ENGINEERING
TOMORROW

Danfoss

Report | Avoided emissions

Decarbonizing Europe's heating: Danfoss compressor VZN175 can avoid 477 tons CO_2 over its lifetime

An explorative study made to illustrate the concrete potential of avoided emissions in each European country due to the use of heat pumps.

heatpumps.danfoss.com

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The study was only possible by making assumptions about the future of the electricity and gas systems and extrapolation of existing data from public EPDs regarding emissions from production, maintenance and end of life of heat pumps and gas boilers. Amongst these assumptions is a forecast of the electricity emission factors and an assumption that natural gas will not become less emission intensive, with the uptake of biogas or synthetic gas for domestic use will remain marginal (European Commission, 2015). The actual emission factor for both electricity and gas can vary from the average, depending on the energy generation conditions (e.g. district energy, origin of gas…). In this study, location based direct emission factors from the IEA are used, which are country-average values. We therefore recommend further studies on country or subnational level to arrive at more exact saving numbers and encourage readers to keep in mind the uncertainty level of the numbers when quoting the report.

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Avoided GHG emissions, VZN175 case, verification 2024

Verifier:
FORCE Technology
Park Allé 345
DK-2605 Brøndby

Verified case:
Potential avoided GHG emissions from replacing gas boilers or less efficient heat pumps with the heat pump VZN175.

Date of verification:
26.08.2024

››› Executive summary

Emissions from the operations of buildings account for 30% of global final energy consumption and 26% of global energy-related emissions. For the building sector to align to the global emissions targets and become net-zero, the energy consumption per square meter needs to be reduced by 35% by 2030 (IEA 2023).

Heat pumps are suitable solutions to address this exact issue and are acknowledged by IEA as a "Proven way to provide secure and sustainable heating". (IEA 2022). Danfoss VZN175 compressor contributes to the IEA scenario by reducing the time to market for heat pumps. Unlike traditional systems requiring multiple compressors, the VZN175 achieves up to 70kW heating capacity with a single compressor. Heat pumps use a completely different technology and are, by design, more energy efficient than gas boilers. The seasonal efficiency of a standard air-to-water heat pump (using VZN175) in an average European climate for renovation (55°C water supply) is 194%. In comparison, the latest generation condensing boiler has an efficiency of about 95%.

Most European countries benefit from a heat pump today compared to a gas boiler. Looking to the full life cycle of a 62kW heat pump and a 62kW gas boiler it shows that the heat pump causes more emissions during production, installation and end of life, 13.5 tCO_2/unit for the heat pump vs 1 tCO_2/unit for the boiler. The higher emissions means that the heat pump does not save emissions from the first plugged-in hour, however, for the heat pump with a VZN175 compressor, the breakeven time is between 3 months and 3.7 years. In addition, the cleaner the electricity grid gets, the better is the case for the heat pump from an emission point of view.

One single heat pump has the potential to **save 477 tons of CO_2** over its lifetime compared to a gas boiler. The result was obtained by considering the different climates and grid emissions in the 8 countries in Europe that make up over 80% of the heating need: Germany, the UK, Italy, France, Poland, the Netherlands, Spain, and Sweden.

››› Heat pumps are a key lever to decarbonize heating of buildings

Emissions from the operations of buildings account for 30% of global final energy consumption and 26% of global energy-related emissions. Out of these 26%, 18% are indirect emissions from the production of electricity and heat used in buildings (IEA 2023). Without action, these emissions are set out to increase as the global need for floor area is expected to grow 15% by 2030, mainly in developing economies. For the building sector to align to the global emissions targets and become net-zero, the energy consumption per square meter needs to be reduced by 35% by 2030. (IEA 2023)

Heat pumps are suitable solutions to address this exact issue and are acknowledged by IEA as a "Proven way to provide secure and sustainable heating". (IEA 2022). In particular, air-source heat pumps (ASHPs) can satisfy all energy services (i.e., space heating, space cooling and domestic hot water production) required by the coupled building with a single device and can exploit a significant share of renewable energy from aerothermal, geothermal or hydrothermal sources with high thermodynamic efficiency (Dongellini et al., 2021).

››› Danfoss compressor VZN175 contributes to the IEA scenario by increasing the speed to market for heat pumps

Danfoss VZN175 is the market's largest R290 inverter scroll, designed to accelerate the heat pump adoption in new or renovated buildings, whilst reducing the carbon footprint. Unlike traditional systems requiring multiple compressors, the VZN175 achieves up to 70kW heating capacity with a single compressor. As the system can supply up to 80°C water temperature down to negative ambient temperature, the retrofit of traditional boilers by heat pumps in renovation is now a reality at reach as the footprint of the systems become comparable.

The VZN175 is running on natural refrigerant R290 known as propane, whose global warming potential is less than 1% of other widely used refrigerants in heat pumps such as R-410A (Smith et al., 2021), which means the impact of leakages from the system is kept to a minimum in accordance with the F-gas regulation(EU 2014).

In addition, compared to equivalent tandem fixed speed solution, VZN175 can increase maximum capacity under 5 kg charge constraint by 20%. The variable speed drive also reduces the energy consumption compared to a tandem fixed speed set-up (5-7% according to Danfoss internal estimation on full A/W system in average EU climate) – contributing to the targets of reduced energy consumption per unit floor area.

The current[1] next best alternatives on the heat pump market runs with 2 fixed speed compressors and reaches an efficiency (sCOP[2]) of 3.25 (Danfoss market intelligence). With the above mentioned variable speed drive and the possibility to only use one compressor gives the VZN175 equipped heat pump the possibility to reach a SCOP of 3.75 – a 15% efficiency increase.

››› A heat pump is inherently more efficient than a gas boiler

The gas boiler is used as the main reference case as nearly 50% of the primary energy demand for heating and cooling buildings in the EU comes from gas. Additionally, almost 30% of European energy consumption is used for water and space heating (European Commission, 2022).

Heat pumps use a completely different technology and are, by design, more energy efficient than gas boilers. The seasonal efficiency of a standard air-to-water heat pump (using VZN175) in an average European climate, for renovation (55°C water supply) is 194%. In comparison, the latest generation condensing boiler has an efficiency of about 95%. This means the heat pump is more than twice as efficient in converting primary energy to heating. For the calculations in this study, however, the boiler efficiency is assumed to be 100%. Apart from being energy efficient, another advantage of the heat pump is its ability to use 100% renewable electricity (Camponeschi C., et al.).

		Seasonal efficiency	Thermal energy produced	Emissions except use phase	Lifetime	Capacity
Reference: 62 kW condensing gas boiler		100%	128 MWh thermal energy produced annually	~1 tCO$_2$eq	15 years	~8 dwellings
Reference: 62 kW heat pump with 2 fixd speed compressors		168%	128 MWh thermal energy produced annually	~13.5 tCO$_2$eq	15 years	~8 dwellings
62 kW heat pump with VZN175 compressor		194% (++ EcoDesign)	128 MWh thermal energy produced annually	~13.5 tCO$_2$eq	15 years	~8 dwellings

Figure 1. *Overview of properties, heat pumps versus gas boiler. Seasonal efficiency given for average bin temperature profile as defined in EN14825. Emissions based on interpolation of data from relevant EPD[3] including production, distribution, installation, end of life and maintenance. The same lifecycle emissions (except use phase) have been assumed for the two heat pumps.*

››› Most European countries benefit from a heat pump today compared to a gas boiler

The study shows that cases where heat pumps are an advantage compared to traditional boilers are the norm, with only 2 countries where the benefit of a heat-pump, from an emission point of view, cannot be established (see methodology chapter for calculations). A country's electricity generation emission factor and the duration of the heating season are critical in determining if emissions from the used electricity exceed the emissions generated by a gas boiler delivering the same heat. The gas boiler becomes a sensible alternative only when the emission factor for electricity reaches over 685 $kgCO_2$/MWh (for cold climate). Looking ahead, however, if the decarbonization trend of electricity grids develops as expected, the heat pump should soon be the most sensible alternative in all European countries.

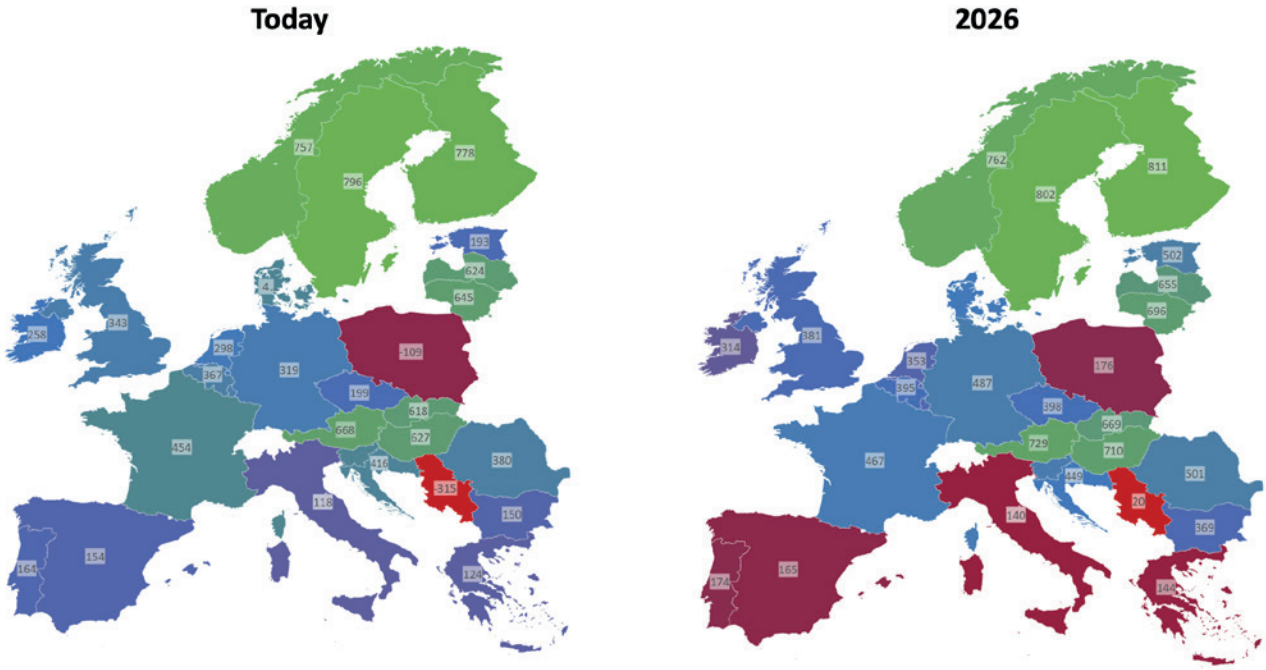

Figure 2: *Kilogram avoided emissions per year and kW capacity and country in Europe using a heat pump (VZN175) versus a gas boiler. Today, 2 countries do not save emissions using a heat pump compared to a gas boiler. But looking towards 2026, all European countries will benefit and already benefitting countries will save even more per installed kW. Today's numbers calculated using 2022 years emission factors for electricity.*

Looking to the full life cycle of a 62 kW heat pump and a 62kW gas boiler it shows that the heat pump causes more emissions during production, installation and end of life, 13.5 tCO_2/unit for the heat pump vs 1 tCO_2/unit for the boiler. The higher emissions means that the heat pump does not save emissions from the first plugged-in hour, however, for the heat pump with a VZN175 compressor, the breakeven time is between 3 months and 3.7 years. This shows that the heat pump is a sensible alternative for emission savings also when the full life cycle is taken into account, as the heat pump generates avoided emissions during more than 11 out of its 15 years lifetime.

As being discussed elsewhere in the report, the numbers are built on forecasts of electricity generation emission factors and external data from EPDs for production of heat pumps. There is therefore a built-in uncertainty in the below numbers that grow more significant the longer the pay off time the heat pump has, caution should be used for countries market in grey below where the estimated impact from the heat pump corresponds to 5% or more, of the estimated avoided emissions. The graph is here to illustrate the differences – and the fact that in the long run, each country will benefit from a heat pump over a gas boiler – rather than showing the exact number of months it takes for a customer to gain back their carbon investment in a heat pump.

[1]Analysis done in summer 2024

[2]This study uses the sCOP factor as a way of comparing the different technologies according to standard EN14825. However, a simulation of the energy consumption can never exactly predict the actual consumption in the real world. The actual consumption will be affected by user behavior, installation correctness and maintenance frequency and unexpected weather conditions. To address this, there is ongoing work to improve the standards further and to educate customers and installers in their choices in regards to the products. So while the sCOP value might not yet be an industry standard value, it is the best available comparison the industry has with substantial data collection behind.

[3]See list of EPDs used in sources.

Time needed until the VZN175 compressor heat pump starts avoid emissions compared to a gas boiler in different European countires with different grid emission factors, Months

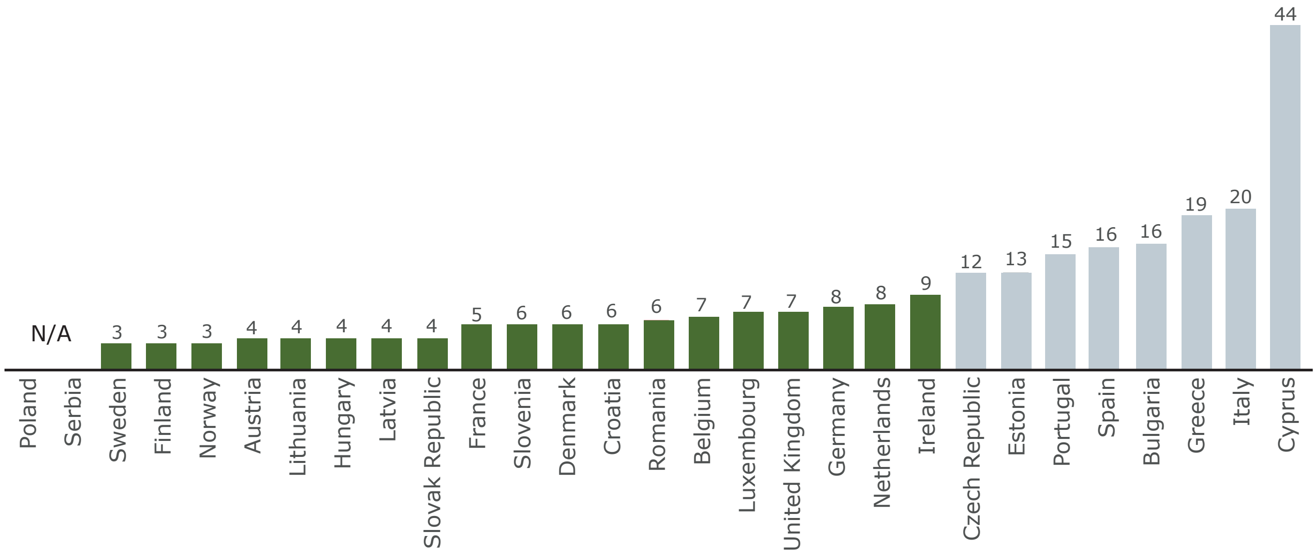

Figure 3: As the VZN175 heat pump is initially more emission intensive to produce and install, emissions are not saved from the first hour. The graph shows after how many months the heat pump starts to deliver avoided emissions. The grey color code indicates that the numbers are more dependent on the assumptions from the EPDs and therefor less certain than for other countries. (Production, maintenance and end of life of the heat pump corresponds to 5% or more of the estimated avoided emissions)

››› Each VZN175 equipped heat pump can potentially save 477 tons of CO_2 emissions over its lifetime compared to a gas boiler

One single heat pump has the potential to save 477 tons of CO_2 over its lifetime compared to a gas boiler. The result was obtained by considering the different climates and grid emissions in the 8 countries in Europe that make up over 80% of the heating need: Germany, the UK, Italy, France, Poland, the Netherlands, Spain, and Sweden. In these 477 tons CO_2, the emissions from production, installation and end of life are already subtracted. The calculation was done taking into account that the electricity grid will get greener over time, in line with IEA stated policy scenario.

Country	Climate	sCOP HP	Heating need (Eurostat, 2024[4]) TWh (% share of total group
Germany	C	2.75	440 (28%)
United Kingdom	A	3.75	281 (18%)
Italy	W	3.95	235 (15%)
France	A	3.75	291 (19%)
Poland	C	2.75	151 (10%)
Netherlands	A	3.75	60 (4%)
Spain	W	3.95	66 (4%)
Sweden	C	2.75	46 (3%)

Table 1: *climate, sCOP factor and heating need for countries making up over 80% of Europe's heating need.*

[4]Data for 2022 used except for UK where 2018 data is used due to data gap.

››› The VZN175 compressor heat pump is 15% more efficient than the next best alternative which has an impact on emission savings

As described above, the next best alternative on the market is a heat pump without the feature of variable speed and a tandem compressors setup which leads to a 13% lower efficiency.

For regions with a high emission factor for the electricity grid, the lower efficiency plays a role as more electricity is needed. Even if it is still beneficial to install a heat pump compared to a gas boiler in the same countries as with the VZN heat pump, the lower efficiency generates emission savings in favor of the VZN heat pump (see table 2).

Country	Saved CO_2 VZN heat pump vs. boiler	Saved CO_2 Next best alternative heat pump vs. Boiler	Difference between heat pumps
	kgCO_2 saved/kW/year		
Sweden	796	790	6
Finland	778	753	25
Norway	757	753	4
Austria	668	621	47
Lithuania	645	600	44
Hungary	627	578	49
Latvia	624	574	50
Slovakia	618	564	53
France	454	446	8
Slovenia	436	415	21
Denmark	434	422	12
Croatia	416	397	19
Romania	380	310	70
Belgium	367	350	17
Luxembourg	351	329	22
UK	343	321	21
Germany	319	229	90
Netherlands	298	269	29
Ireland	258	227	31
Czechia	199	85	114
Estonia	193	78	115
Portugal	164	158	6
Spain	154	148	6
Bulgaria	150	29	121
Greece	124	112	12
Italy	118	106	12
Cyprus	55	35	20
Poland	-109	-264	155
Serbia	-315	-509	193

Table 2: *Overview of net emission savings from using a VZN175 heat pump instead of next best alternative (column 3). Each technology was first compared to the boiler where the results are found in the first and second column. The difference is found in the third column.*

››› Conclusion

In conclusion, this study supports the IEA's assertion that heat pumps are essential for achieving climate targets. Heat pumps offer significant advantages over gas boilers in most European countries and their benefits will only increase as electricity grids become more decarbonized. Currently, a top-tier heat pump can save an average of 477 kg of CO_2 over its lifetime compared to gas boilers. Each replacement of a gas boiler with a heat pump contributes meaningfully to reducing carbon emissions. These findings underscore the critical role heat pumps play in our transition to a more sustainable and climate-friendly energy system.

As has been highlighted in the report, the study builds on external data and more research is needed to confirm the numbers on a country level.

››› Danfoss commitments in climate

We want to become the preferred partner in helping our customers decarbonize, and we have built a strong foundation for achieving our own targets. In January 2020, we took a significant step toward contributing to the goals of the Paris Agreement by committing to set science-based targets. Our emission reduction targets have been validated and approved by the Science Based Targets initiative in May 2022. Danfoss is committed to reduce 46.2 % of absolute scope 1 and 2 GHG emissions by 2030 from a 2019 base year. Danfoss also commits to reduce absolute scope 3 GHG emissions by 15% within the same timeframe.

››› Methodology

In March 2023, the World Business Council for Sustainable Development (WBCSD) has published its "Guidance on Avoided Emissions: Helping business drive innovations and scale solutions towards Net Zero", to support solution providers willing to make credible claims on the environmental performance of their products. Danfoss welcomes this important contribution to ensuring robust environmental claims, providing decision-makers with tools and information to select the most impactful solutions supporting a global sustainability transition.

As recommended by the WBCSD, avoided emissions potential are estimated using a full lifecycle approach on the system considered.

Avoided emission calculation methodology

In summary, the avoided emissions were calculated using a 3 step approach:

1. The total energy consumption of the chiller over the lifetime was calculated using the sCOP factor and the thermal energy output. The energy consumption was then multiplied by the grid emission factor in each country to get the total emissions. A decline in emission factors for electricity was assumed over time. A specific reduction pathway was estimated per country but in line with IEA stated policy scenario (IEA, 2023). Upstream emissions were added to the electricity emission factors but kept constant at 2023 values.

2. The total energy need for the boiler was calculated assuming a 100% efficiency so that the work delivered by the machine corresponds to the required energy input. The energy consumption was then multiplied with the emission factor for gas which was country specific but constant over time, in line with the EU commissions work: Study on actual GHG data for diesel, petrol, kerosene and natural gas considering biogas for domestic use to be marginal.

3. The avoided emissions were then derived by subtracting the total emissions generated by the heat pump from the total emissions generated by the gas boiler. The difference in production, installation and end of life emissions between the heat pump and the gas boiler was also subtracted from the result (the heat pump generating more emissions than the boiler in the other life stages).

Deriving the sCOP factor for a heat pump

To estimate the emissions during the use phase of the VZN175 heat pump, simulations were done in the Danfoss tool Cool Selector using the specific polynomials for the VZN175 compressor. The aim of the simulations was to derive the seasonal performance factor which indicates the energy consumption over the year for a heat pump (not the compressor, as the total energy is dependent on the application). The polynomials are derived during testing in labs in accordance with testing protocols by ASERCOM. The simulations in the Cool Selector tool build on the standard EN 14 825:2017 and are presented in table 3. Table 3 also shows the corresponding sCOP factors for the next best alternative (NBA). The sCOP for average climate could be found in product sheets while the other climates were estimated using the same ratio between the VZN and the NBA as for the average climate.

	Heating capacity	sCOP Average climate	sCOP Cold climate	sCOP Warm Climate
	kW			
VZN175	62	3.75	2.75	3.95
Next best alternative (NBA)	62	3.25	2.38	3.42

The sCOP for average climate for the next best alternative is taken from product sheets, the other climates are estimated using the same rations

Table 3: *Outcome of simulations in Cool Selector for the VZN175 compressor system and overview of sCOP factors for the NBA.*

Emissions from the boiler

The boiler was considered to be of the same capacity as the heat pumps. For simplification, an assumption is made that the same thermal energy needs to be delivered and that the boiler can do that with 100% efficiency, meaning that the gas used is equal to the thermal energy the boiler needs to deliver. The emission factor for natural gas were derived from Sphera – LCA calculator and specific for each country. Where there were gaps in the Sphera database, an average European factor was used (Bastos et al, 2024). The gas emission factors included all types of upstream emissions.

All other emissions, excluding use phase
The lifecycle emissions, except use phase, of the heat pumps and the gas boiler were estimated using public available and third party verified EPDs. As few EPDs were available for the gas boilers, peer reviewed LCAs published in scientific papers were also used. The functional unit for the documents is "production of 1 kW of heating and cooling over the reference lifetime of the product", this unit was, however, not used as a unit of comparison to derive the CO_2 footprint of the boiler or heat pump. The reason was the dependency on the assumptions of the use phase. If e.g different running hours or climates have been selected, the functional unit is not a good base of comparison. Instead, a CO_2 value per kg of product was used as both the weight of the system and the CO_2 per unit was available in the EPDs (and could be derived also in the LCAs).

The EPDs below were consulted to find production, installation, and end of life emissions. The number of available EPDs for boilers on the usual EPD databases are low, hence an approximation had to be done with existing data, even if the capacity for these units is lower. In other aspects, the EPDs are comparable, both for boilers and heat pumps. They share the functional unit, all machines are defined to be used and produced in Europe. The heat pump EPDs are all generated using the same product rules. For the boilers, as mentioned above, some research papers were used where the same functional unit was used, but other aspects could be different.

EPD code	Brand	Capacity	Weight	Weight per capacity	Emissions exc. use phase	Emission per kg
	kW	kW	kg	kg/kW	kg CO_2 per unit (no model D)	kg CO_2/kg
	Boilers					
ARST-00002-V01.01-E+N	Ariston	12.25	31	3	760	24.2
REME-00003-V01.01-EN	Remhea	20	28	1	265	9.4
REME-00003-V01.01-EN	Remhea	24	30	1	274	9.1
REME-00003-V01.01-EN	Remhea	30	31	1	279	9.0
VARMAX B3 275KW 20MB 2 3 PIQ	Atlantic	275	569	2	5132	9.0
Famiglette et al. (2020)	N/A	35	61	2	285	4.7
Vignali (2016)	N/A	24	40	2	132	3.3
Numbers used	Average weight per kW used: 1.7 kg/kW				Averagee of all sources: 9.8 kg CO_2/kg unit	
	Heat pumps					
CARR-10024-V01.02-EN	Carrier	167	1778	11	102393	57.6
CARR-10027-V01.01-EN	Carrier	91	1217	13	20474	16.8
AUER-00003-V01.01-FR	Auer	53	640	12	2952	4.6
AUER-00003-V01.01-FR	Auer	27	465	17	2183	4.7
UNIC-00041-V01.01-FR	Uniclima	35	476	14	13701	28.8
BROT-00001-V01.01-EN	Brötje	30	380	13	3397	9.0
BROT-00001-V01.01.-EN	Brötje	20	361	18	3106	8.6
BAXI-00009-V01.01	Baxi	20	361	18	3106	8.6
DDTH-00027-V01.01-FR	DeDietrich	25	272	11	2881	10.6
REME-00015-V01.01-EN	Remeha	25	272	11	2902	10.7
DAIK-00013-V01.01-FR	Daikin	22	198	9	4019	20.3
Numbers used	Average weight per kW used: 13.3 kg/kW				Averagee of all sources: 16.4 kg CO_2/kg unit	

››› Limitations of the study

As Danfoss does not manufacture neither heat pumps nor gas boilers, there exist no source of internal data to determine the exact emissions generated during the lifetime of the machines. Instead, the study relies on external EPDs. This is a major uncertainty in the study as the number of external EPDs were limited and the EPDs were not transparent enough to be completely comparable. As a consequence, an average of the values in the EPDs were used, despite showing quite variable results. This methodology has a larger impact on the results for the countries where the calculations result in small volumes of avoided emissions, such as Cyprus and Italy. It has less impact where the avoided emissions are significant.

Another limitation of this study comes from the electricity generation emission factor used which are derived from IEA Stated Policies Scenario (STEPs). This scenario reflects existing policy frameworks and stated policy plans. It does not forecast future and unannounced policy frameworks. Country level forecasted emission factors were derived from regional ones, under the assumption that countries' grid within a region will decarbonize at the same pace. Although policy packages such as EU's Fit for 55 are likely to drive electricity grid decarbonization across EU, the actual decarbonization rate may differ country by country.

Last but not least, while a full life cycle approach for electricity generation was followed, upstream and downstream emission factors (e.g. transmission and distribution losses) have been considered stable over time.

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››› Reference standards and documents used

Bastos et al 2024: Bastos, Joana; Monforti-Ferrario, Fabio; Melica, Giulia (2024): GHG Emission Factors for Local Energy Use. European Commission, Joint Research Centre (JRC) [Dataset] PID: http://data.europa.eu/89h/72fac2b2-aa63-4dc1-ade3-4e56b37e4b7c

Camponeschi C., Goni M., Cioffi F., Dongellini M., Naldi C., Morini G.L., Germano L., Genovese F., Cervellati A., Casolari A., Corsaro F., Ciancamerla M., Ballotta L. 2024. Potential of Energy Saving of Propane Heat Pump as replacement of gas boilers with low and high temperature emitters

Coulomb D., Dupont J.L.L., Marlet V., Morlet V. 2017. The impact of the refrigeration sector on the climate change. International Institute of Refrigeration, 35th informatory note on refrigeration technologies. Paris (France), p. 17. Retrieved from: https://iifiir.org/en/fridoc/the-impact-of-the-refrigeration-sector-on-climate-change-141135 (last access: 12/12/2023)

Dongellini M., Naldi C., Morini G.L. 2021. Influence of sizing strategy and control rules on the energy saving potential of heat pump hybrid systems in a residential building. Energy Conversion and Management, 235, 2021, 114022

IEA (2022), The Future of Heat Pumps, IEA, Paris https://www.iea.org/reports/the-future-of-heat-pumps, License: CC BY 4.0

IEA (2023), Emission Factors

EU (2014) regulation (eu) no 517/2014 of the European parliament and of the council of 16 April 2014 on fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006

EPA (2023) Source: Carbon factors provided by the U.S. Environmental Protection Agency, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021, Tables A19, A-24, A-31, and A-215. Heat content of fuels provided by the U.S. Environmental Protection Agency Greenhouse Gas Emissions Factor Hub, survey Form EIA-923, and Appendix Tables A1-A3 of the EIA Monthly Energy Review https://www.eia.gov/environment/emissions/CO_2_vol_mass.php

European Commission (2022), Directorate-General for Energy, Kranzl, L., Fallahnejad, M., Büchele, R. et al., Renewable space heating under the revised Renewable Energy Directive – ENER/C1/2018-494 – Final report, Publications Office of the European Union, 2022, https://data.europa.eu/doi/10.2833/525486

European Commission, (2015), DG Energy, Study on actual GHG data for diesel, petrol, kerosene and natural gas. Work order ENER/C2/2013-643

Eurostat, 2024 - https://doi.org/10.2908/NRG_D_HHQ, Dataset: Disaggregated final energy consumption in households – quantities. Online data code: nrg_d_hhq, Downloaded: 2024-07-22. Data from 2022 used except for UK where 2018 data is used

IPCC (2006) Guidelines for National Greenhouse Gas Inventories, Volume 2: Energy, Tables 1.4 and 2.5. Net calorific value converted to gCO_2/kWh.

Smith et al., (2021) Chris Smith (United Kingdom), Zebedee R. J. Nicholls (Australia), Kyle Armour (United States of America), William Collins (United Kingdom), Piers Forster (United Kingdom), Malte Meinshausen (Australia/Germany), Matthew D. Palmer (United Kingdom), Masahiro Watanabe (Japan), The Earth's Energy Budget, Climate Feedbacks and Climate Sensitivity Supplementary Material, https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter07_SM.pdf

EPDs used for calculating emissions from the full lifecycle except use phase:

EPDs taken from the PEP eco passport website: https://register.pep-ecopassport.org/pep/consult

Heat pumps:

Auer: ZéPAC, Pompe à chaleur non réversible pour application à moyenne température Gamme HRC70 40 à 80 kW. Registration number: AUER-00003-V01.01-FR, Date of issue:: 05-2022

Carrier: FC series reversible heat pump unit 50FC 020-093 R454b, Registration number : CARR-10027-V01.01-EN, Date of issue: 05/2022

Uniclima: Pompes à chaleur air/eau pour la production d'eau chaude sanitaire collective sans ballon, Registration number: UNIC-00041-V01.01-FR, Date of issue: 01/2023

Daikin Europe N.V: Daikin VRV IV+ Pompe a chaleur air/air (unite exterierure), Registration number: DAIK-00013-V01.01-FR, Date of issue: 07/2023

Boilers:

Ariston: Condensing boiler Alteas One+ Net 24 (reference: 3301771) providing heating and domestic hot water production for individual dwelling, Registration number: ARST-00002-V01.01-EN, Date of issue: 12-2023

Atlantic: VARMAX B3 275KW 20MB 2 3 PIQ 275 kW, Registration number SCGA-00126-V01.01-FR, Date of issue: 2022/10/01

Jacopo Famiglietti *, Tommaso Toppi, Lorenzo Pistocchini, Rossano Scoccia, Mario Motta (2020) A comparative environmental life cycle assessment between a condensing boiler and a gas driven absorption heat pump, Milano, Italy, Department of Energy, Politecnico di Milano

Giuseppe Vignali (2016), Environmental assessment of domestic boilers: A comparison of condensing and traditional technology using life cycle assessment methodology, Parma, Italy, Department of Industrial Engineering, University of Parma