and end users leapfrogged directly to R-744.

The number of transcritical R-744 installations for the commercial sector in Europe has increased exponentially, from just 140 in 2008 to 57,000 in 2022. With an average annual growth of 40.14%, the years with the strongest growth correspond with the entry into force of the

regulation: 67% between 2014 and 2015 and 59% between 2015 and 2016. This relation proves that market players are attentive to policy regulations and can respond promptly. In this last year, growth was 48%.⁹⁸

Domestic and commercial refrigeration switched to natural refrigerants without the need for false intermediate solutions. Heat pump manufacturers could follow suit, going directly from fluorinated substances to natural refrigerants and leapfrogging intermediate solutions such as refrigerant blends and low-GWP HFOs.

Figure 23: Evolution of the number of transcritical CO₂ installations in Europe – commercial applications only (2008–2022)



Source: ATMosphere (2022)

Job market and announced investments

Heat pump manufacturers consider a steeper market ramp-up to be entirely feasible. Significant investments are already being made in this sector, totalling at least €3.3 billion to 2025.⁹⁹ The sector will benefit from positive trends in turnover and increasing employment.

The EU hosts over 35% – the threshold of strong performance – of identified innovating companies globally in heating & cooling networks, superinsulation materials, heat pumps, steel decarbonisation and more.¹⁰⁰

Focusing on heat pumps used for heating, employment was around 117,000 in 2020.¹⁰¹ The broader EU heat pump value chain employed 318,800 people directly and indirectly – an increase of 26% from 2019.¹⁰² The heat pump sector employs people in RD&I, manufacturing, installing and maintenance.

In the impact assessment drafted by the European Commission's DG CLIMA unit in charge of undertaking the revision of the EU F-gas Regulation, a dedicated section reports on the macroeconomic effects of the different policy options considered. From a job creation perspective, all levels of ambition are conducive to higher job creation than conservative policy options. The results show that for both the Proportionate Action and the Maximum Feasibility scenarios – both entailing swifter

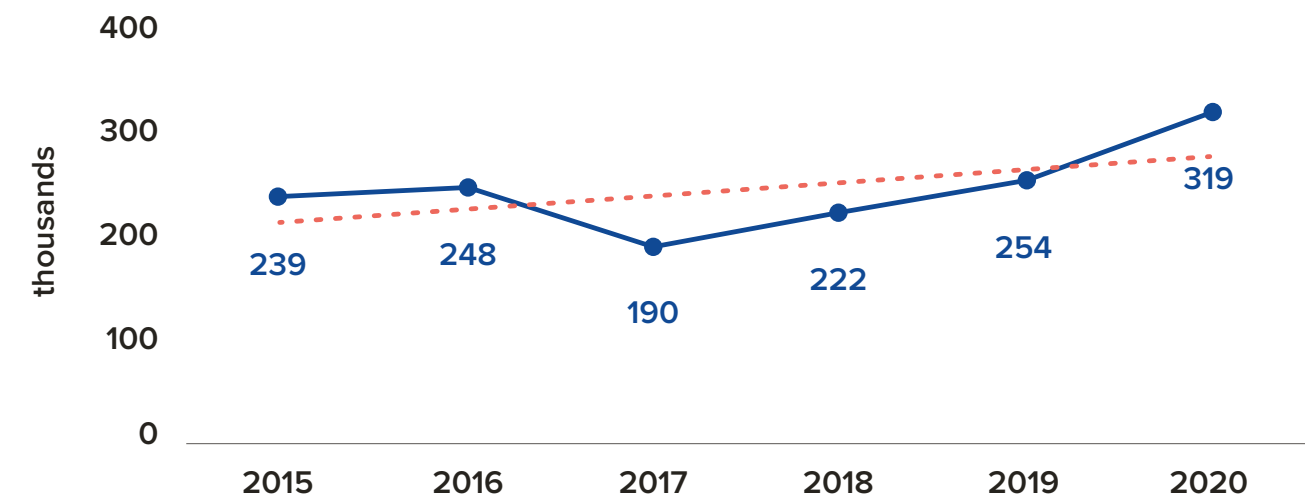
decoupling from high-GWP HFCs in favour of less environmental- and climate-invasive refrigerants – increase jobs in the European Union. The estimated amount of jobs would grow substantially more in the long run (i.e., by 2050) than the minimal conversion of jobs from the f-gas sector needed in the short term (i.e., by 2030).¹⁰³

Many training institutions are already providing courses to RACHP installers that deal with flammable refrigerants such as R-290, with updates for technicians already holding a F-gas certification that last around two days, with both theoretical and practical knowledge provided.¹⁰⁴

More entities are crowding into the space of training targeting natural refrigerants, launching, for instance, initiatives directly targeted at hydrocarbons in air-to-air systems.¹⁰⁵ This way technicians can upgrade their skills by supporting the transition of the RACHP sector away from fluorinated greenhouse gases.

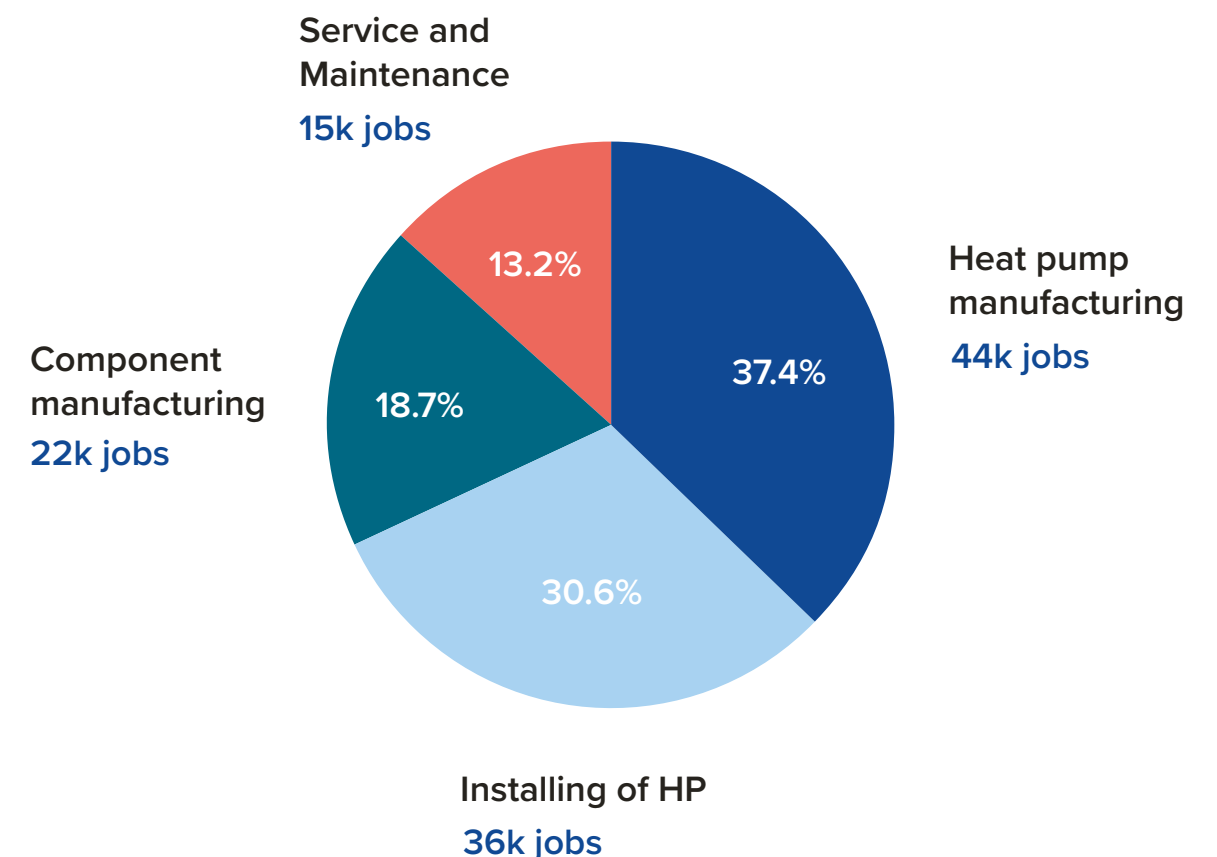
As expanded on in the next section, surveyed stakeholders mostly agree with the European Commission's view. They are confident of the growth related to the increasing sales of heat pumps with natural refrigerants and the possibility of making such heat pumps a leading technology for Europe.

Figure 24: Direct and indirect jobs in heat pumps in the EU, 2015-2020



Source: European Commission (2022)

Figure 25: Employment impact of heat pumps



Source: EHPA (2022)

Investment-wise, many manufacturers have already announced their own commitments to scale up heat pump production to meet the objectives of REPowerEU.¹⁰⁶ A non-exhaustive list of announced investments in manufacturing capacity and logistics by companies working with natural refrigerants in domestic heat pumps, or having planned to do so, is presented below:

- Group Atlantic** intends to expand production of low-capacity ATW heat pumps at its two production plants in the north of France, doubling the current annual output of 120,000 ATW units within two to three years, and is investing €120 million to achieve this goal. The extended ATW heat pump production lines will produce the IXTRA model ATW heat pump adopting a residential range with R-290.¹⁰⁷ The company also plans to hire 300 additional employees in 2023.¹⁰⁸ Additionally, the acquisition of the German-based company Hautech (renowned for its geothermal heat pumps using R-290) enriches their portfolio with green technology solutions. “The eco-friendly performance of R-290 refrigerant-grade propane is perfectly in line with our efforts to reduce the environmental footprint of our solutions”, announced Damien Carroz, M&A Director.¹⁰⁹
- Hoval** is working on expanding its capacity and is building new heat pump production facilities at its headquarters in Liechtenstein and in Slovakia with a total investment of about €60 million.¹¹⁰ This will lead to the creation of around 500 new jobs. The production volume target is set at 30.000 units.¹¹¹
- Nibe** is investing heavily in a new innovation centre; it will be ready for 2024. An exhibition centre and accompanying educational premises with a focus on sustainability are also being built.¹¹² Because of the opportunities for growth, the company has embarked on a very ambitious investment program, expecting to invest over SEK 5 billion (€460 million) in increased production capacity.¹¹³ Furthermore, Nibe’s newest air source heat pump S2125 with R-290 has been proclaimed the Best Heating Product of the Year.¹¹⁴

- Panasonic** announced an investment of about €145 million at its factory in the Czech Republic¹¹⁵ to increase capacity to 500,000 air-to-water units per year by March 2026. Panasonic will also strengthen its ATW heat pump lineups by releasing a new residential model with R-290 refrigerant in Europe in May 2023 and intends to more than double the lineup by the fiscal year ending in March 2026.¹¹⁶
- Quantum** raised €42 million to accelerate the launch of its next-generation residential R-290-based heat pump.¹¹⁷
- Vaillant** doubled its production capacity. In 2021, the Vaillant Group spent €300 million primarily on heat pumps, research & development and digitalisation. Substantial funds were invested in the expansion of production capacities for heat pumps.¹¹⁸ It will receive a €120-million loan from the European Investment Bank (EIB) to finance the research and development of electric heat pumps. This fund will give the company an even greater financial scope to accelerate its transformation in line with its green and ESG-linked financing strategy.¹¹⁹ In November 2022, the company announced the launch of a production line for its R-290-charged aroTHERM plus air-to-water monobloc heat pump at its plant in the UK.¹²⁰
- Viessmann** announced at the beginning of May 2022 that it would invest €1 billion over the next three years to expand heat pump production capacities, research and development and green climate solutions, including a €200 million investment in R-290-based heat pump manufacturing in Poland (employing 1,700 people).¹²¹
- Daikin** announced in July 2022 that it would invest €300 million in a new plant for residential heat pump units in Poland employing 1,000 people by 2025.¹²² A new expansion announcement was launched in October 2022, referring to the expansion of its German heat pump manufacturing base in Güglingen.¹²³ This investment in its factory in Germany will enable production to be tripled by 2025 and will add 500 new employees in support of this growth. At ISH 2023, Daikin announced its next generation ATW heat pumps: the new Daikin Altherma 4 will be provided also with R-290.¹²⁴

- Clivet** (part of Midea Group) will open a new factory in North Italy with a capacity of 300,000 units and employing over 700 new workers.¹²⁵ Clivet will thus shorten the delivery period of water pumps, plate exchangers and other key components of heat pumps which are manufactured in Europe and heat pump products which were ordered in Europe solving the global supply chain security issue for its heat pump production. In the last year, the volume of the lines for the production of heat pumps alone have more than doubled, reaching more than 15,000 pieces to date.¹²⁶ Clivet has recently showcased its R-290 ATA split system at the trade show Chillventa 2022.¹²⁷
- Bosch** stated in May 2022 that it would invest over €300 million in the heat pump business over the next three years and is expecting the market to grow by 15 to 20% annually until 2025.¹²⁸ The company’s Compress 6800i AW charged with R-290 is set to be launched in 2023.

Further investments are planned by heat pump and component manufacturers, and smaller manufacturers are also increasing their capacity at very fast rates but may struggle to achieve the same economies of scale, if regulatory certainty towards the uptake of natural refrigerants is not provided.¹²⁹

Table 5: Recently announced investments in heat pumps production by selected manufacturers in Europe

Company	Region/ country	Investment allocation	Investment (EUR)	Date of completion	Active in the heat pump sector with natural refrigerant products?*
Vaillant	EU	Heat pump and energy efficiency	130 mln	2022–2023	Yes
Hoval	Lichtenstein, Slovakia	Heat pumps	60 mln	2023–2024	Yes
Clivet	Italy	Heat pumps	60 mln	2024	Yes
Bosch	Europe	Heat pumps	300 mln	2025	Yes
Daikin Europe	Belgium, Czech Republic, Germany, Poland	Heat pumps, digitalisation, R&D and service capacity	1.2 bln	2025	Yes
Nibe	Sweden	Heat pumps	460 mln	2025	Yes
Viessmann	Poland	Heat pumps and other green solutions	1 bln	2025	Yes
Panasonic	Czech Republic	Heat pumps	145 mln	2026	Yes

*present or near future, domestic capacities below 12 kW and both direct and indirect systems considered.
Research performed February 2023.
Source: International Energy Agency (2022), own elaboration

Input from industry stakeholders

The survey and the interviews, conducted to gather information from industry stakeholders, focused mainly on the following topics:

- production and estimated growth rates
- current market share for natural refrigerants and forecasts
- availability and cost of components needed specifically for natural refrigerant-based equipment
- time required for switching the production line from synthetic to natural refrigerants
- impact on the job creation market, and
- preferred bans for both direct and indirect domestic heat pump technology

The following section aims to provide a snapshot of the market as it currently is in Europe, with active stakeholders working along the value chain providing insightful impressions, figures and comments.

The product portfolio of seventy percent of the respondents is already between 50 and 100% made of natural refrigerant-based heat pumps. Data on current production is generally treated as sensitive information that companies can be reluctant to share, especially in times of policy pressures. Some companies cited confidentiality concerns but actively collaborated on questions touching on more qualitative aspects. Nevertheless, it is industry knowledge that R-290-based heat pumps are already manufactured in the thousands and placed on the market by multiple brands.

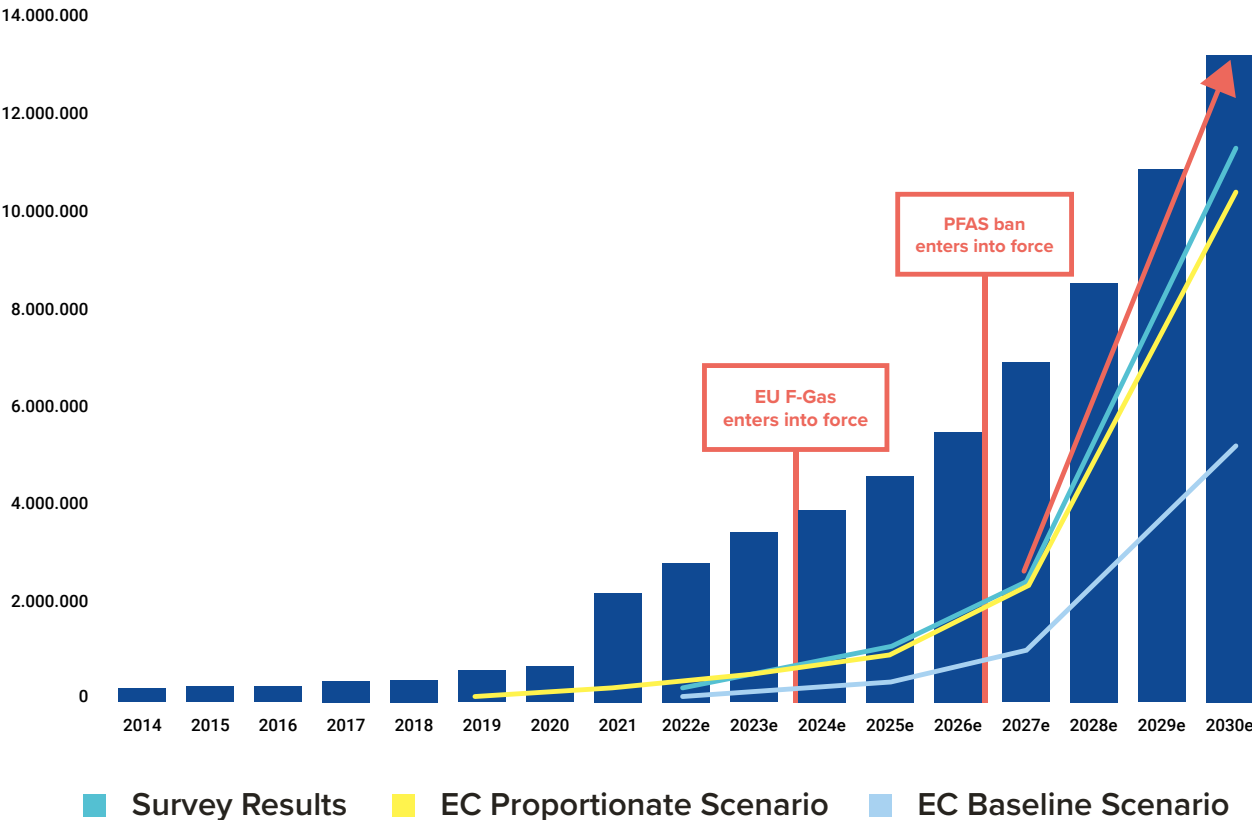
Survey respondents generally showed optimism and confidence regarding their companies' growth estimates and projections, especially regarding natural refrigerant solutions. The expected production growth rates up to 2030 have an exponential trend, with respondents providing information that far exceeds three-digit values and more than doubles production year on year. Responses varied from a more conservative stated estimate of growth - "doubling production every five years" - to the most optimistic: "up to 1000% in 2030" by a German and a Swedish company interviewed.

In view of the expected regulatory measures and growth plans of companies with natural refrigerants, it is expected that the market share will also grow in favour of natural refrigerants.

This is what our survey revealed: from a very low market share in 2022 – around 3-5% – to an average of 10% in 2025 (with the exception of two respondents that already indicate a market share of 40% in 2025), up to 85% or more in 2030. The most widespread opinion among interviewees is that natural refrigerants will have a leading position after 2030 in indirect systems for domestic capacities. These forecasts tend to coincide with those provided above in Table 5.

The following figure takes into account the current data and estimates of air-to-water heat pumps units sold in Europe together with different projections of natural refrigerants market share.

Figure 26: Air-to-water yearly sold units (current data and estimates until 2030) with natural refrigerants market penetration rate in new units (different projections)



Legenda:

- Yearly sold units assumed to increase at 22% after 2021, calculated as average on data reported by EHPA and based on REPowerEU's plan.
- Estimated entry into force of EU F-gas: 1 January 2024 (assumed provisions proposed by the European Commission in the COM(2022) 150 final - 2022/0099 (COD); Estimated entry into force of PFAS Universal Restriction Intention: 1 January 2027 (assumed provision proposed by the European chemical agencies in the Annex XV Restriction Report of February 2023, targeting f-gases that are PFAS and with granted derogations allowing for building codes, safety standards and refilling of existing systems).
- The European Commission proportionate action scenario foresees a penetration rate of hydrocarbons in new heat pumps - small (<12 kW, excluding small reversible air-to-air heat pumps) at 97% in the period 2024-2036, 100% in 2050.
- The European Commission baseline scenario foresees a penetration rate of hydrocarbons in new heat pumps - small (<12 kW, excluding small reversible air-to-air heat pumps) at 56.1% in the period 2024-2036, 70% in 2050.
- The ATMOsphere survey scenario tends to coincide with the European Commission proportionate action, with respondents reporting market penetration of natural refrigerants in domestic heat pumps at 10% in 2025 and 85% or more in 2030.

Source: own elaboration based on ATMOsphere's survey, EHPA database and European Commission Impact Assessment modelling.

At ISH 2023, industry representatives were asked to comment on the infographic in Figure 26 and provide additional input for this section of the report.

Figure 26 presents the current data and estimates of air-to-water heat pump units sold in Europe per year together with different projections of the market share of natural refrigerants.

Industry stakeholders showcasing air-to-water systems confirmed the survey results and appeared optimistic that the market can be penetrated at least to the extent shown in the proportionate action scenario modelled by the European Commission and represented in the figure. Some companies also suggested that the yellow trajectory can be exceeded in case of stronger regulations in both the EU F-gas Regulation and the PFAS Universal Restriction Intention.

All stakeholders agreed that the technology is well in place and that there is a crowding-in effect occurring in heat pumps: almost all companies in the European heat pump sector currently have options with natural refrigerants in their portfolio or are adding them in the short term. This is further supported in Annex I of this report, where different heat pump systems for residential settings are reported from ca. 40 different companies.

The capacity to scale up to meet demand is directly related to regulatory signals: clarity in these two key pieces of legislation is expected from policymakers. Different companies have suggested that they are committed to deliver six-digit yearly production numbers. A general reduction of fluorinated refrigerants' GWP is assumed in companies' business plans, as well as the restriction envisioned on f-gases that are PFAS. A company representative clearly stated: "HFOs are not an option."

To avoid a continuous change in refrigerants, entailing continuous change in components and equipment, some companies have directly leapfrogged from R-401a to R-290, reporting an approximate timeline of two years for this process. A market leader also reported its intention to transition the whole range of heat pumps in their portfolio to natural refrigerants, working toward this goal by 2027.

Oil- and gas-based boiler manufacturers report a competitive edge in terms of handling flammability concerns; multiple interviewed representatives from these companies see in manufacturing R-290-based heat pumps the clearest transition pathways for their business from fossil fuel-based to electricity-based equipment.

The section of the survey focused on components aims to highlight the differences, if any, between components used in the production of heat pumps with natural refrigerants and those used with fluorinated refrigerants, as well as differences in availability and cost. Results vary depending on the natural refrigerant considered by respondents. Most comments about component availability referred to heat pumps in general, not specifically to natural refrigerant-based ones, referencing shortages and supply chain difficulties. A respondent cited the need to support the transition towards natural refrigerants with the mass production of dedicated components. At ISH 2023, different companies launched compressors for flammable refrigerants such as hydrocarbons aimed at previously unserved capacities.¹³⁰ A general perception expressed during the interviews is that demand will drive innovation, which will likewise be driven by clear regulatory measures.

The cost difference of components (around 20% on average) is due, according to most of the respondents, to the additional safety measures required for heat pumps installed indoors. However, this is a consideration that applies mostly at system level, and a more detailed analysis at component level can be found in Box 2 above. Some respondents remarked that the current number of suppliers makes the price of specific components higher; therefore, a broadening of the market and more standardisation of the products would lead to economies of scale. Long-term contracts can also greatly reduce this initial cost premium.

Interviewees expressed that the shift towards natural refrigerants will support job creation by, for instance, relocating some of the jobs from air-conditioning giants located in Asia to Europe. One company has witnessed remarkable growth over the past years, citing a job increase of up to 300%. This is echoed by another company that reports growth in sales related to the high demand of heat pumps based on natural refrigerant R-290.

A respondent cited solar photovoltaic panels as an example; China is now leading the world market due in part to Europe and North America's having outsourced their production in previous decades. "Without sensitive industrial policies, there is a high risk of losing the European heating industry to Asia," reported this industry representative, who is working on natural refrigerant heat pumps. This view is reinforced by the conclusions of the European Commission's competitiveness report on heat pumps, which reported that development with natural refrigerants is thought to enhance European ingenuity and support its industry against non-European competitors.¹³¹

Production lines already involving flammable substances, such as some fluorinated refrigerants, are considered easier to switch to R-290. Industry representatives largely agree on a timeframe for switching production from fluorinated refrigerants to R-290 of up to three years, with some citing five. According to work performed at the Montreal Protocol level, companies have converted production lines from non-flammable refrigerant HCFC-22 to flammable refrigerant R-290 in less than three years for split systems with domestic capacities.¹³² This is confirmed by another recently published industry report that has found that some industry players are investing in the conversion of production lines towards heat pumps with natural refrigerants, expecting conversion work averaging two years, with manufacturing scheduled to begin shortly to satisfy the growing market.¹³³

As Table 1 shows, industry is already installing heating systems relying on lower-GWP refrigerants, such as R-290, HFC-32 and HFO-513, in European homes. This is reducing the need to secure quotas from the EU f-gas HFC phase-down system and allowing lawmakers to introduce stricter bans on the GWP of refrigerants to yield climate benefits.

Asked about proposed prohibitions related to indirect systems, particularly ban no. 17 on plug-in and self-contained equipment as proposed by the European Commission, industry representatives were strongly in favour of tightening the requirements and linking the HFC Phase Down and Annex IV – Placing on the market restrictions – with the parallel process under the Universal PFAS Restriction proposal.

One respondent suggested altering the capacity division so that air-source heat pumps below 20 kW capacity with refrigerant above GWP 150 would be banned from 2025, and heat pumps with refrigerants above GWP 150 with capacities greater than 20 kW would be banned as of 2026.

Another industry respondent argued that the maximum GWP level should be 150 for monoblocs as of 2027 and 2030 for split. They thought a complete ban on synthetic refrigerants for all new heat pump units should kick in as of 2035 and for all units as of 2045. This representative further called for greater consideration of TFA as a degradation product of certain fluorinated substances used as refrigerants (see Table 3), calling for a ban on heat pumps using TFA-forming fluorinated refrigerants.

Concerns over persistent substances such as PFAS and TFA are increasingly affecting industry opinion of these fluorinated gases. This hesitance to adopt these gases will likely increase following the unfolding of the PFAS Universal Restriction Intention in Europe and work conducted on PFAS in other regions, such as the U.K. and the U.S. It is therefore clear that industry supports further action on f-gases through phase-down and phase-out measures.

Asked also about ban no. 18 on split systems, one respondent expressed that "no matter which technology is used, the EU F-gas and REACH Regulation[s] will pave the way for natural refrigerants." Split systems with R-290 are already on the European market, and more companies are preparing for the launch of this kind of direct expansion system with natural refrigerant R-290 in 2023. Industry is therefore well aware of the current legislative process targeting fluorinated refrigerants that are PFAS, noticing how these refrigerants have been increasingly subject to scrutiny by authorities due to the drawbacks of their chemistry, whether contributing to ozone depletion and global warming or making them persistent in the environment.

At the recent ATMosphere Europe Summit 2022, a representative of the European Commission stated that equipment manufacturers should choose to produce heat pumps with natural refrigerants where they can and that it is just a matter of time until all heat pump capacities will be served with alternatives to fluorinated gases.¹³⁴

Annex I:

Insight from IHS, 13-17 March 2023

ATMOsphere Team’s members involved in this project spent three full days at the international trade fair ISH 2023 in Frankfurt, Germany, held from 13 to 17 March 2023.

The aim of this task was to collect further evidence in support of this report, gather additional quantitative and qualitative data through one-on-one interviews with relevant industry stakeholders, complement data gaps from the previous survey and allow stakeholders to elaborate on the transition towards natural refrigerants that the heat pump sector is experiencing.

Data collected during the trade show were also used to stress-test the assumptions this report relies on. The data collected support the stance that the European industry is steadily yet firmly adopting natural refrigerants across all heat pumps’ technologies and capacities. Regulatory measures are regarded as the direction of travel, and industry stakeholders are asking for clear signals from policymakers at the European and national levels. The revision of the EU F-gas Regulation and the impending PFAS Universal Restriction Intention are seen as the most important areas in the future of fluorinated refrigerants.

From a technological perspective, natural refrigerants such as hydrocarbons have been proven to be able to replace fluorinated greenhouse gases in all vapour compression technologies. For air-to-water systems, whether monoblocs or split, the evidence listed below confirms a wide uptake of natural refrigerants across

Europe. A clear example is the number of exhibitors exposing R-290-based heat pumps: ca. 40 different companies across five halls, more than 50% of the companies listed on the trade fair website in the air-to-water technology section.

When it comes to air-to-air technology, industry players are also working towards reducing reliance on HFC-32, a medium-GWP fluorinated greenhouse gas, by developing R-290-based solutions and marketing them today, as discussed in Box 1 of this report.

The table below has the goal to report the different numbers of heat pumps models charged with R-290 that were on show at ISH 2023. The list does not aim to be exhaustive, but rather to show the substantial amount of R-290-based heat pumps that were exhibited, informing policymakers active on the revision of the EU Fgas Regulation and the Universal PFAS Restriction of the variety of heat pumps based on natural refrigerants available today and in the near future in Europe.



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ARGO - ITALY

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BRÖTJE - GERMANY

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ctc-heating.com



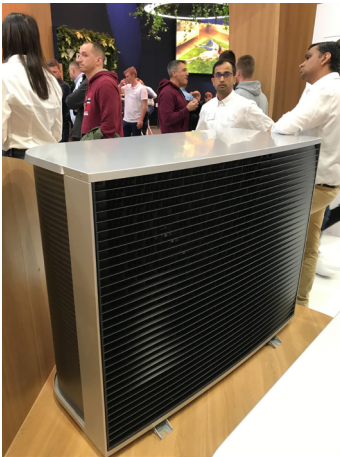
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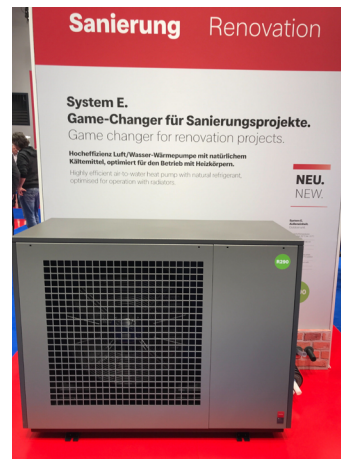
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**GALMET - POLAND**

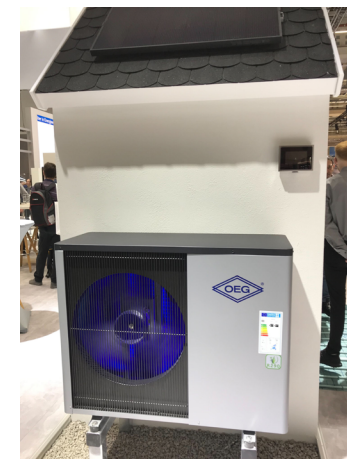
galmet.com.pl

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**GLENDIMPLEX**

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**OEG - GERMANY**

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Annex II:

Examples of HP Market Development in Different European Countries

The following annex is reported to highlight the relevance of air-to-water systems across Europe for the continent's heating structure. The same European Commission attributes higher importance to air-to-water systems in their modelling of the deployment of heat pumps to meet the objectives of REPowerEU, assuming in their calculation a greater deployment of this technology rather than air-to-air systems, which are usually purchased to deliver cooling rather than heating.

Germany

The Immediate Action Programme for Buildings¹³⁵ has an objective that at least 65% of newly installed heating systems must be powered by renewable energies from 2024.¹³⁶ So far, around 1 million heat pumps have been installed in Germany. Another 5 million heat pumps must therefore be added to achieve the climate targets by 2030.¹³⁷ The Climate Neutral Germany 2045 scenario shows the market development that is necessary to achieve the climate targets of the building sector.¹³⁸ The market share of heat pumps must increase from around 17% in 2020 to almost 50% by 2025 and, by 2030, it must be at least 70%.

On average, this requires the addition of more than 500,000 heat pumps per year.¹³⁹

By way of comparison, in 2021, around 154,000 new heating heat pumps were installed in Germany, and almost two thirds of all heat pumps sold were installed in existing buildings (Fig. 28).

However, the heat pump market has seen a significant increase in the last two years. In 2021, heat pump sales increased by 28%, and in 2022 the growth was 53% with about 236,00 units sold.

Breaking down 2022 sales data per type of ambient heat source, the German heat pump association Bundesverband Wärmepumpe (BWP) recorded a total of 205,000 air-to-water heat pumps sales – an increase of 61% (it was 33% in 2021), of which around 104,000 were monobloc devices (+ 68%) and 65,000 split devices (+49%). Brine-water heat pumps increased by 15%, with 31,000 ground-source systems sold in 2021.¹⁴⁰

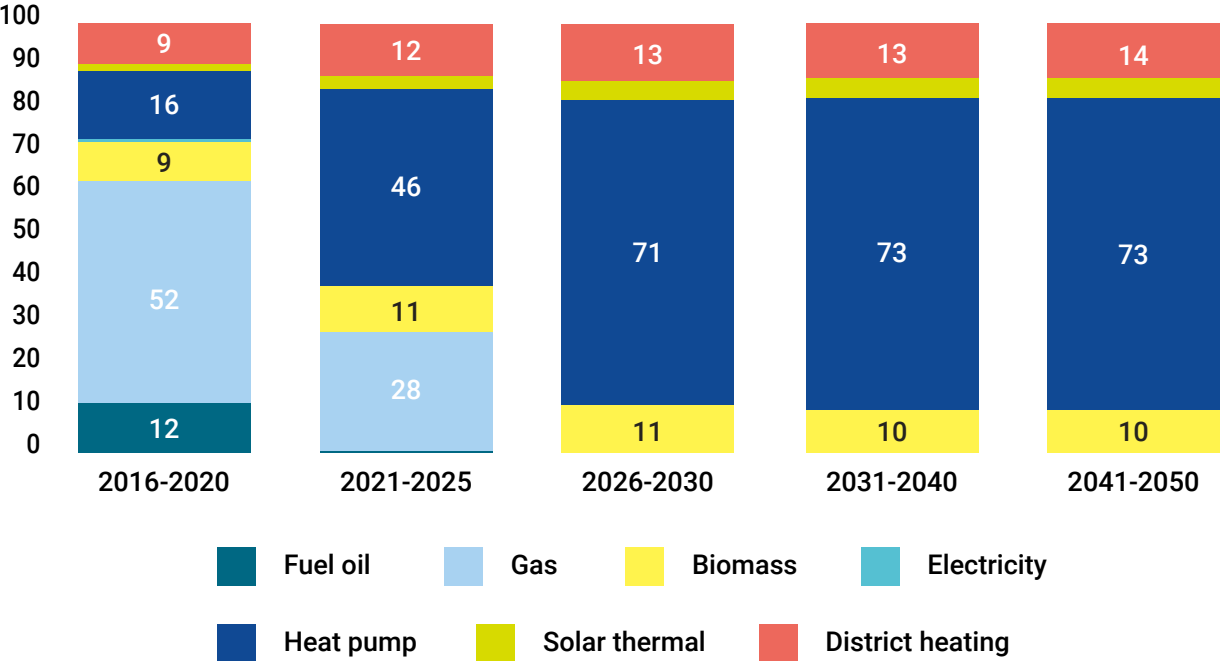
Sales of heat pumps for domestic hot water also rose sharply: 45,500 units sold in Germany in 2022, +93% over the previous year.¹⁴¹

The investment costs of a heat pump are currently two to three times higher than those of a gas boiler (without taking subsidies into account). However, economies of scale related to the production of heat pumps based on natural refrigerants are meant to close this current investment gap, as well as target subsidies schemes introduced by governments.

As reported above, Germany is explicitly favouring the uptake of heat pumps with natural refrigerants in it, granting an additional 5% support than f-gas-based heat pumps.

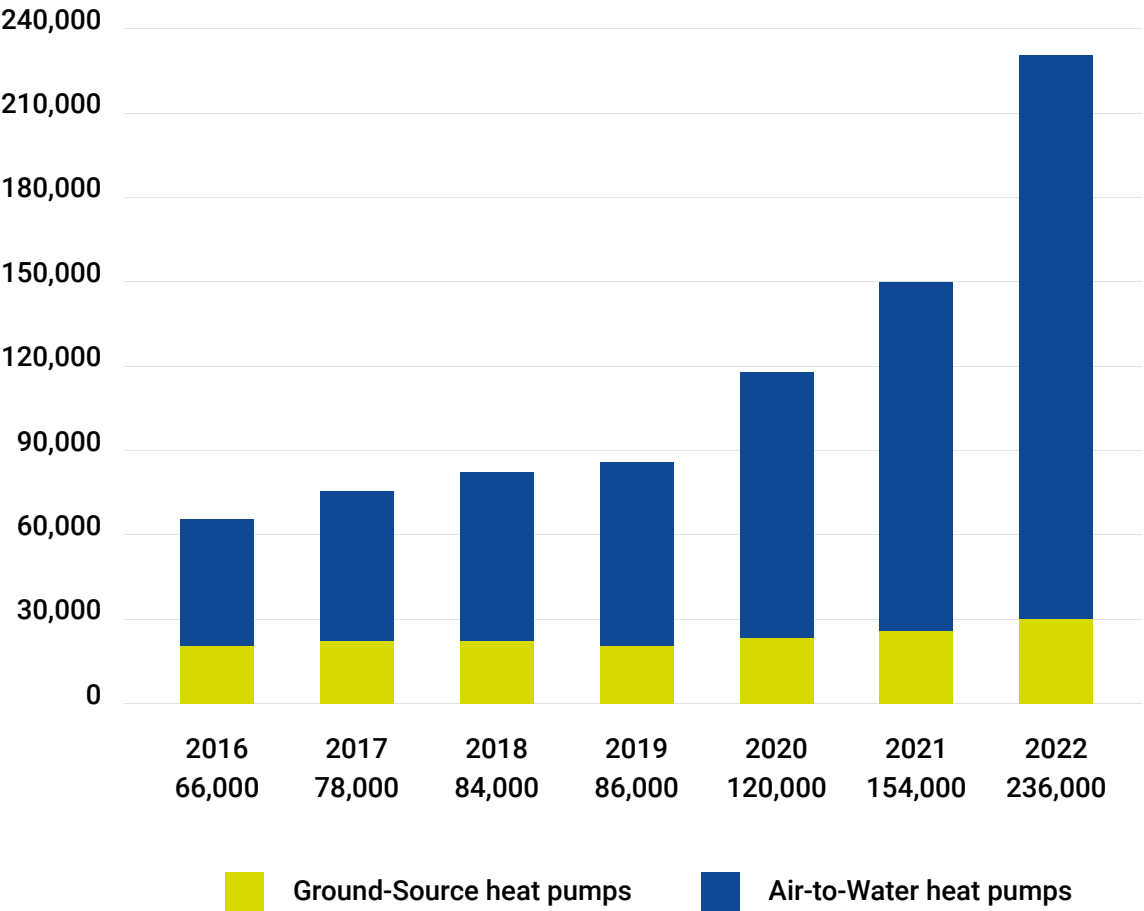
According to industry, these high costs are made up of two main elements: the manufacturing and installation costs. Over the past two years, the Federal Government has provided more than €80 billion for investment related to climate protection as part of its Climate Protection and Economic Stimulus Programme. Between 2022 and 2025, the government plans to considerably increase funding for projects related to climate policy to more than €93 billion.¹⁴²

Figure 27: Sales structure of heat generators (space heating) in Germany



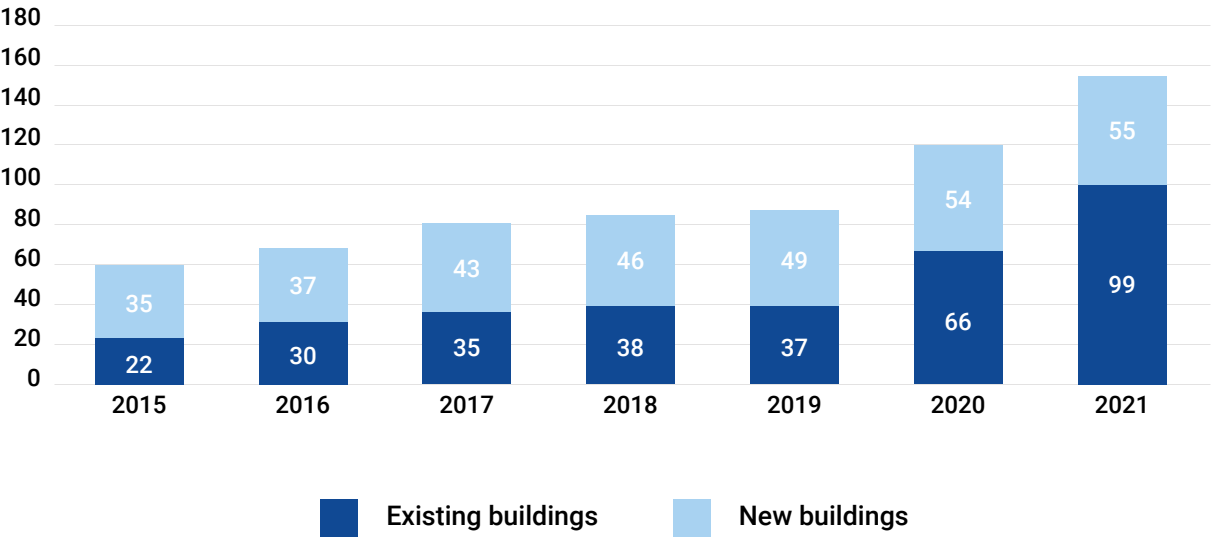
Source: Agora Energiewende (2021)

Figure 29: Sales data of heat pumps for heating in Germany from 2015 to 2022



Source: Bundesverband Wärmepumpe - Absatzstatistik (2022)¹⁴³

Figure 28: Market sales of heating heat pumps in new and existing buildings (2015-2021)



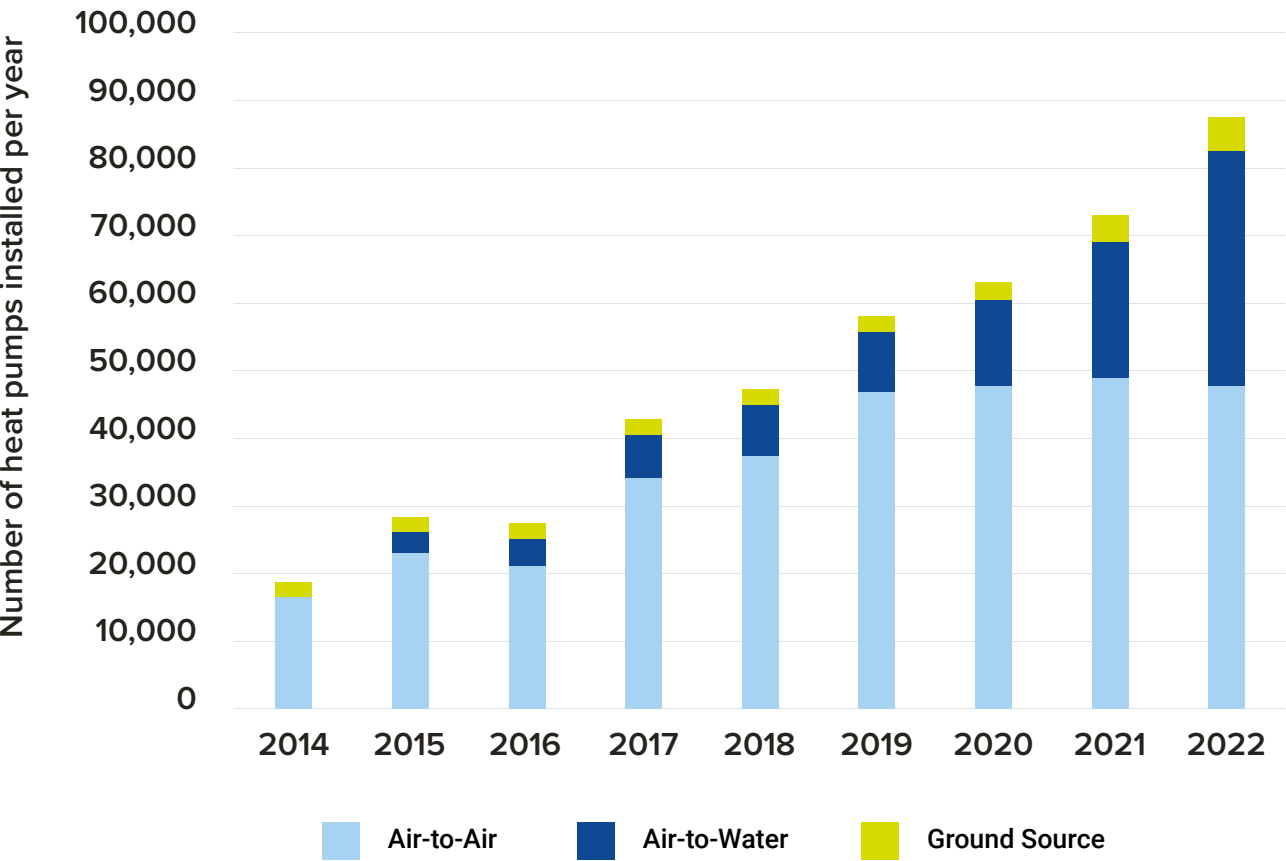
Source: Agora Energiewende (2022)

Denmark

The Danish heat pump market expanded by 20% in 2022.¹⁴⁴ It is true that the district heating market share is among the highest in the world in the Nordic country – supplying approximately two thirds of Danish private households with space heating and domestic hot water.¹⁴⁵ However, individual heat pumps are playing an increasing role, especially in areas with low-density populations.

In Denmark the cost of installing and running a heat pump is about half the cost of a gas boiler.¹⁴⁶ This was achieved by cutting taxes to almost zero on electricity used by heat pumps.¹⁴⁷ Regulation is also an important driver: since 2012 it has no longer been possible to install oil-fired and fossil gas-fired boilers in new buildings, and since 2017 the same applied to existing buildings.

Figure 30: Danish Heat pump market by type of source (2014-2022)



Source: Rosenow, J. (2023). Author elaboration from Danish Energy Agency.

Finland

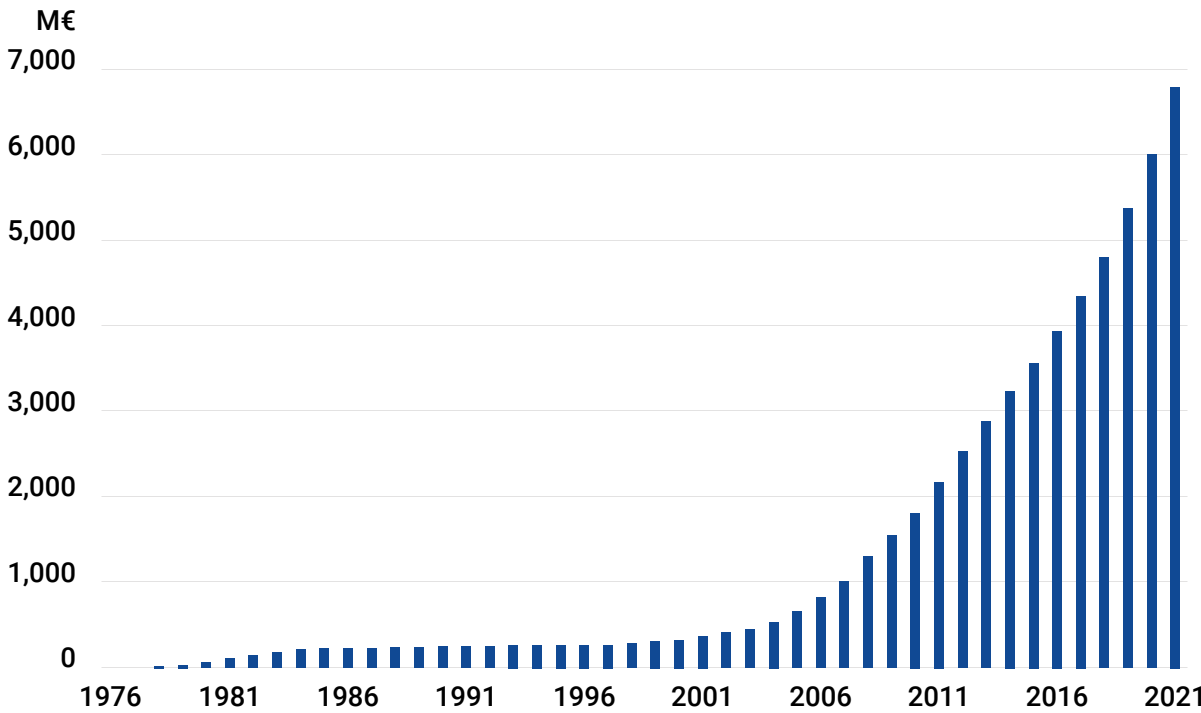
In 2021, the Finnish market grew by 25%.¹⁴⁸ 1.2 million heat pumps already provided almost 20% of the heating needs. Thanks to the high profitability of investments, the growth of the heat pump market just keeps accelerating. The cumulative investments in the heat pump sector amounted to €7 billion in 2021.¹⁴⁹ Partly helped by the aid available for replacing oil boilers, air-to-water heat pumps showed the highest growth rates: more than 50%. In fact, a total of 12,500 ATW HPs were sold in 2021.

In 2022, sales of heat pumps soared: 196,000 heat pumps were sold (compared with 130,000 units in 2021). According to statistics from SULPU, the Finnish Heat Pump Association, 160,000 air-to-air heat pumps were sold. As for air-to-water heat pumps, sales grew by almost 60%, and 19,000 pumps were installed. The sales of ground-source heat pumps increased by about 20%, with 12,000 pumps sold.¹⁵⁰

Reasons for this increase include subsidies for the replacement of oil boilers and the improvement of their energy efficiency, along with rising energy prices.¹⁵¹ Finland opting for air-to-air systems is a result of its generally wealthy population, using this technology conventionally deployed for cooling purposes as a means to cool homes during increasingly warmer days, and relying on the inverter technology to also provide partial warming effects complemented with other heating appliances connected to the electricity grid. This same general concept can be applied for other Nordic countries, such as Sweden and Norway.

The current impressive sales figures would be even higher if heat pumps and resources were able to keep pace with demand.¹⁵³ Shortages of human resources in the heat pump and refrigeration industries are threatening to slow down even the green transition unless the education system is developed at all levels to meet today's needs, said Jussi Hirvonen, the executive director of the Finnish Heat Pump Association SULPU.

Figure 31: Cumulative Investments in Heat Pump Systems in Finland (from 1996 to 2021)¹⁵²



Source: SULPU, Finnish Heat Pump Association (2022)

Italy

The Italian ATW heat pump market achieved impressive sales of more than 150,000 units in 2021, up from 57,000 units in 2020 and about 40,000 units in 2017.¹⁵⁴

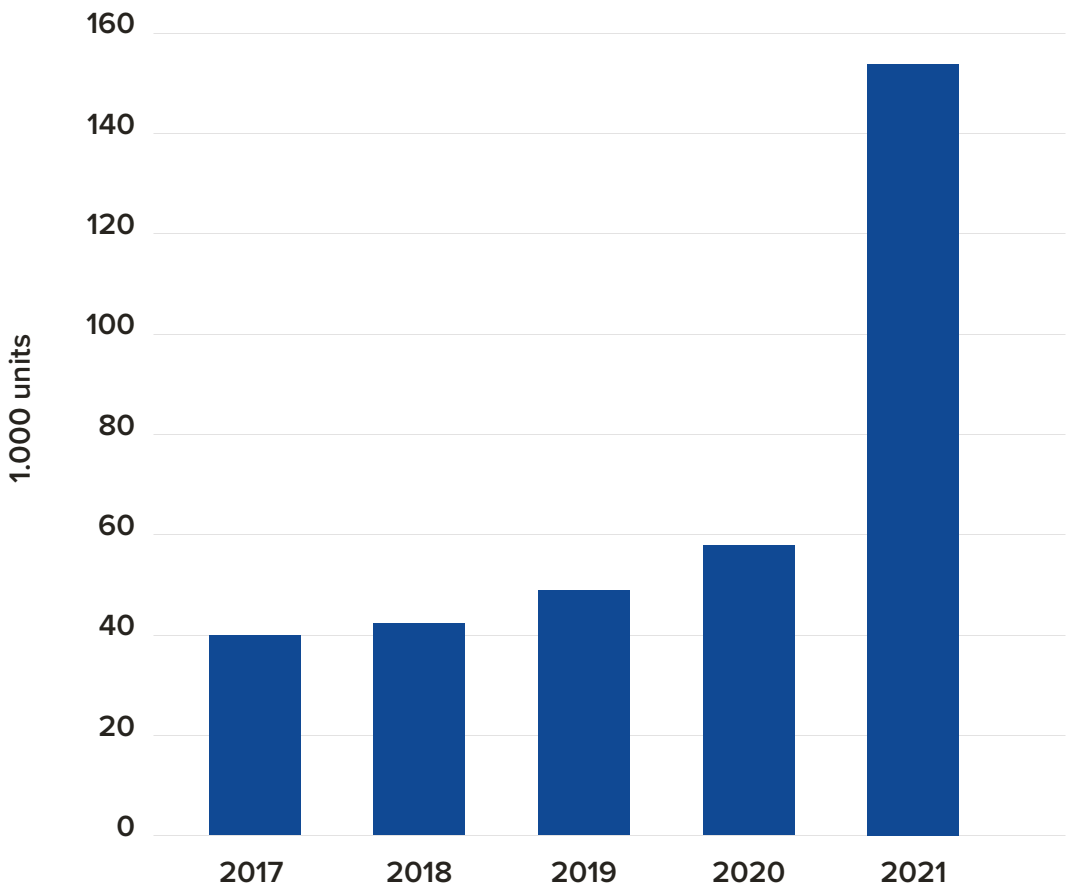
Of the total 150,000 units, hybrid systems, a challenging new segment, represented about 62,000 units. Sales of hybrid systems significantly increased due to a very positive match with special incentive plans launched by the Italian government to enhance energy efficiency in buildings. ATA units are normally prevalent for cooling.

Assoclima’s survey on the Italian heat pumps market for the period of January–June 2022 confirms growing numbers in the air-cooled hydronic equipment (cooling and heating) of 102% in volume and 96% in value.

The growth of hydronic heat pumps continues with triple-digit growth rates: 114.4% in volume and 143.3% in value for models with power ratings below 17 kW, mainly intended for the residential sector.¹⁵⁶

“The survey shows a general increase in prices which, in some cases, justifies a higher increase in value than in volume. This is evidently a phenomenon due to the increase in production costs, raw materials and transport, which could occur even more sharply in the coming periods”, said Marcello Chiriaco from Anima Confindustria. Italy is also scoring high in ATA inverter systems sold, purchased mainly for their cooling effect.

Figure 32: ATW Heat Pump Sales in Italy (2017-2021)



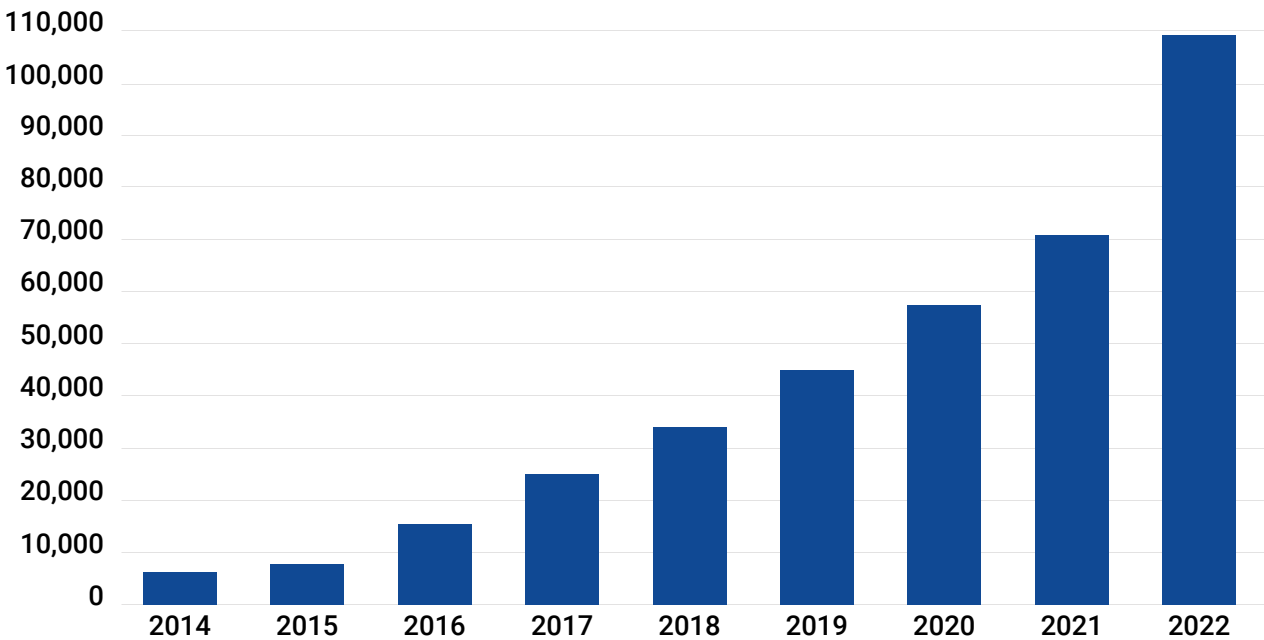
Source: Assoclima (2022)¹⁵⁵

The Netherlands

In countries such as the Netherlands, where heat supply is traditionally based on natural gas, the heat pump market has also developed successfully in recent years: heat pump sales have expanded almost tenfold since 2015. The reasons for this include a favourable price ratio of electricity and natural gas, advanced municipal heat planning and ambitious targets for phasing out the use of natural gas for heat supply.¹⁵⁷

The Dutch heat pump market expanded by 57% in 2022 with 110,000 installations (70,000 heat pumps installed in new buildings and around 40,000 in existing homes).¹⁵⁸

Figure 33: Sales of heat pumps in the Netherlands



Source: Duurzaam Verwarmd (2023)

Poland

In 2022, sales of air-to-water heat pumps for space heating in Poland increased by up to 140% compared to the same period in 2021.¹⁵⁹ The number of ground source heat pumps sold also increased by 28%. Air-to-water heat pumps for domestic hot water preparation recorded a sales increase of only about 2%.

In December 2022, the share of heat pumps in applications for heat source replacement under the Clean Air Programme reached a high of 63%, while in January 2022 it was only 28%.

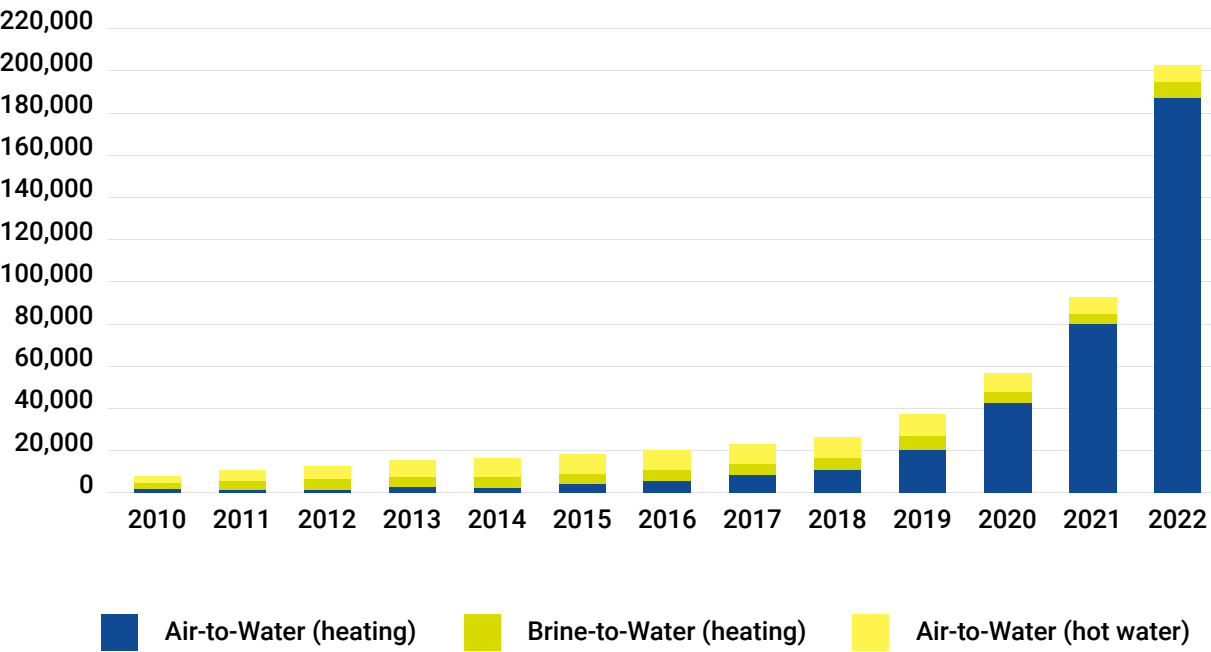
In terms of absolute value, a total of nearly 93,000 heat pumps were sold in 2021 according to updated forecasts by PORT PC (Polish Heat Pump Association).¹⁶⁰

In the whole of 2022 their sales exceeded 203,000 units, including 188,000 ATW units (93% of the total heat pump sales), 7,200 ground source heat pumps and 7,900 heat pumps for domestic hot water.

This means that the share of heat pumps in the total number of heating devices sold in the Polish market in 2022 reached nearly 30%, thanks in part to a growing confidence in this technology among both users and installers.

PORT PC predicts further significant increases in heat pump sales in Poland in 2023: it could be by about 40–50% for air-to-water units compared to 2022 and by about 30–40% for ground source heat pumps.

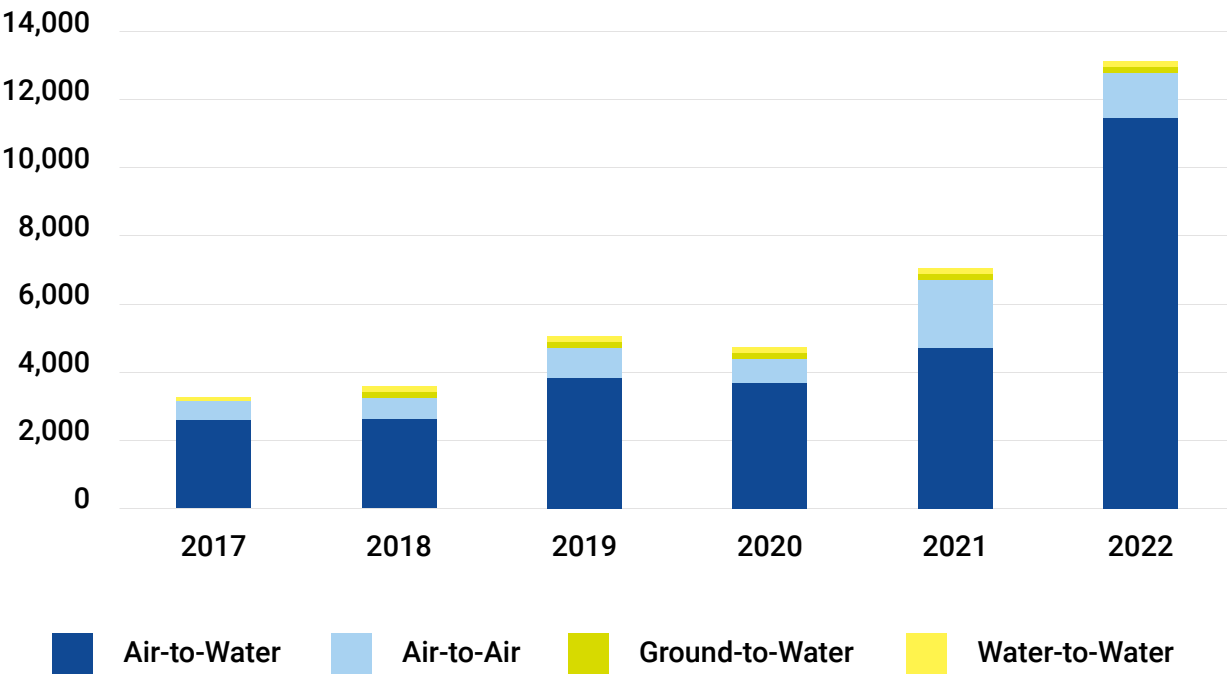
Figure 34: Heat pump market in 2022 in Poland



Slovakia

The Slovak heat pump market almost doubled in 2022. Air-to-water systems installation rates grew by a whopping 142%. This is remarkable in a country where about 90% of homes heat with fossil gas.¹⁶¹ According to data available, the country seems to favour the installation of ATW systems.

Figure 35: Heat pump sales in Slovakia



Source: SZ CHKT (Slovak Association for Refrigeration, Air

Source: Polish Heat Pump Association (2023)

Annex III:

RACHP and Flammable Refrigerants

In his review “History of Flammable Refrigerants”, Dr. Daniel Colbourne writes that the history of refrigeration and RACHP is tightly intertwined with the use of flammable refrigerants.¹⁶² By analysing textbooks, technical articles and patents from the mid-18th century to the present day, his paper provides for a technology-neutral and unbiased assessment of the use of flammable refrigerants in the industry.

During the 19th century, many early inventions employed flammable refrigerants. Until CFCs were commercialised in the 1930s, about a quarter of smaller systems used a variety of different flammable refrigerants, including ethyl ether (R610), methyl chloride (R40), ethyl chloride (R160), methylene chloride (R30), methyl formate (R611) and isobutane (R600a), and the majority of industrial/commercial systems used ammonia (R717).

“Whilst most of the refrigerants for smaller systems became substituted with CFCs, this was primarily due to mitigation of toxicity hazards, rather than ignition risks,” Colbourne writes, adding that “flammability of refrigerants was not a major issue, more of an inconvenience”. “[Flammability] is in principle a characteristic that is readily handled by good design and adherence to rules.” Elaborating on the uptake of halocarbons, Colbourne states, “Arguably, the replacing halocarbons were not necessarily ‘better’ refrigerants, but easier to use given there were fewer concerns to worry about.” He concludes that “the first ever refrigerant was flammable and it is likely that most of the ‘last’ refrigerants will also be flammable (before other technologies replace vapour compression cycle).”

The paper recalls that nowadays refrigerants that are flammable are consistently used across different applications, such as mobile air-conditioning (mainly HFO-1234yf, a 2L flammable refrigerant) and stationary heat pumps and air conditioners (HFC-32, a 2L flammable refrigerant).¹⁶³ The mass production of domestic fridges containing hydrocarbons as refrigerants – as explained in the box above – eased the transition and the adoption of flammable heat media in other applications. As reported by UNEP in its landmark 2018 report, hydrocarbons are today extensively used in other RACHP applications, such as commercial refrigeration, portable air conditioners, chillers and heat pumps.¹⁶⁴ Colbourne’s paper also highlights that in 1994 Italian OEM DeLonghi launched the first split air conditioners and movable conditioner charged with R-290.

It is roughly since this transition occurred that the industry has parted into two broad groups. The first calls for a return to “old” refrigerants across RACHP applications, also called natural refrigerants due to their chemical composition being present in nature. The second supports “new”, or halogenated, ones. Chemical companies manufacturing new refrigerants back these stakeholders and are active members of European and international RACHP associations, steering from within their position on relevant dossiers such as the EU F-gas Regulation.¹⁶⁵

Flammable substances are widespread in our society, even in other appliances or commonly used objects. We currently use natural gas in our stoves, to heat domestic water, in gas-fuelled boilers and to run the majority of the cars on the road. In Europe, a medium-size car, for instance, is generally equipped with a 50-litre ignitable gasoline tank.¹⁶⁶

Annex IV:

The relevance of direct emissions

As this report has proved, the market for heat pumps is increasing rapidly across different technologies. Air-source heat pump technology is the one currently in the spotlight and most referred to in the policy debate surrounding heat pumps at the global level.

However, the use of air conditioning units and heat pumps contributes to climate change in two prominent ways.¹⁶⁷

First, the generation of electricity used to power these systems emits CO₂, i.e., creating indirect emissions from electricity usage. The level of these emissions depends on the carbon factor of the electricity grid.¹⁶⁸

Second, the fluorinated greenhouse gases used are refrigerants, which are emitted to the atmosphere during these systems’ operations, i.e., direct emissions. These refrigerants often have a global warming potential that is normally thousands or hundreds of times higher than that of CO₂. Additionally, fluorinated greenhouse gases may be emitted during production of these very substances when they leak from the systems they are held in, or when they are not disposed of properly.¹⁶⁹

The figures reported in this annex are the result of a model built to show the total cumulative direct emissions from these systems, with a focus on the estimated leaked amount (in kg) and the related CO₂e. This model is calculated for Room ACs and ATW heat pumps from 2014 to 2030 in Europe.

This scenario relies on the current refrigerant landscape and shows applications’ emission if these systems are not forced by prohibitions in the EU F-gas Regulation to change the refrigerants in new equipment or if they are not subject to controlled use.

The data on which the following model is based – including actual datasets and estimates – use a time-span of 16 years, which the modelers deem authoritative considering that the average lifetime of the targeted appliances is approximately 10–15 years.¹⁷⁰

The European Commission indicates a leakage rate for operation of 3.5% and 5.0% for, respectively, small domestic heat pumps (*Heat pumps – small <12 kW*)

and split AC (*Room AC – Single split, which includes small multi-split <12 kW and reversible air-to-air heat pumps*).¹⁷¹

Given a time series of Room ACs’ demand in Europe from 2013 to 2021,¹⁷² it was possible to calculate future estimates (up to 2030). The estimates made by JARN and Statista specifically for 2022¹⁷³ and 2028 were also considered.¹⁷⁴ A conservative estimate of the demand for RACs by 2030 is more than 15 million units.

The number of units for each year has been multiplied by the charge of refrigerant as indicated in the report of reference for this annex, which has been used by the European Commission for its proposal of the EU F-gas Regulation.¹⁷⁵

In Room ACs, the amount of charge differs by refrigerant: 1.5 kg for HFC-410a, 1.2 kg for HFC-32 and 0.75 kg for R-290. The charge considered in each year is also affected by the market share of the refrigerants mentioned, so this amount decreases as the use of refrigerants with a lower required charge increases. This is assumed to occur at a slower pace than in a scenario where bans would be introduced.

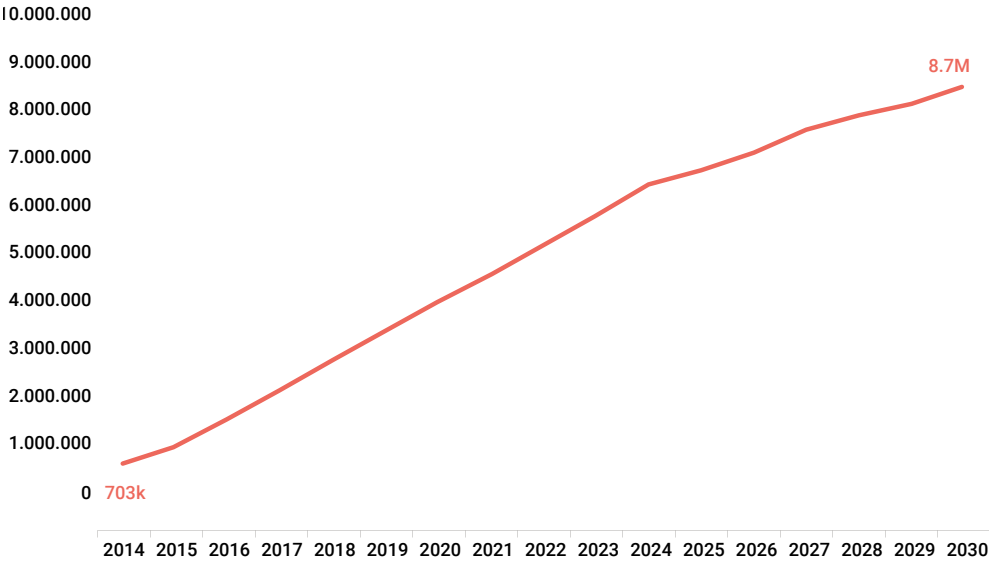
Starting from the historical time series of air-to-water heat pumps sales available from 2014 to 2021, future projections can be calculated.¹⁷⁶ But the projections were weighted reflecting the REPowerEU plan that has proposed a target of doubling annual heat pump sales.

The same procedure for calculating total leakage was also adopted for small domestic heat pumps, but in that case, the refrigerants considered and their charges were as follows: 2.6 kg for HFC-410a and HFC-134a, 2.08 kg for HFC-32 and 1.3 kg for R-290.¹⁷⁷

The leakage rate is calculated and subtracted from the total annual refrigerant charge. The amount of refrigerant within the equipment decreases year by year. The process is repeated throughout the period considered.

The cumulative leakage for all equipment considered from 2014 to 2030 will reach nearly 9 million kg of refrigerant in 2030.

Figure 36: Cumulative Leakage (2014-2030) for Room ACs and small HPs



Own elaboration based on data from BSRIA, JRAIA, Statista.

Figure 37: Cumulative emissions estimation (2014-2030)

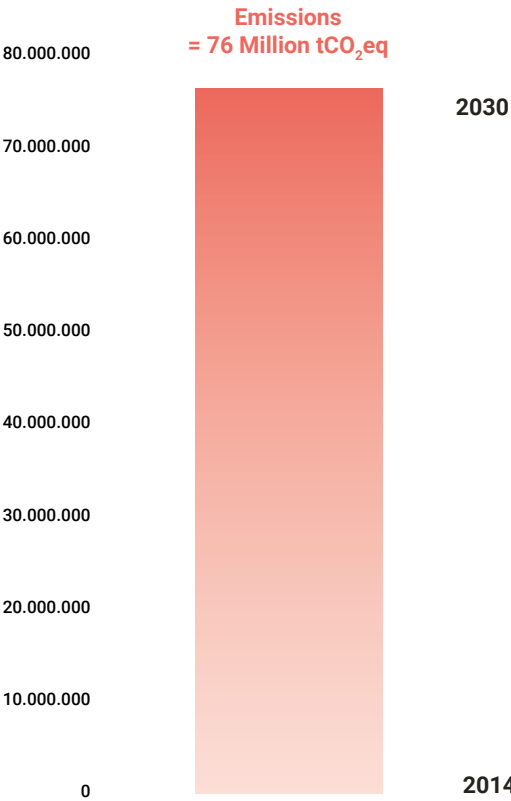
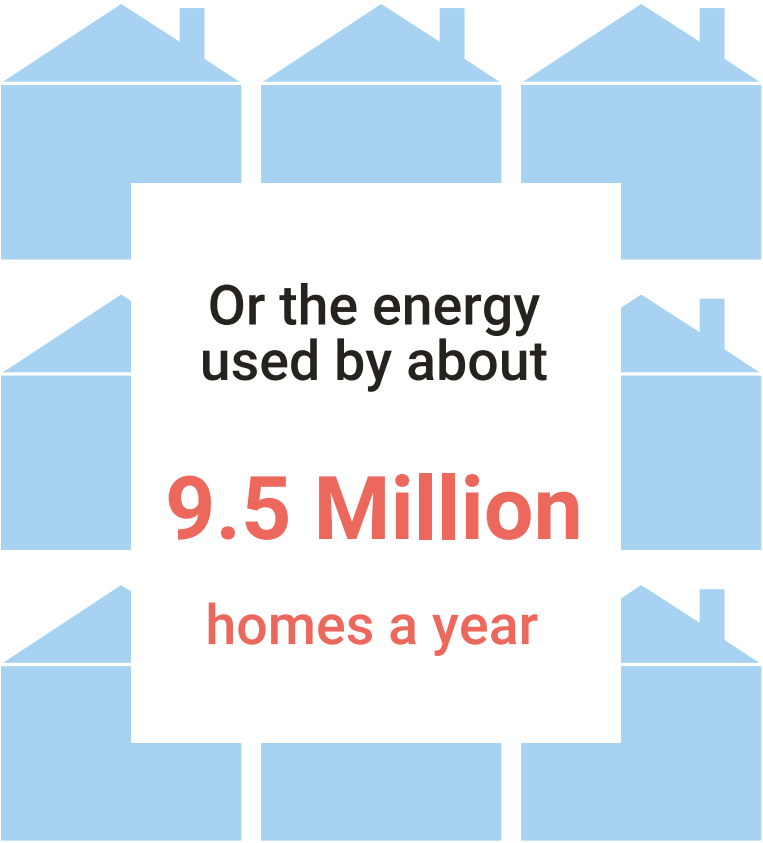
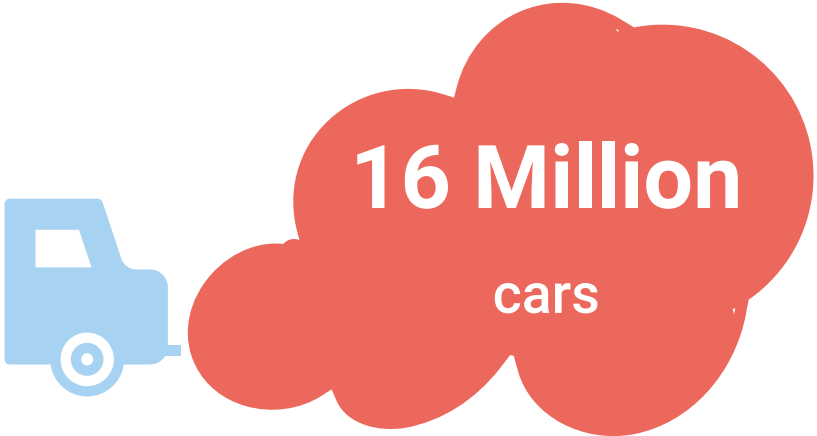


Figure 38: CO₂eq emissions – Equivalences with emissions from cars and home energy

This is equivalent to annual greenhouse gas emissions from approximately



The emissions resulting from the refrigerant leakage were converted into CO₂ equivalent, considering the market share of refrigerants used for the aforementioned products – which are understood to be mainly HFC-410a, HFC-134a, HFC-32 and R-290 – and their different 100 years GWP as published by IPCC (AR6).¹⁷⁸

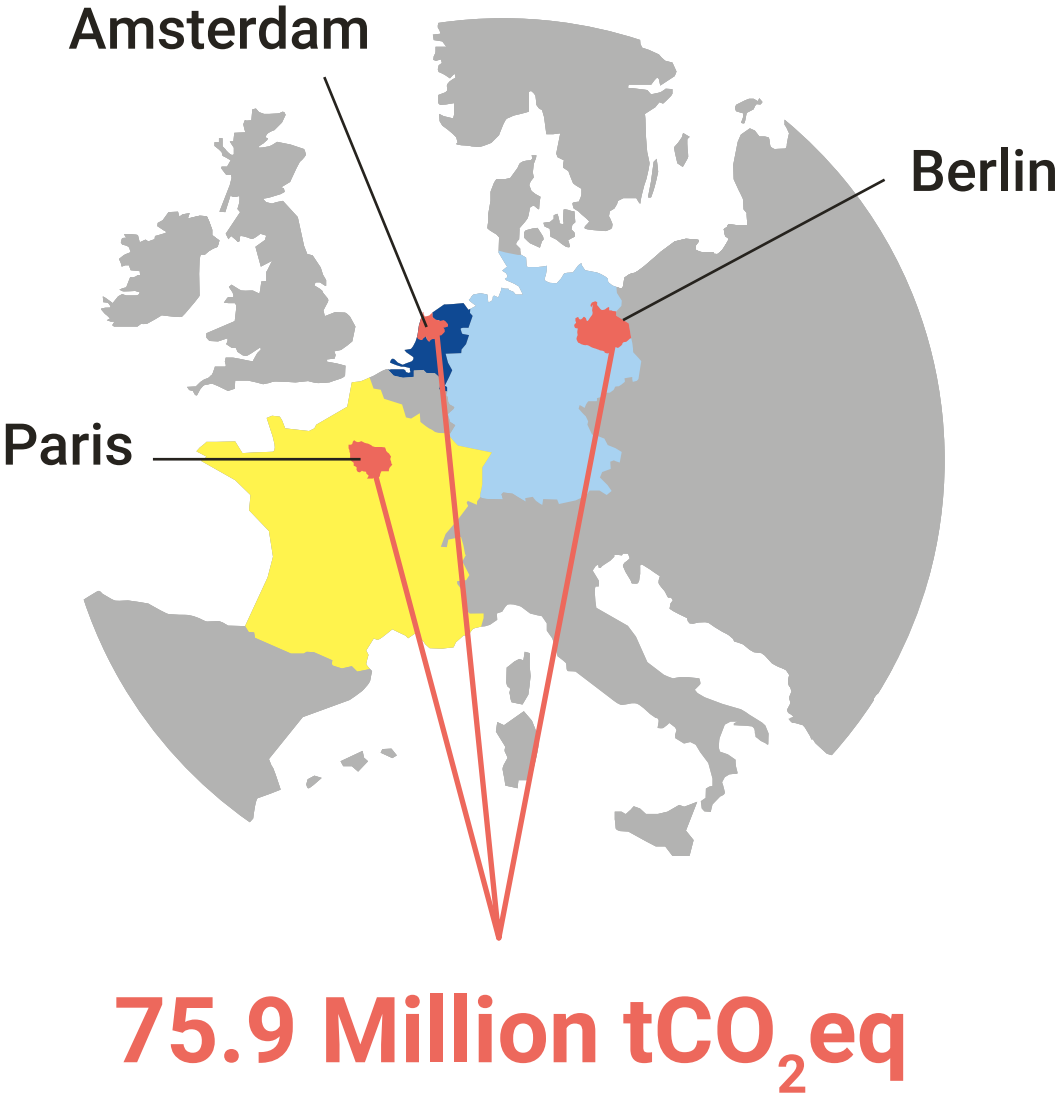
The cumulative emissions from 2014 to 2030 amount to 76 million metric tons of CO₂e.

The 76 million metric tons of CO₂e emissions can be translated in a more tangible and visually impacting metric, using tools such as the Greenhouse Gas Equivalencies calculator.¹⁷⁹

76 million metric tons of CO₂e emissions are equivalent, for example, to the total emissions released from more than 16 million cars¹⁸⁰ or 303.6 billion kilometres driven by an average gasoline-powered passenger vehicle. The same amount also corresponds to the emissions created by the energy used in one year by 9.5 million homes.

76 million metric tons of CO₂e emissions are also equivalent to those recorded by the metropolitan regions of Amsterdam, Berlin and Paris combined in 2020.¹⁸¹

Figure 39: CO₂eq emissions of three big European Metropolitan Regions (2020)



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² DEFRA (2022). F-gas Regulation in GB, Assessment Report. Available online at: <https://www.gov.uk/government/publications/assessment-of-the-f-gas-regulation-in-great-britain>

³ According to analysis by Öko-Recherche, in most cases national building codes and regulations do not pose barriers for the use of alternatives to f-gases in Europe. However, three European countries currently have building codes hindering the adoption of flammable refrigerants: France, Italy and Spain.

⁴ Trevisan, T. (2022). Haier to Launch R290 Air-to-Air Split Heat Pump in Europe in 2023. [Hydrocarbons21.com](https://hydrocarbons21.com/haier-to-launch-r290-air-to-air-split-heat-pump-in-europe-in-2023/). Available online at: <https://hydrocarbons21.com/haier-to-launch-r290-air-to-air-split-heat-pump-in-europe-in-2023/>

⁵ Garry, M. (2022). Higher Hydrocarbon Charges Unanimously Approved in IEC Standard for Home ACs and Heat Pumps. [Hydrocarbons21.com](https://hydrocarbons21.com/higher-hydrocarbon-charges-unanimously-approved-in-iec-standard-for-home-ac-and-heat-pumps/). Available online at: <https://hydrocarbons21.com/higher-hydrocarbon-charges-unanimously-approved-in-iec-standard-for-home-ac-and-heat-pumps/>

⁶ Koegelenberg, I. (2022). Fraunhofer Researchers Say Low-Charge Propane Heat Pump Sets Efficiency Record. [Hydrocarbons21.com](https://hydrocarbons21.com/german-fraunhofer-researchers-say-low-charge-propane-heat-pump-sets-efficiency-record/). Available online at: <https://hydrocarbons21.com/german-fraunhofer-researchers-say-low-charge-propane-heat-pump-sets-efficiency-record/>

⁷ More information available at: <https://www.eurovent-certification.com/en/advance-search/counter> and <https://keymark.eu/en/certificates/certificates-data-base>

⁸ Trevisan, T. (2022). GIZ Study Finds Minimal Cost Difference Between Use of Hydrocarbons and F-Gases in Split ACs. [Hydrocarbons21.com](https://hydrocarbons21.com/giz-study-finds-minimal-cost-difference-between-use-of-hydrocarbons-and-f-gases-in-split-ac/). Available online at: <https://hydrocarbons21.com/giz-study-finds-minimal-cost-difference-between-use-of-hydrocarbons-and-f-gases-in-split-ac/>

⁹ European Commission (2022). REPowerEU: affordable, secure and sustainable energy for Europe. Available online at: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en

¹⁰ European Commission (2022). Heat Pumps in the European Union. Status Report on Technology Development, Trends, Value Chains and Markets. Available online at: https://setis.ec.europa.eu/heat-pumps-european-union_en

¹¹ Öko-Recherche (2022). Impact Assessment Final Report – ANNEXES. Available online at: https://climate.ec.europa.eu/system/files/2022-04/f-gases_external_preparatory_study_annexes_en.pdf

¹² According to Table A.7 List of TFA-forming halogenated refrigerants and blowing agents from the UBA study 73/2021 Persistent degradation products of halogenated refrigerants and blowing agents in the environment: type, environmental concentrations, and fate with particular regard to new halogenated substitutes with low global warming potential. Available online at: https://www.umweltbundesamt.de/sites/default/files/medien/5750/publikationen/2021-05-06_texte_73-2021_persistent_degradation_products.pdf

¹³ ATMOSphere, 2021. Accelerating the EU's shift towards natural refrigerant domestic heat pumps. Available online at: <https://atmosphere.cool/heat-pumps-report-2022/>

¹⁴ European Commission (2022). Commission Staff Working Document - Impact Assessment Report Accompanying the document Proposal for a Regulation of the European Parliament and of the Council on fluorinated greenhouse gases,

amending Directive (EU) 2019/1937 and repealing Regulation (EU) No 517/2014. Available online at: https://climate.ec.europa.eu/system/files/2022-04/f-gases_impact_assessment_en.pdf

¹⁵ IEA (2022). HPT Annex 54, Heat pump systems with low-GWP refrigerants. Available online at: <https://heatpumping-technologies.org/annex54/wp-content/uploads/sites/63/2022/02/iea-annext-54-2021-annual-report-v2-021822.pdf>

¹⁶ HFO-454C GWP 100 years values are sourced from IPCC AR4, whereas HFC-452B, HFC-454B and HFO-513A from ATMOsphere X FGN, 2021. Impact of Refrigerants Fact Sheet #1 (V.1.1.) - Real GWP: 20 years vs. 100 years. Available online at: https://atmosphere.cool/fact_sheets/impact-of-refrigerants-fact-sheet-1-v-1-1/

¹⁷ European Commission (2022). Commission Staff Working Document - Impact Assessment Report Accompanying the document Proposal for a Regulation of the European Parliament and of the Council on fluorinated greenhouse gases, 50 amending Directive (EU) 2019/1937 and repealing Regulation (EU) No 517/2014. Available online at: https://climate.ec.europa.eu/system/files/2022-04/f-gases_impact_assessment_en.pdf. Page 33.

¹⁸ The additional demand is computed on 9.5 million hydronic heat pumps (both packaged and split systems) and 4.9 million single split air-to-air heat pumps, with refrigerant assumed to be HFC-32 at first, and R-290 subsequently.

¹⁹ European Heat Pumps Association (2022). 2021 Heat Pump Market Data Launch. Available online at: https://www.youtube.com/watch?v=_ADMvwG4tPo

²⁰ European Commission (2020). Report from the Commission: The availability of refrigerants for new split air conditioning systems that can replace fluorinated greenhouse gases or result in a lower climate impact. Available online at: https://climate.ec.europa.eu/system/files/2020-09/c_2020_6637_en.pdf

²¹ Trevisan, T. (2022). Study: Adopting Propane Split ACs Would Avoid Up to 01.2 Degree Celsius of Global Warming. [Hydrocarbons21.com](https://hydrocarbons21.com). Available online at: <https://hydrocarbons21.com/study-adopting-propane-split-ac-s-would-avoid-up-to-0.12-degree-celsius-of-global-warming>

²² Öko-Recherche (2022). Impact Assessment Final Report – ANNEXES. Available online at: https://climate.ec.europa.eu/system/files/2022-04/f-gases_external_preparatory_study_annexes_en.pdf

²³ According to Table A.7 List of TFA-forming halogenated refrigerants and blowing agents from the UBA study 73/2021 Persistent degradation products of halogenated refrigerants and blowing agents in the environment: type, environmental concentrations, and fate with particular regard to new halogenated substitutes with low global warming potential. Available online at: https://www.umweltbundesamt.de/sites/default/files/medien/5750/publikationen/2021-05-06_texte_73-2021_persistent_degradation_products.pdf

²⁴ European Environmental Agency (2022). ETC CM report 2022/03: Fluorinated greenhouse gases 2022. Available online at: <https://www.eionet.europa.eu/etcs/etc-cm/products/etc-cm-report-2022-03>

²⁵ Respectively, 16(4) and 11(4) of the European Commission proposal.

²⁶ Hafner, A., Ciconkov, R. (2021). Current state and market trends in technologies with natural refrigerants. 9th IIR Conference: Ammonia and CO2 Refrigeration Technologies, Ohrid, 2021. DOI: 10.18462/iir.nh3-co2.2021.0035

²⁷ Öko-Recherche et al. (2022). Support contract for an Evaluation and Impact Assessment for amending Regulation (EU) No 517/2014 on fluorinated greenhouse gases. Impact Assessment Final Report – ANNEXES. Available online at: https://climate.ec.europa.eu/system/files/2022-04/f-gases_external_preparatory_study_annexes_en.pdf

²⁸ Norwegian Chemical Agency (2021). Application of Fluorinated Gases (F-Gases) in the European Economic Area. Available online at: <https://www.miljodirektoratet.no/publikasjoner/2021/juli-2021/application-of-fluorinated-gases-f-gases-in-the-european-economic-area/>

²⁹ Eickhout, B. DRAFT REPORT on the proposal for a regulation of the European Parliament and of the Council on fluorinated greenhouse gases, amending Directive (EU) 2019/1937 and repealing Regulation (EU) No 517/2014 (COM(2022)0150 – C9-0142/2022 – 2022/0099(COD)). Available online at: https://www.europarl.europa.eu/doceo/document/ENVI-PR-737211_EN.pdf

³⁰ Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law'). Available online at: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32021R1119>

³¹ Trevisan, T. (2022). Virtual Briefing On F-Gases And PFAS Restriction Intention. Available online at: <https://www.cleancoolingcoalition.eu/blog/virtual-briefing-on-f-gases-and-pfas-restriction-intention/>

³² Eickhout, however, concedes on one application, maintaining the GWP level at 750 for split systems between 12 and 200kW.

³³ European Parliament (2023). Compromise amendments 1-22. 2022/0099(COD). Available online at: https://www.europarl.europa.eu/meetdocs/2014_2019/plmrep/COMMITTEES/ENVI/AMC/2023/03-01/F-gasescompromiseamendments_EN.pdf

³⁴ Colbourne, D. (2022). Can refrigerants below 150 GWP be used in heat pumps in Europe? GIZ Proklima. Available online at: <https://www.green-cooling-initiative.org/news-media/publications/publication-detail/2022/10/25/can-refrigerant-with-a-gwp-below-150-be-used-for-heat-pumps-in-europe>

³⁵ ATMOsphere (2022). Accelerating the EU transition towards domestic natural refrigerants heat pumps. Available online at: <https://atmosphere.cool/heat-pumps-report-2022/>

³⁶ Carel's Blog (2020). Six reasons to use propane as refrigerant. Available online at: <https://www.carel.com/blog/-/blogs/six-reasons-to-use-propane-as-refrigerant?> These data are referred to Italy without significant differences in the rest of Europe.

³⁷ Öko-Recherche (2022). Monitoring of refrigerant prices against the background of Regulation (EU) No 517/2014. Available online at: https://industriaeformazione.it/wp-content/uploads/2022/12/Excerpt_Price-monitoring-Q3-2022.pdf

³⁸ European Environmental Agency (2022). ETC CM report 2022/03: Fluorinated greenhouse gases 2022. Available online at: <https://www.eionet.europa.eu/etcs/etc-cm/products/etc-cm-report-2022-03>

³⁹ Joint Research Center (2020). Study on the EU's list of Critical Raw Materials - Factsheets. Available online at: https://rmis.jrc.ec.europa.eu/uploads/CRM_2020_Factsheets_critical_Final.pdf

⁴⁰ European Commission (2022). Heat Pumps in the European Union. Status Report on Technology Development, Trends, Value Chains and Markets. Available online at: https://setis.ec.europa.eu/heat-pumps-european-union_en

⁴¹ European Commission (2020). Report on the availability of hydrofluorocarbons on the Union market. Available online at: https://ec.europa.eu/clima/system/files/2020-12/20201216_c_2020_8842_en.pdf

⁴² World Bank (2015). Current landscape of HFO patents and technology cooperation between industries in developed and developing countries. Available online at: <https://ozone.unep.org/system/files/documents/WB%20IP%20Side%20Event%20-%20Landscape%20of%20HFO%20Patents%20WB%20final.pdf>

⁴³ Ammonia is often a by-product of fertiliser production, hydrocarbons and R-744 from the oil and gas industry. However, these are products of companies active in the industrial gas industry, with refrigerants frequently occupying a small of these companies' market portfolios. With regard to R-744, efforts are underway to transform carbon dioxide sucked from the atmosphere into usable refrigerant.

⁴⁴ Kleinschmidt, J., Gschrey, B., Barrault, S. (2020). Briefing paper: HFC availability on the EU market. Available online at: https://www.oekorecherche.de/sites/default/files/publikationen/briefing_paper_hfc_availability_en.pdf

⁴⁵ European Commission (2022). Commission Staff Working Document - Impact Assessment Report Accompanying the document Proposal for a Regulation of the European Parliament and of the Council on fluorinated greenhouse gases, amending Directive (EU) 2019/1937 and repealing Regulation (EU) No 517/2014. Available online at: https://climate.ec.europa.eu/system/files/2022-04/f-gases_impact_assessment_en.pdf

⁴⁶ United Nations Environment Programme (UNEP). About the Montreal Protocol.

<https://www.unep.org/ozonaction/whowe-are/about-montreal-protocol>

⁴⁷ European Commission (2022). Heat Pumps in the European Union. Status Report on Technology Development, Trends, Value Chains and Markets. Available online at: https://setis.ec.europa.eu/heat-pumps-european-union_en

⁴⁸ European Commission (2022). Ibidem.

⁴⁹ KTH (2021). KTH researchers supporting hydrocarbons as refrigerants in heat pumps. Available online at: <https://www.energy.kth.se/news-and-events/nyheter/kth-researchers-supporting-hydrocarbons-as-refrigerants-in-heat-pumps-1.1239379>

⁵⁰ ATMosphere (2022). The Rising Threat of HFOs and TFA to Health and the Environment. Available online at: <https://atmosphere.cool/hfo-tfa-report/>; Rusyanto, P. (2021). Environmental impact of HFO refrigerants & alternatives for the future. Available online at: <https://www.openaccessgovernment.org/hfo-refrigerants/112698/>

⁵¹ Behringer, D. et al. (2021). Report No. FB000452/ENG, Persistent degradation products of halogenated refrigerants and blowing agents in the environment: type, environmental concentrations, and fate with particular regard to new haloge-nated substitutes with low global warming potential, Published by German Environment Agency May 2021.

⁵² See, for instance, Campbell et al. (2021). Photodissociation of CF₃CHO provides a new source of CHF₃ (HFC-23) in the atmosphere: implications for new refrigerants. Available online at: https://www.researchgate.net/publication/349087211_Photodissociation_of_CF3CHO_provides_a_new_source_of_CHF3_HFC-23_in_the_atmosphere_implications_for_new_refrigerants; Nilsson et al. (2009). A photochemical reactor for studies of atmospheric chemistry. Available upon request at: <https://www.sciencedirect.com/science/article/abs/pii/S1352231009001678>; Qing et al. (2018). Atmospheric chemistry of E-CF₃CHCHCF₃: Reaction kinetics of OH radicals and products of OH-initiated oxidation. Available upon request at: <https://www.sciencedirect.com/science/article/abs/pii/S0009261418303889>

⁵³ HFC-23 is a very potent greenhouse gas with a GWP100 of 14,800. Campbell et al. (2021) suggest that the secondary GWP of HFO-1234ze would then be in the range of 1,400±700 considering the amount of HFC-23 which may form from HFO-1234ze in the atmosphere. DOI: 10.21203/rs.3.rs-199769/v1

⁵⁴ Even if mainly related to feedstock uses, according to the Environmental Investigation Agency (2022). Chemical Nightmare – Ending emissions of fluorochemical greenhouse gases. Available online at: <https://eia-international.org/wpcontent/uploads/Chemical-Nightmare-SINGLES.pdf>, increasing use of HFO-1234ze is likely to cause higher quantities of HFC-23 in the atmosphere as its degradation product.

⁵⁵ Trevisan, T. (2023). NGO DUH Sues German State Over Lack of TFA Monitoring in River. [R744.com](https://r744.com). Available online at: <https://r744.com/ngo-duh-sues-german-state-over-lack-of-tfa-monitoring-in-river/>

⁵⁶ PFAS are intended as substances that contain at least one fully fluorinated methyl (CF₃-) or methylene (-CF₂-) carbon atom (without any H/Cl/Br/I attached to it). A substance that only contains the following structural elements is excluded from the scope of the restriction: CF₃-X or X-CF₂-X', where X = -OR or -NRR' and X' = methyl (-CH₃), methylene (-CH₂-), an aromatic group, a carbonyl group (-C(O)-), -OR", -SR" or -NR"R"; and where R/R'/R"/R'" is a hydrogen (-H), methyl (-CH₃), methylene (-CH₂-), an aromatic group or a carbonyl group (-C(O)-).

⁵⁷ Denmark, Germany, the Netherlands, Norway and Sweden.

⁵⁸ Trevisan, T. (2023). European Chemical Agency Publishes Proposal to Restrict PFAS Chemicals, Including Some F-Gases and TFA. [R744.com](https://r744.com). Available online at: <https://r744.com/european-chemical-agency-publishes-proposal-to-restrict-pfas-chemicals-including-some-f-gases-and-tfa/>

⁵⁹ Forever Pollution Project. Available online at: <https://foreverpollution.eu/>

⁶⁰ Hosea, L., Salvidge, R. (2023). Belgium has highest levels of PFAS chemical pollution in Europe, study reveals. Euractiv. com. Available online at: <https://www.euractiv.com/section/chemicals/news/belgium-has-highest-levels-of-pfas-chemical-pollution-in-europe-study-reveals/>

⁶¹ European Commission (2022). Heat Pumps in the European Union. Status Report on Technology Development, Trends, Value Chains and Markets. Available online at: https://setis.ec.europa.eu/heat-pumps-european-union_en

⁶² European Commission (2022). Ibidem.

⁶³ IEA (2023). Global heat pump sales continue double-digit growth. Available online at: <https://www.iea.org/commentaries/global-heat-pump-sales-continue-double-digit-growth>

⁶⁴ JARN (July 2022). World ATW Heat Pump Market – 2022 Update. Available online at: https://www.ejarn.com/detail.php?id=73821&l_id=3

⁶⁵ Products considered in the research are: air filters, AHU, chilled beams, chillers, domestic heat pumps, fan coil units, IT cooling, rooftops and VRF for the RACHP sector, and cooling towers, CO₂systems and heat exchangers for the refrigeration sector.

⁶⁶ Eurovent Market Intelligence (EMI) Webinar (07 February 2023). HVACR Europe: Impact of the component shortage and key trends in 2022.

⁶⁷ EMI Webinar. Ibidem.

⁶⁸ Hayes, C. (2023), German Manufacturer Rheinmetall Wins €770 Million Contract to Supply R290 Compressors for Heat Pumps, in Hydrocarbons21. Available online at: <https://hydrocarbons21.com/german-manufacturer-rheinmetall-wins-770-million-contract-to-supply-r290-compressors-for-heat-pumps/>

⁶⁹ EHPA (2021). Market Data. Available online at: https://www.ehpa.org/press_releases/heat-pump-record-3-million-units-sold-in-2022-contributing-to-repowereu-targets/

⁷⁰ Some countries are excluded from this data, such as IE, EE, LT, SK, due to data still in preparation.

⁷¹ European Commission - Joint Research Centre (2022). Heat Pumps in the European Union. Available online at: https://setis.ec.europa.eu/heat-pumps-european-union_en

⁷² European Commission - Joint Research Centre (2022). Heat Pumps in the European Union. Available online at: https://setis.ec.europa.eu/heat-pumps-european-union_en. Looking at the broader market that includes reversible heat pumps used as air conditioners, the EU has 42 million heat pumps in operation, of which 38 million are air-source.

⁷³ European Commision, (2022). Heat Pumps in the European Union. Status Report on technology development, trends, value chains and markets. Available online at: https://setis.ec.europa.eu/heat-pumps-european-union_en

⁷⁴ Statista (2021). Total emissions of carbon dioxide (CO₂) in the member states of the European Union (EU) in 2019 (in million metric tons). Available online at: <https://www.statista.com/statistics/789024/emissions-co2-dioxide-of-carbonby-country-eu/>

⁷⁵ European Heat Pump Association (EHPA) (2022). Market data. Available online at: www.ehpa.org/market-da-ta/

⁷⁶ JARN (July 2022). World ATW Heat Pump Market – 2022 Update. Available online at: https://www.ejarn.com/detail.php?id=73821&l_id=3

⁷⁷ The ATW heat pump market in France prefers the split type rather than the monobloc, and the split type achieved a market share of over 91%, while monobloc-type ATW models accounted for less than 9% (ibid).

⁷⁸ Kuokkanen, A., Georgakaki, A., Mountraki, A. and Letout, S. (2021). European climate neutral industry competitiveness scoreboard 2021, European Commission, 2022, JRC129337. Available online at: <https://publications.jrc.ec.europa.eu/repository/handle/JRC129337>

⁷⁹ IEA HPT. Strong growth of heat pump markets in different parts of the world. More information available at: <https://heatpumpingtechnologies.org/strong-growth-of-heat-pump-markets-in-different-parts-of-the-world/>

⁸⁰ European Geothermal Energy Council (EGEC) (2022). 2021 EGEC Geothermal Market Report. Available online at: www.egec.org/wp-content/uploads/2022/06/MR21_KF.pdf

⁸¹ IEA (2021). The Future of Heat Pumps. Available online at: <https://iea.blob.core.windows.net/assets/01324438-d634-4d49-95d8-3d08aaab00d5/TheFutureofHeatPumps.pdf>

⁸² Sweden has one of the highest CO₂ prices in the world, with a CO₂ tax of €130 per tonne of CO₂ (as of 04/2022) (World Bank 2022). Due to the early introduction of the CO₂ tax in 1991, natural gas has traditionally played a subordinate role in heat generation in buildings.

⁸³ REN21 (2022). Renewables 2022: Global Status Report. Available online at: www.ren21.net/wp-content/uploads/2019/05/GSR2022_Full_Report.pdf

⁸⁴ More information available on: <https://cooltechnologies.org/>

⁸⁵ Geelen, C. and van Gerwen, R. (2021). Natural Refrigerants in heat pumps. Available online at: <https://www.topsectorenergie.nl/sites/default/files/uploads/Urban%20energy/publicaties/Natuurlijke%20koudemiddelen%20in%20warmtepompen%20-%208%20juni%202021.pdf>

⁸⁶ Kurmayer, N. (November 2022). Boost for Germany's heat pump makers as industrial policy meets climate action. Available online at: <https://www.euractiv.com/section/energy-environment/news/boost-for-germanys-heat-pump-makers-as-industrial-policy-meets-climate-action/>

⁸⁷ Trevisan, T. (2023). Germany Grants Bonus Subsidy to Home Heat Pumps that Use Natural Refrigerants. Hydrocarbons21. Available online at: <https://hydrocarbons21.com/germany-grants-bonus-subsidy-to-home-heat-pumps-that-use-natural-refrigerants/>

⁸⁸ European Commission, (2022). Heat Pumps in the European Union. Status Report on technology development, trends, value chains and markets. Available online at: https://setis.ec.europa.eu/heat-pumps-european-union_en

⁸⁹ ATMOSphere (2023). The Rising Threat of HFOs and TFA to Health and the Environment. Available online at: <https://atmosphere.cool/hfo-tfa-report/>

⁹⁰ JARN (2022). World ATW Heat Pump Market – 2022 Update. Regional Report - Europe. Available online at: https://www.ejarn.com/detail.php?id=73822&l_id=3

⁹¹ Colbourne, D., Suen, K.O. (2015). Comparative evaluation of risk of a split air conditioner and refrigerator using hydrocarbon refrigerants. International Journal of Refrigeration Volume 59, November 2015, Pages 295-303. DOI: <https://doi.org/10.1016/j.ijrefrig.2015.06.026>

⁹² United Nations Industrial Development Organization - UNIDO, 2015. Demonstration Sub-Project for Conversion from HCFC-22 to Propane at Midea Room Air-conditioner Manufacturing Company - Demonstration Sub-Project for Conversion of Room A/C Compressor Manufacturing from HCFC-22 to Propane at Guangdong Meizhi Co. Available online at: <http://www.multilateralfund.org/Our%20Work/DemonProject/default.aspx>

⁹³ GIZ Proklima (2019). R290 Split Air Conditioners Resource Guide. Available online at: https://www.green-cooling-initiative.org/fileadmin/Publications/2019_C4_R290_SplitAC_ResourceGuide.pdf

⁹⁴ Öko-Recherche (2022). Support contract for an Evaluation and Impact Assessment for amending Regulation (EU) No 517/2014 on fluorinated greenhouse gases. Impact Assessment Final Report – ANNEXES. Available online at: https://climate.ec.europa.eu/system/files/2022-04/f-gases_external_preparatory_study_annexes_en.pdf. These estimates, however, do not take into account data regarding possible penetration rates for blends such as HFC-454B, HFC-454C and HFC-455A at European level.

⁹⁵ Öko-Recherche (2022). Ibidem.

⁹⁶ Roy Z., Halder G. (2020). Replacement of halogenated refrigerants towards sustainable cooling system: A review. Science Direct, Vol. 3, 15 November 2020. Available online at: <https://www.sciencedirect.com/science/article/pii/S2666821120300272>

⁹⁷ Morgan, J. (2018). How Greenpeace changed an industry: 25 years of GreenFreeze to cool the planet. Available online at: <https://www.greenpeace.org/international/story/15323/how-green-peace-changed-an-industry-25-years-of-green-freeze-to-cool-the-planet/>

⁹⁸ ATMOSphere Report 2022. Accelerating the EU's shift towards natural refrigerant domestic heat pumps. Available online at: <https://atmosphere.cool/product/accelerating-the-eus-shift-towards-natural-refrigerant-domestic-heat-pumps/>

⁹⁹ European Commission - Joint Research Centre (2022). Heat Pumps in the European Union. Available online at: https://setis.ec.europa.eu/heat-pumps-european-union_en

¹⁰⁰ Kuokkanen, A., Georgakaki, A., Mountraki, A. and Letout, S. (2022). European climate neutral industry competitiveness scoreboard 2021. JRC129337. Available online at: <https://publications.jrc.ec.europa.eu/repository/handle/JRC129337>

¹⁰¹ EHPA (2022). Mass rollout of rooftop solar and heat pumps, presentation at IEA workshop, 13 July 2022.

¹⁰² JRC, 2021, based on EurObserv'ER.

¹⁰³ European Commission (2022). Commission Staff Working Document - Impact Assessment Report Accompanying the document Proposal for a Regulation of the European Parliament and of the Council on fluorinated greenhouse gases, amending Directive (EU) 2019/1937 and repealing Regulation (EU) No 517/2014. Available online at: https://climate.ec.europa.eu/system/files/2022-04/f-gases_impact_assessment_en.pdf

¹⁰⁴ Trevisan, T. (2022). European Commission Finds Ambitious F-gas Regulation Would Align with Heat Pump Goals. Hydrocarbons21.com. Available online at: <https://hydrocarbons21.com/european-commission-finds-ambitious-f-gas-regulation-would-align-with-heat-pump-goals/>

¹⁰⁵ Trevisan, T. (2022). European Providers Join Forces to Launch Training on Hydrocarbon Split AC. Hydrocarbons21.com. Available online at: <https://hydrocarbons21.com/european-providers-join-forces-to-launch-training-on-hydrocarbon-split-ac/>

¹⁰⁶ JARN (2022). Heat Pump Manufacturers Strengthening Their Business in Europe. Available online at: https://www.ejarn.com/photo_report.php?id=75794&l_id=

¹⁰⁷ Tardy, A. (2022). Atlantic veut produire encore plus de ch'ti PAC, in Génie Climatique Magazine (24.11.2022). Available online at: <https://www.genieclimatique.fr/tendances/17806/atlantique-veut-produire-encore-plus-de-ch-ti-pac55>

¹⁰⁸ JARN Newsletter (December 2022). Atlantic to Ramp up Heat Pump Production in the North of France. Available online at: <https://www.ejarn.com/detail.php?id=76235>

¹⁰⁹ Group Atlantic News. Available online at: <https://www.groupe-atlantic.fr/en/News/Groupe-Atlantic-confirms-its-expansion-into-green-technologies-with-the-acquisition-of-the-Hautec-Group>

¹¹⁰ Liechtenstein in news (October 2022). Available online at: https://www.liechtenstein.li/en/liechtenstein_news/hovalerweitert-produktionskapazitat-fur-warmepumpen

¹¹¹ <https://www.ehpa.org/wp-content/uploads/2022/11/HP-Investments-Website-3.0.pdf>

¹¹² Nibe news. Available online at: <https://www.nibe.com/investors/nibenews.5.3052f8ad17c32e64de1604.html>

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¹¹⁴ JARN News (December 2022). https://www.ejarn.com/detail.php?id=76083&l_id=

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