Heat Pumps

Integrating technologies to decarbonise heating and cooling

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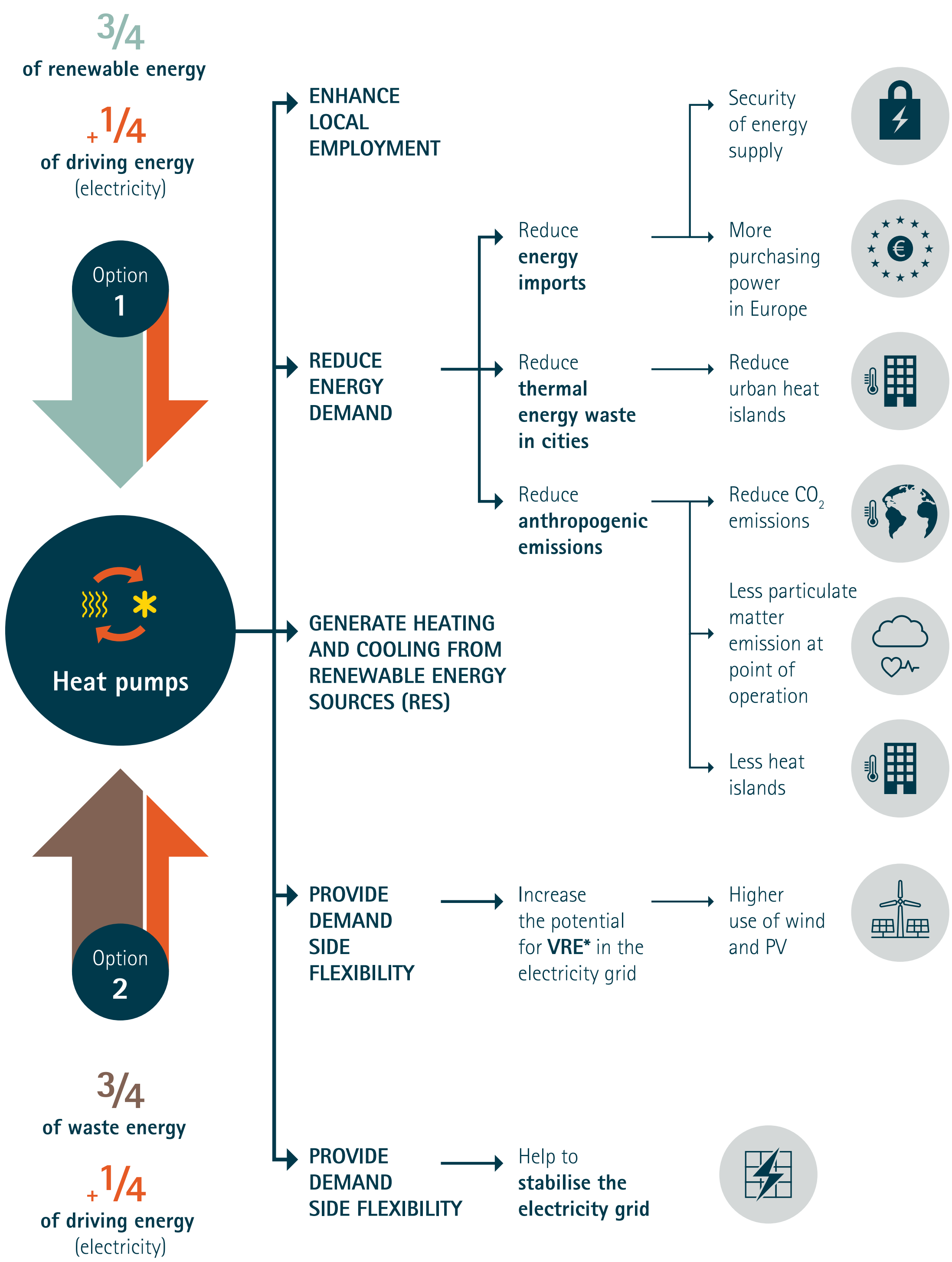
European Copper Institute
Copper Alliance

THE ADDED VALUE OF HEAT PUMP TECHNOLOGIES



*VRE= Variable renewable electricty

Heat Pumps

Integrating technologies to decarbonise heating and cooling

ABSTRACT

Heat pump technology can deliver major economic, environmental and energy system benefits to Europe. Heat pumps use renewable energy and may be the single most efficient technology for heating and cooling, particularly when both services are required in the same location and at the same time.

Heat pumps are installed in larger numbers only recently, while the underlying concept has been around for over 150 years. The technology is now becoming a keystone to the energy mix for decarbonising heating and cooling in industry and society at large. The energy transition is therefore not a technology challenge but rather a policy and awareness-raising issue.

This special report sheds light on the fundamental principle of the technology, the renewable and waste-energy based sources used, the financial and energy efficiencies that are achieved, the business models being deployed, and the non-technical benefits for the environment and society.

Directed at policy-makers and industry players, this report advances the unique integrative function that heat pumps provide for decarbonising the heating and cooling sectors, thus explaining why heat pump technology will be at central component of Europe's future energy system.

ABOUT THE AUTHOR

Thomas Nowak is an economist and a renewable energy afficionado. He is convinced that we have all the necessary technologies to continue the full process of decarbonisation of the heating/cooling sector and of society at large. Thomas Nowak is the Secretary General of the European Heat Pump Association (EHPA) based in Brussels to advance the industry interests around Europe. He lives a 100% C02 emission free building by combining small-scale decentral power production (PV), a heat pump and a contract for green electricity.

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Introduction

DECARBONISING EUROPE BY 2050

Decarbonising society without decarbonising heating and cooling is not possible.

Heating is fundamental to human life. At the most elemental level, the sun gives life to plants via the process of photosynthesis and warms the Earth to be habitable for animal and human life. Heat from fire revolutionised cooking and all things related to making forms more malleable. Beyond alchemy and the melting of metals into new shapes, the channelling of heat provided the means to make new structures, habitats, roads and cities. Steam produced from coal drove the industrial revolution and then the discovery of oil and gas exploded the transport sectors to power trade around the world. But it is not only heating - today global value chains would be impossible without cooling.

For centuries, heating was provided by burning fossil energy sources – wood, coal, oil and gas. However, the negative environmental effects are no longer acceptable to society. The 2015 UNFCCC Conference of the Parties (CoP) in Paris agreed to "limit global warming to well below 2°C." The Paris Agreement implies a full decarbonisation of our economic activity on Earth and the way we power that activity, most notably its energy system, and to a large extend also its material economy.

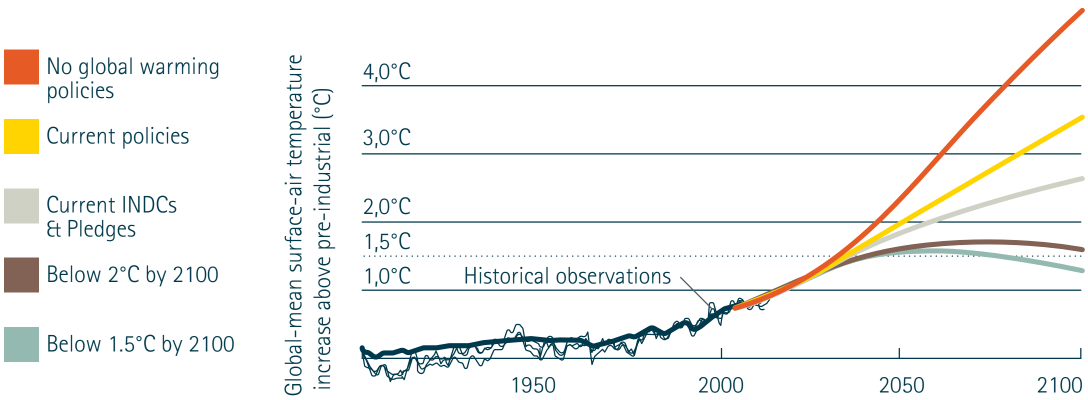
The decarbonisation scenarios calculated by the Intergovernmental Panel for Climate Change (IPCC) show clearly that if global warming is to be limited to 1,5°C with a probability of 50%, world-wide CO_2 emissions need to be reduced to zero by the middle of the 21st century. All pathways to achieve this target include negative emissions – the filtering of CO_2 from the atmosphere – while the technologies to do this are in their infancy at best.

While not very visible, Heating and cooling has a special role to play in the transition towards a sustainable energy system. Globally, this sector is responsible for close to 40% of final energy demand. In Europe, 52% of final energy demand comes from heating and cooling; 25% are used for electricity generation; and 23% in transport. The decarbonisation of society without decarbonising heating and cooling is thus impossible.

Fortunately, in the heating and cooling sector, technologies are available today to achieve 100% decarbonisation. Heat pumps can play a major role as stand-alone solutions or in combination with biomass, solar thermal energy, direct geothermal and - to a smaller extent - green gas and oil. The challenge in this sector is less a technology one, but mostly one of political will that requires a much more ambitious political effort to modify the legislative framework governing heating and cooling to make it compatible with full decarbonisation by 2050.

Today, heat pump technologies can facilitate a fundamental change towards a 2050-ready heating and cooling system. "Heat pumps allow society to remove emissions from heating and cooling, and they have several additional economic, environmental and societal benefits for a sustainable future, not least do they help modernise our economies and maintain non-delocalised jobs in Europe. This report sums up the state-of the-art of heat pump technology and provides an overview of its benefits in light of the goal to decarbonise Europe by 2050.

Figure 1 **POSSIBLE CO_2 EMISSION PATHWAYS**



Source: Climate Analytics GmbH

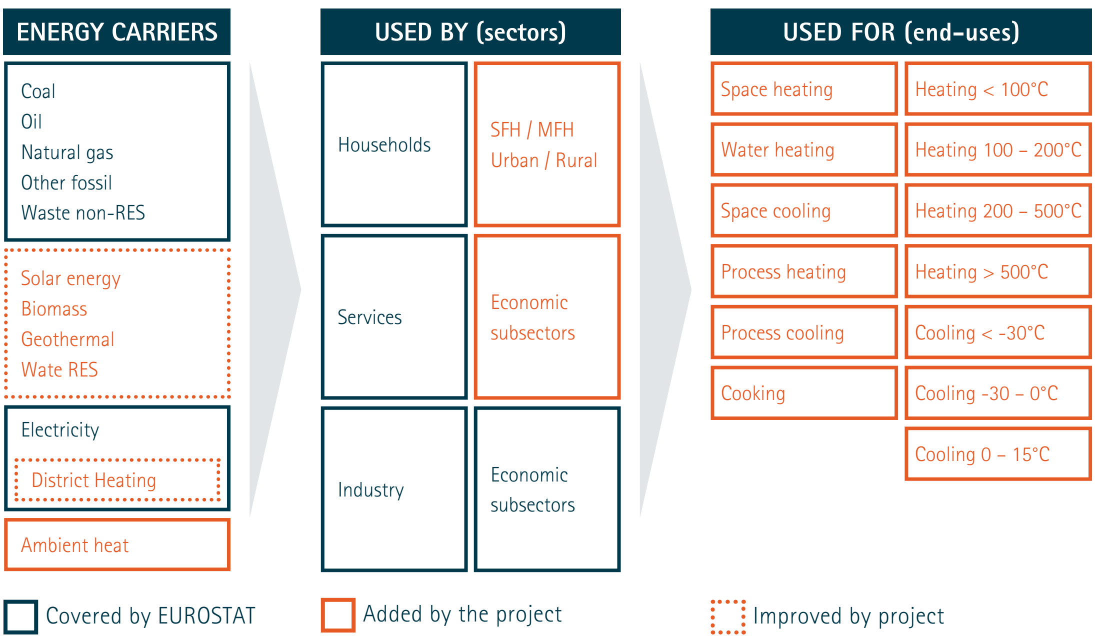
Chapter 1: HEATING AND COOLING DEMAND IN EUROPE

When heat pumps are used, heating and cooling are two sides of the same coin. Using both in a smart way will help close energy cycles.

Heating and cooling is needed across societies and industries. The challenge is to address, curb and minimise the environmental impact of Europe's growing energy demand. While the impact of heating and cooling on Europe's energy demand has been acknowledged, fundamental and precise data was not available in the past. This applies to Europe as a whole and to its Member States and regions. The quality of the statistics measuring energy demand and energy efficiency of buildings varies greatly from country to country, making any attempt to aggregate it on a European level difficult.

The European Commission took a huge step forward in remedying this situation by tendering research on the heating and cooling market in Europe. The March 2016 report *Mapping and analyses of the current and future (2020-2030) heating/cooling fuel deployment (fossil/renewables)* is arguably the most comprehensive and most consistent report available; it evaluates existing energy statistics, extends them by services, and distinguishes demand by energy carrier and sector.

Figure 2 **STRUCTURE OF END-USE BALANCES CALCULATED IN COMPARISON TO EUROSTAT FINAL ENERGY BALANCES**



Source: Fraunhofer Institute

The waste or excess heat from a cooling process should always be recovered to be reused.

The resulting end-use balances (Figure 2) allows for a much more focused policy development and – if the report is continuously updated – will enable an evaluation of policy impacts in the future as well as subsequent target-oriented adjustments.

The addition of renewable energy, district heating and ambient heat to the current fossil energy sources, the addition of sectors and the extension by services provided, as well as the split by related temperature levels are all important enhancements to energy statistics. They will allow for a more refined analysis, identification of priority areas and the assessment of fossil fuel replacement options as well as the estimation of related savings potential.

Based on 2015 data, Europe's final energy demand is approximately 12,600 TWh. 6,352 TWh (50.3%) is for heating and cooling, with fossil gas being the dominant energy carrier (42%), followed by oil, biomass and electricity (all 12%). District heating accounts for 9% and coal for 8%. Electricity is then used for direct electric heating or heat pumps. The breakdown of this demand is shown in Figure 3 and Table 1.

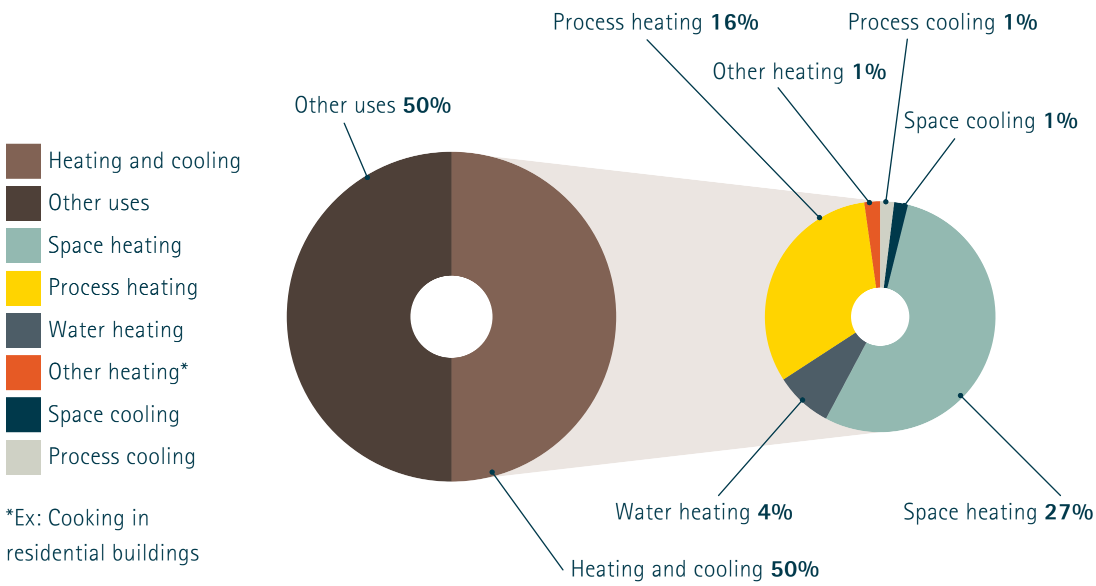
Table 1 **FINAL ENERGY DEMAND FOR HEATING AND COOLING IN EU28 (2015)**

	ANNUAL FINAL ENERGY DEMAND	SHARE OF HEATING/COOLING FINAL ENERGY DEMAND
Space Heating	3,387 TWh	53%
Process heating	2,011 TWh	32%
Water heating	521 TWh	8%
Other heating	191 TWh	3%
Process cooling	155 TWh	2%
Space cooling	87 TWh	1%
TOTAL	**6,352 TWh**	

Source: Heat Roadmap Europe

The combined energy demand for space and process heating is responsible for 85% of the energy used for heating and cooling or 43% of total final energy demand in the EU. While the demand for cooling is expected to increase significantly, in 2018 it constitutes only 3.8 % of total final energy demand. From the available data it can be concluded that the decarbonisation of Europe's energy system relies on the successful decarbonisation of heating. Still cooling should not be neglected, as demand for it is expected to rise significantly in the future. Taking a joint perspective on heating and cooling and providing both services based on renewable/waste energy will help decarbonise

Figure 3 **EU28 FINAL ENERGY DEMAND BY END-USE ALL SECTORS IN 2015 [TWH]**



Source: Profiling heating and cooling demand in 2015. D3.1 Heatroadmpa Europe project (2017), Fleiter, T. p. 14

the sector. While cooling should be given more attention, solving the heating issue is the biggest individual challenge for the decarbonisation of the sector.

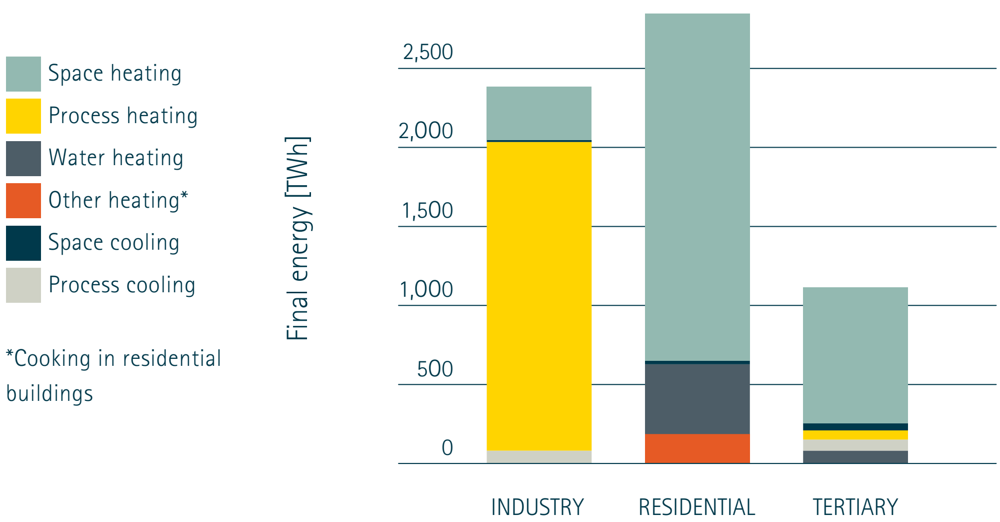
From a technical perspective, nearly all cooling devices use the refrigeration cycle which can provide heating and cooling at the same time. "Especially in commercial buildings, the deployment of heat pumps in conjunction with an energy management system can help to avoid wasting energy. Waste heat from cooling one part of the building can be distributed to other parts, where heating is needed or this energy can be used to provide domestic hot water. In consequence, final energy demand would be reduced and energy cycles would be closed."

In all sectors, the current deployment of heat pumps is far below its potential.

Distinguishing the energy use by sector shows that space and water heating are responsible for the largest share of energy demand in residential and commercial buildings, while process heating dominates industrial applications and space heating is only of minor importance in this area. The latter gives an indication that space heating demand in industrial applications can be covered by using the waste heat from industrial processes. The surplus of these processes could also be used to heat the building stock outside the given industrial premise – if the energy can be made available via energy grids at the required temperature level, time and location. Better data is necessary to evaluate this option and fortunately numerous research projects are addressing this information gap. A good overview of the energy use in heating and cooling was provided as the result of a tender mapping this sector and this data has been update as part of the "Heat Roadmap" Europe project. The latter also presents energy use maps for different countries as well as an interactive thermal atlas for all Europe.

Looking at the split of energy use between sectors, Figure 4 shows that heating is the dominant service in residential and tertiary sectors, while process heating dominates in industry.

Figure 4 **SPLIT OF ENERGY USE AND APPLICATION AREA**

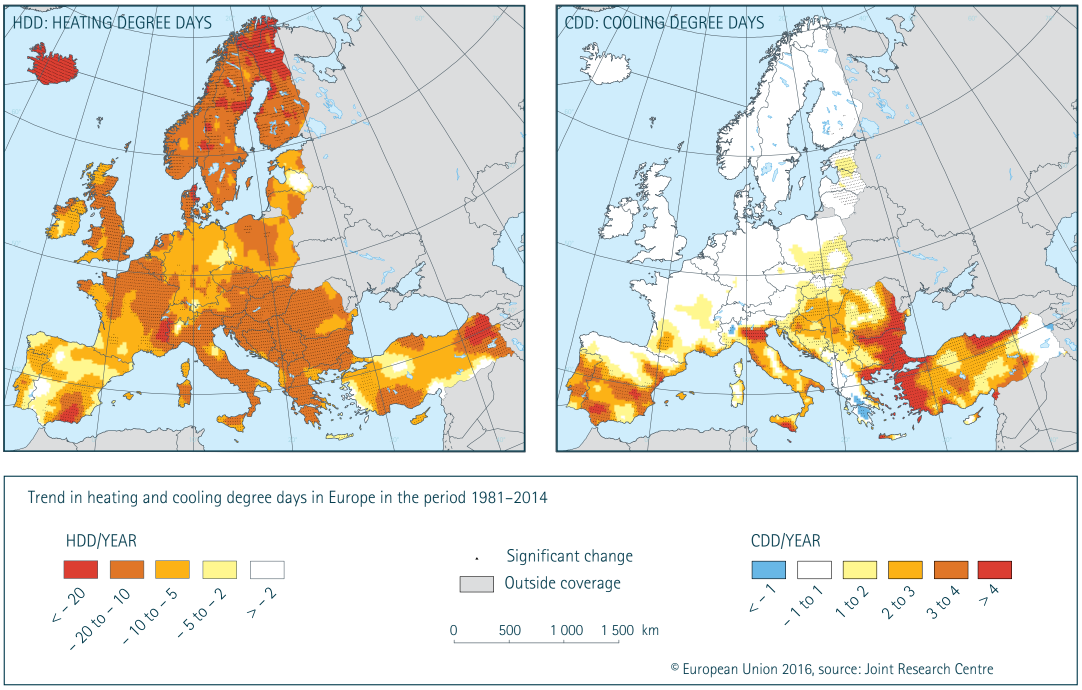


Source: Own visualisation, based on data from Fraunhofer Institute

When it comes to the replacement potential of these demands by heat pumps, heating and hot water production are the most obvious, while opportunities in process heating - using available technologies - are limited to temperature ranges below 170°C. The current deployment of heat pumps in all sectors is far below the potential.

Heating and cooling demand in Europe depends on the climate zone in combination with respective building traditions and local or national energy efficiency standards. Variations from country to country, significantly influence the replacement potential for heat pumps. Obviously, heating demand is higher in colder climates while cooling demand dominates in warmer climates. What is not so obvious is that the number of heating degree days (HDD) across Europe are decreasing, while the number of cooling degree days (CDD) is increasing as shown in Figure 5.

Figure 5 **CHANGE IN HEATING AND COOLING OVER THE 33 YEARS: MAP OF HEATING DEGREE DAYS IN COMBINATION WITH ENERGY DEMAND PER M²**



Source: European Environment Agency

Building envelopes are getting better – meaning they are losing less thermal energy through walls and windows (better insulation quality) and have better ventilation (tighter windows and roofs). Comfort requirements are also increasing, which means inhabitants of warmer regions are more likely to turn on cooling systems in hot summers and conversely to turn up the heat in cold winters.

With regards to heat pumps, this creates a business opportunity, as the technology provides heating and cooling at the same time and the waste heat from the cooling process could be used to provide hot water at very low additional cost.

With gas being responsible for 51% of all hot water production, providing hot water with essentially free excess heat from cooling processes can truly be called "a low hanging fruit of decarbonisation".

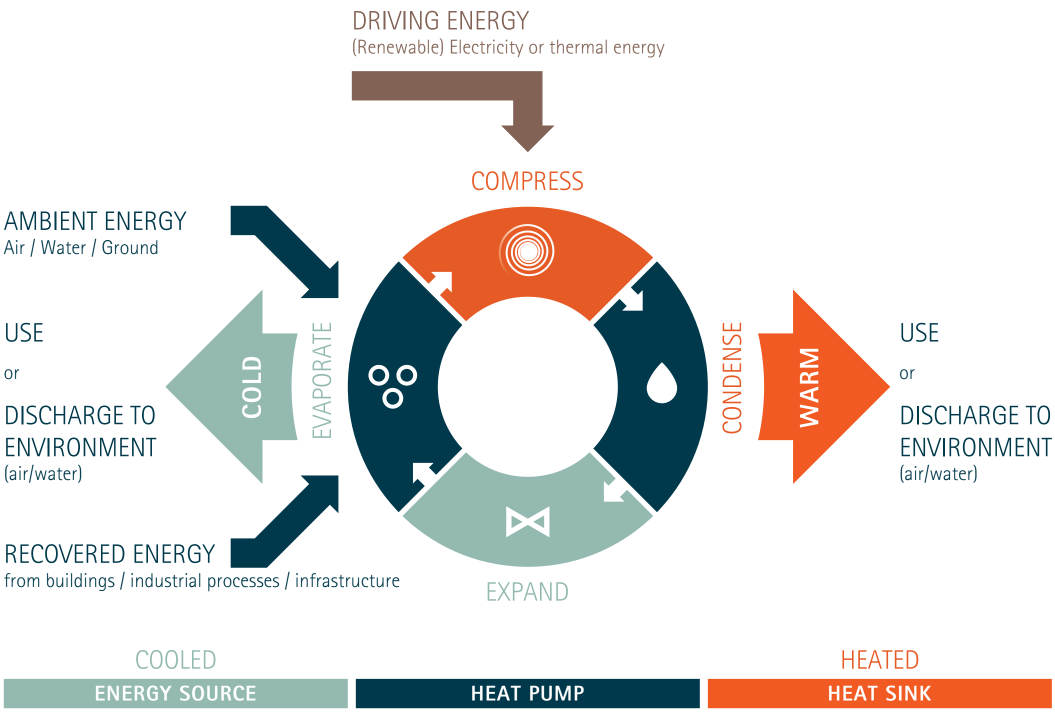
Chapter 2: HEAT PUMP TECHNOLOGIES

WHAT IS A HEAT PUMP?

A heat pump is a device that can provide heating, cooling and hot water for residential, commercial and industrial applications. Any heat pump installation can provide heating and cooling in parallel. Depending on which service is used predominantly, the machine is called a heat pump, an air-conditioning unit, or a cooling/refrigeration machine.

Numerous thermodynamic principles exist and are used to provide heating and cooling. Consequently, the term heat pump does not refer to a single solution but to an array of technologies that can be used. This was enough reason for the International Energy Agency (IEA) to rename its knowledge centre into "technology collaboration program on **heat pumping technologies** (IEA HPT TCP)".

Figure 6 **VAPOUR COMPRESSION CYCLE PROVIDING HEATING AND COOLING SIMULTANEOUSLY**



Source: EHPA

The refrigerant cycle provides heating and cooling simultaneously.

The electric vapour compression cycle (see Figure 6) is deployed in most heat pumps available in the market and will thus be used to illustrate the technical operating principle in this paper.

Apart from the electric compression cycle, a heat pump compressor can be driven by an electric motor or a gas engine. A smaller share of heat pumps use the vapour compression cycle but are driven by combustion engines. Depending on the process, this is further distinguished in adsorption and absorption processes. Other heating and cooling technologies, some of them still in an experimental stage and few with market relevance are based on cold gas compression as well as on thermoelectric, thermomagnetic, thermoacoustic and thermoelastic processes.

100% RENEWABLE ENERGY WITH HEAT PUMPS IS FEASIBLE TODAY.

When the driving energy needed to drive the refrigerant cycle in heat pumps is renewable energy (from wind, PV, green gas, etc), heat pumps are a 100% renewable, 100% emission free solution. Since the heat pump unit can also use electricity produced on site, it is reducing the stress that an increased electricity demand may put on the grid. Heat pump systems can serve as thermal batteries providing demand response services and allow more renewable electricity in electricity generation.

THE UNIVERSAL APPLICATION POTENTIAL OF HEAT PUMPS

While this whitepaper focusses on heat pump applications in buildings and industry the technology itself is much more widely used. Every family owning a fridge, benefits from it, as the refrigeration cycle cooling your food is the same that can heat your home. The technology is also deployed in dish washers, washing machines and tumble dryers to significantly improve their energy efficiency and it will be essential to increase the range of electric cars by ensuring proper operating temperatures for the batteries and comfort for the passengers.

2.1 TECHNICAL PRINCIPLE

HOW DOES A HEAT PUMP WORK?

The basis of a compression heat pump is the refrigeration cycle which is also known as a thermodynamic cycle. It consists of 5 components (cf. Figure 6).

- **an evaporator (a “liquid-to-gas” heat exchanger)**
- **a compressor**
- **a condenser (a “gas-to-liquid” heat exchanger)**
- **an expansion valve**
- **a transfer fluid (refrigerant)**

EVAPORATION AND COMPRESSION

The underlying principles of the refrigeration cycle are experienced regularly in real life: everyone has felt cold at some point when stepping out of the shower or a swimming pool even in summer because the water on the skin is confronted with cooler ambient air and evaporates. **Evaporation** needs energy – evaporating water on skin uses energy from the human body thus cooling down the skin and creating a chill effect.

And to exemplify compression: every cyclist that has had a flat tire knows that compressing a gas will heat it up. The effect can best be felt after filling the bicycle tire with air: the tip of the bicycle pump will be warm, if not even hot which is the result of **compressing** air molecules in the confined space of the tube. The same happens in the heat pump when the electric compressor fan captures and compresses the refrigerant vapour molecules.

In the compression refrigeration cycle, a transfer fluid (refrigerant) transports the heat from a low-temperature **energy source** to a higher temperature **energy sink.** In the evaporator, the refrigerant is exposed to the energy source and evaporates. Mechanical energy – usually via an electric motor or a gas engine – is used to compress the refrigerant gas. In this step, the temperature is raised to the required level. At a high temperature, the high pressure gas enters the condenser, where the energy is transferred to a distribution medium. The refrigerant vapour is cooled down and becomes a liquid again. This liquid (still under pressure) is then fed into an expansion valve. The result is a low pressure, low temperature liquid, ready to enter the evaporator. This process is running continuously in a closed (and depending on the design: hermetically sealed) cycle.

Heat pumps can use renewable energy from air, water and ground sources as well as excess energy from processes and exhaust air from buildings.

The refrigerant cycle provides heating and cooling simultaneously: in **heating mode,** the energy source is cooled down continuously and heat is provided to the energy sink of the process. For heating a building, ambient or waste energy is the heat source and the building is the heat sink.

In **cooling mode,** cooling down the energy source continuously is the desired service. In this case, the energy produced is discharged to the environment as waste. A good illustration of this process is a refrigerator: the inside of the fridge is cooled continuously and as the temperature in the fridge drops consequently so does the temperature in the food or drink products stored inside. To keep the process running, the energy is discharged to the environment via the heat exchanger on back side of the fridge. When a building is insulated properly, it can be heated by recovering and reusing the excess energy of the fridge.

OPERATING TEMPERATURES AND TEMPERATURE LIFTS OF HEAT PUMPS

Heat pumps can operate at outdoor temperatures between about -20 to -25°C and 25°C. They typically cover a temperature range of about 50-70 K, depending on the refrigerant used and the system design. Larger temperature gaps can be overcome by a staged design combining two compressors, typically with different refrigerants, that lift the temperature in two stages from outdoor temperature to useful temperature level. In this case, the heat provided by the first heat pump unit is the energy source for the second refrigeration process.

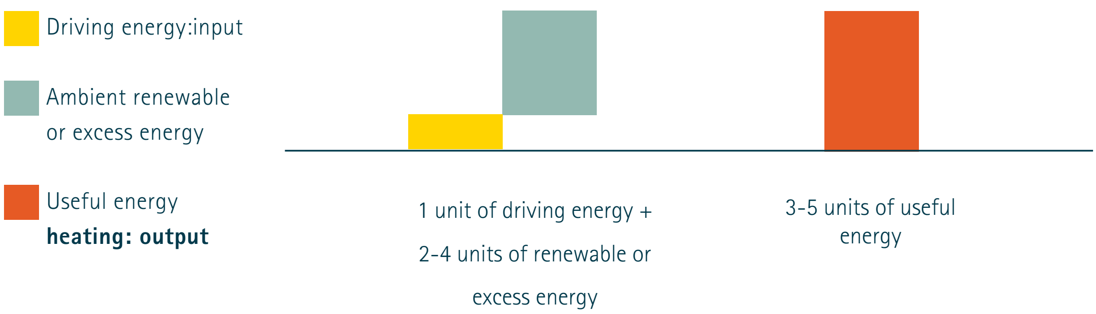
Industrial heat pumps are most often bespoke systems designed to cater to specific needs. Depending on the system design and refrigerant used, a temperature difference of about 70K is covered with a maximum useful heat of around 150 to 170°C. The majority of applications is providing heating at 30 - 55°C and hot water at 55°C to 65°. The latter can be increased by deploying CO_2 heat pumps that efficiently provide hot water at 90°C. One of the challenges in industrial heat pump design is the selection of components that can operate at higher temperatures on the side of the energy source.

2.2 ENERGY SOURCES FOR HEAT PUMPS

HOW ARE HEAT PUMPS POWERED?

An electric compression heat pump uses electricity to run the compressor and the pumps; a sorption heat pump uses thermal energy to drive the cycle. In the total energy balance, the share of driving energy needed to drive the cycle is comparatively small; in heating mode, one unit of driving energy generates approximately 3-5 units of useful heat (see Figure 7).

Figure 7 **HOW ENERGY IS GENERATED BY A HEAT PUMP SYSTEM**

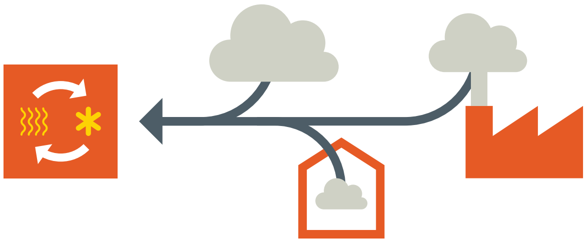


Source: Own

Most of the energy generated is extracted from the environment: heat pumps can use renewable energy from air, water and ground. Heat pumps can also use excess energy from industrial processes, infrastructure installations (sewers, subway, underground parking) and reuse exhaust air from buildings. Distinguishing between renewable and excess energy is sometimes not easy, however the impact is the same: an evident reduction of non-renewable final energy demand and related emissions. The ratio between the share of driving energy and renewable/excess energy is determined by the coefficient of performance (COP) of the machine.

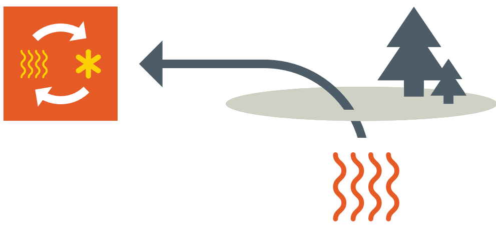
The type of energy used determines the heat pump technology deployed and is also part of the typical naming convention:

— **AIR SOURCE HEAT PUMPS**
use outside, indoor or exhaust air as energy sources.



— **GROUND SOURCE (OR GEOTHERMAL) HEAT PUMPS**
use energy from the ground, extracted via a closed loop horizontal or vertical collector. Energy from the ground is transferred to a transfer fluid ("brine" or water) and transported to the heat pump unit.

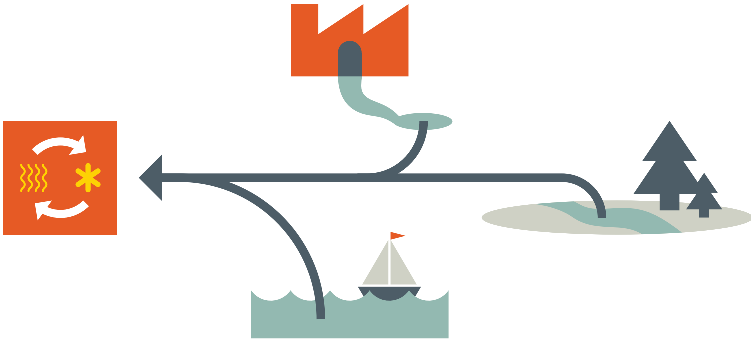
A special type of ground source heat pump are direct expansion heat pumps that do not use a transfer fluid, but circulate the refrigerant through pipes directly in the ground, thus saving one pump and achieving better efficiency.



WATER SOURCE HEAT PUMPS

in principle identical to ground source units: instead of a closed loop heat exchanger with a transfer fluid, they use water directly (open loop).

Water source heat pumps can be connected to aquifers, rivers, lakes or the sea, and to wastewater, cooling water from industrial systems, or a district heating system.



When several heat generators are combined, this is called a **hybrid system.** Typical combinations are (list not exhaustive):

- Air source heat pumps and small gas boiler for peak load
- Heat pump and solar thermal collector
- Heat pump and biomass boiler
- Heat pump and direct electric back up (this is somehow a standard configuration, as most storage tanks have a resistant heater. Whether or not it is used depends on the system configuration.)

HOW IS HEAT PUMP ENERGY DISTRIBUTED?

With the ongoing 'greening' of the electricity mix all heat pumps are reducing the emissions of buildings. Heat pump systems use air or water to distribute energy. The medium used to distribute the energy is the second determining factor in naming a heat pump system. This can either be a water-based (hydronic) or an air-based system.

In hydronic distribution systems, heat generated by the heat pump is transferred to radiators, floor heating or wall-based emitters that then condition the respective rooms or - when transferred via heat exchangers - processes. The water loop is typically used for heating and (with limited effect) also for cooling.

EU Directive 2009/28 defines air (aerothermal), water (hydrothermal) and ground (geothermal) as renewable energy sources to be used with heat pumps to generate useful heating and cooling.

In air-based distribution systems, conditioned air is transported directly or via ducts to the rooms or processes. So-called 'polyvalent' systems, provide heating, cooling and/or dehumidification.

A mix of both is also possible where energy is distributed in water-based systems, but disseminated in the room via decentral heat exchanger units, known as fan-coils.

The presented distinction illustrates that heat pump solutions are available for a variety of combinations between energy sources and distribution. They can provide comfort for many cases, but proper planning and design are essential to maintain end-user comfort.

Table 2 **NAMING CONVENTION FOR HEAT PUMPS**

ENERGY SOURCE	Hydronic, water based distribution system: typically used for heat distribution, only of limited use, when cooling is required	Air (ducted or non ducted) distribution system, used for heat and cold distribution, dehumidification also possible
Air	Air/water heat pumps use air as energy source and a hydronic system for energy distribution production – either with floor/wall heating or via radiators.	Air/air heat pumps use air as energy source and ducts to distribute the energy in the building
Water	Water/water heat pumps use Water as energy source and a hydronic system for energy distribution production – either with floor/wall heating or via radiators.	Water/air heat pumps use water as energy source and ducts to distribute the energy in the building
Ground	Ground/water heat pumps use geothermal energy as energy source and a hydronic system for energy distribution production – either with floor/wall heating or via radiators.	Ground/air heat pumps use geothermal energy as energy source and ducts to distribute the energy in the building

Chapter 3: SOCIAL, ENVIRONMENTAL AND ECONOMIC BENEFITS OF HEAT PUMPS

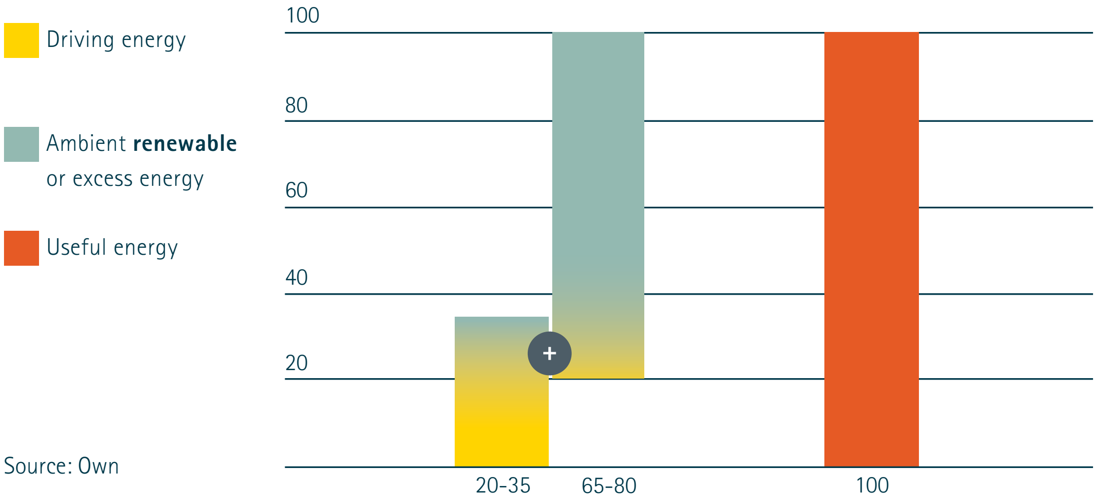
3.1. INTEGRATING RENEWABLE ENERGIES

— DO HEAT PUMPS REALLY USE RENEWABLE ENERGY?

This question is asked most often by people that doubt the use of electricity for heating and because many people think that heat pumps are simply an electro-technology in disguise. The answer, however, to this question is a resounding: "YES! Heat pumps can generate a lot of heat from renewable energy sources and use only a smaller part of driving energy to do so."

How so? Picture a building or industrial process that needs 100 units of energy. If equipped with a heat pump, the operator pays for 20-35 units of final energy while the building or process requires 100 units of useful energy to be kept comfortably warm/operating. This energy is provided by the heat pump. The difference between the driving energy (that needs to be paid for) and the energy demand of the building/process covered by the heat pump (known as useful energy) is recognised as renewable, if captured from the ambient - air, water or ground (see Figure 8). The Directive on the promotion of the use of

Figure 8 **ENERGY USE IN AN ELECTRIC COMPRESSION HEAT PUMP IN HEATING MODE**



Source: Own

renewable energy sources generally applies to heating and cooling. While a calculation method to determine the share of renewable energy for heating has been established, the equivalent method to determine the renewables share in cooling has yet to be developed.

Heat pumps that are operated with 100% green electricity can provide 100% renewable, emission-free heating and cooling today.

In Europe, heat pumps are a renewable energy technology by thermodynamics and by definition. Article 2 of the European Directive on the promotion of energy from renewable sources (2009/28/EU) defines aerothermal, geothermal, and hydrothermal energy as renewable. Article 5 stipulates that this energy should be counted in European energy statistics. A method for the calculation of this contribution is given in the Annex to the Directive as well as in a subsequent European Commission decision.

Renewable energy is counted as final energy: the difference between the useful energy produced from the heat pump and the driving energy used to drive the unit is deemed renewable (see the green area in Figure 8). Calculation factors are to be determined for the different categories of heat pumps covered and include: the capacity of the heat pump, its operating hours, its efficiency and the number of heat pumps sold.

HEAT PUMPS + SOLAR PHOTOVOLTAICS = A MARRIAGE FORGED IN HEAVEN

The combination of a photovoltaic generator, a heat pump and both battery and thermal storage moves a building a long way from energy user to prosumer for heating and (if required by the user) cooling.

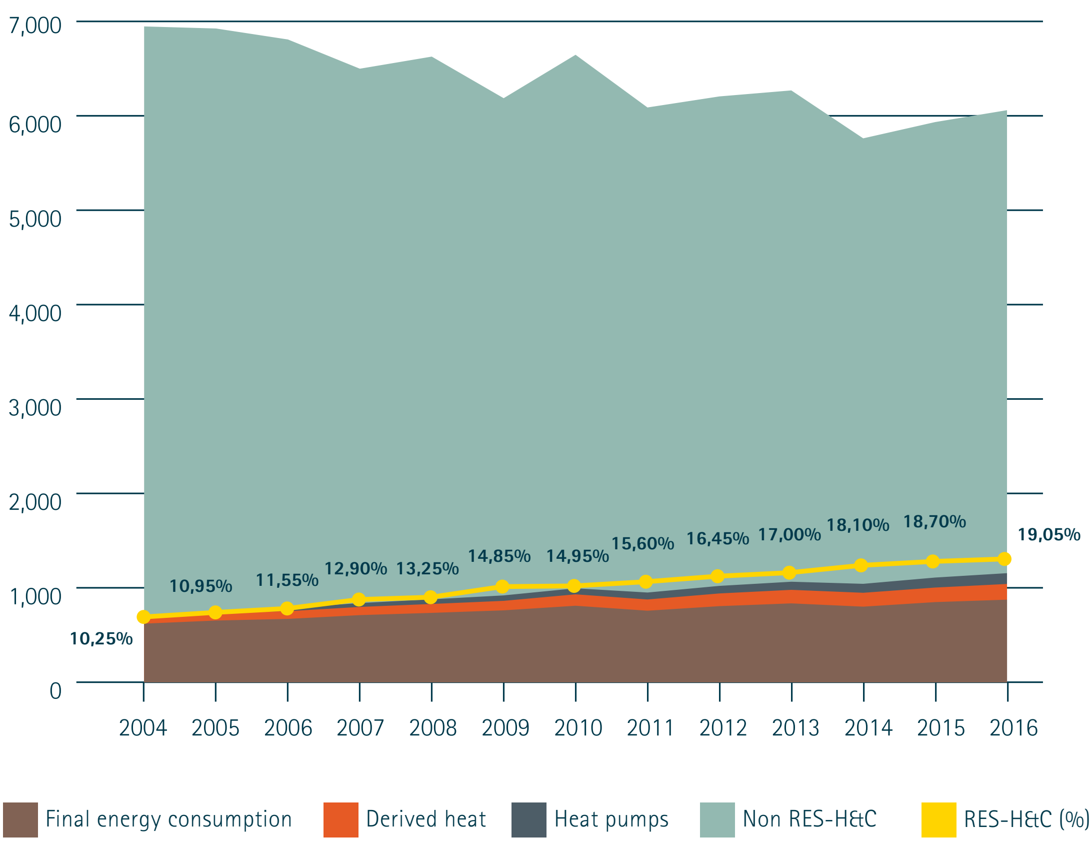
When heating or hot water is required, operating times of the heat pump can be adjusted to maximise on-site, auto-produced electricity or the use of surplus green electricity from the grid. Additional demand can be induced by super heating both the hot water tank or the building core while maintaining end-user comfort. The waste cold from this process can be used to provide cooling to the building.

When cooling is required, the waste heat from the cooling process can be used for hot water production (as then typically no heating is required in parallel). Most striking is the parallel relation between high solar irradiation and cooling requirement. The mentioned system design maximises the relief of the grid in summer, when typically additional demand from cooling can be observed. Integrated thermal and battery storage as well as smart controls allow the shift of cooling demand from hours of darkness to daytime, thus avoiding a cooling induced evening peak on the grid.

Heat pumps operated with 100% green electricity provide 100% renewable, emission-free heating and cooling today. From an energy statistics perspective however, the origin of the driving energy is treated as a black box. Eurostat counts the generated thermal energy in the heating segment, while the share of green electricity is accounted for separately in the electricity statistics.

The use of renewable energy for heating is published annually on the Eurostat website. As Figure 9 shows, the development is insufficient for a fast decarbonisation of the heating sector.

Figure 9 **DEVELOPMENT OF THE RES SHARE OF FINAL ENERGY USED FOR HEATING AND COOLING**



Source: Eurostat Shares

3.2. HEAT PUMPS AND ENERGY EFFICIENCY

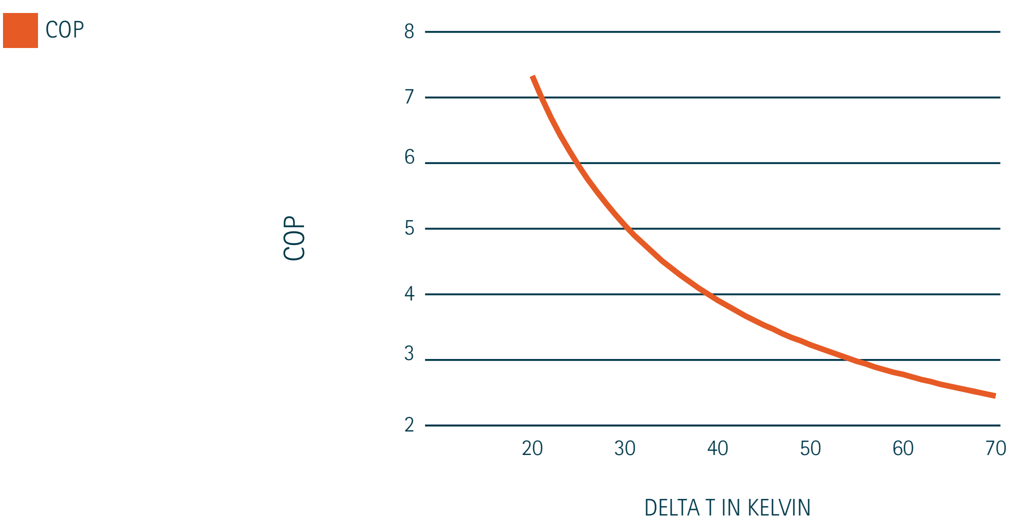
HOW IS THE EFFICIENCY OF HEAT PUMPS DETERMINED ?

The thermal efficiency of a heat pump is described as coefficient of performance (COP). This factor describes the ratio of thermal energy produced (in other words the useful energy available for heating or cooling) over input energy to the process (in case of the electric compression heat pump this is the electricity needed to run the compressor).

Figure 10 **EFFICIENCY OF A HEAT PUMP: THE RATIO BETWEEN USEFUL ENERGY AND ENERGY INPUT**

The efficiency of the heat pump depends on the temperature difference between the energy source and the energy sink (delta T, in K). The smaller the temperature needed for heating and the higher the temperature of the heat source, the less work must be done by the compressor and thus, the more efficient the heat pump unit will be. The same applies for cooling. Figure 11 illustrates this relation.

Figure 11 **$COP_{HEATING}$ AS A FUNCTION OF THE TEMPERATURE DIFFERENCE BETWEEN HEAT SOURCE AND HEAT SINK**



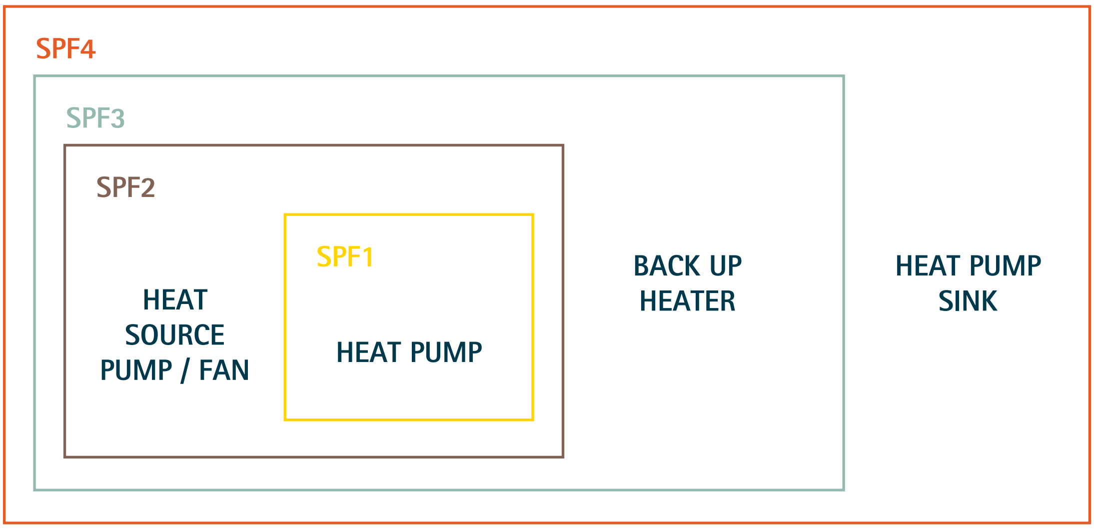
The coefficient of performance is determined under standard conditions in a laboratory. This standardized approach allows the comparison of different heat pumps with regards to their efficiency. Measurements are based on standard EN14511.

The **efficiency of a heat pump systems** in operation depends on the unit's efficiency and the thermal energy requirements of the building in which it is operated. In residential applications, the energy demand of the building depends mainly on its energetic quality and its local climate zone. The seasonal efficiency of a heat pump is determined by weighing the efficiency of the unit at standard operating conditions with the number of days at which these occur. The resulting measure is the **Seasonal Coefficient of Performance (SCOP)**. This factor is determined using European standard EN 14825 and is also used to provide a more realistic comparison of heat pumps across different climate zones. The approach is the basis to determine heat pump efficiency in the ecodesign regulation which is then applied to determine the energy label for heat pumps.

The efficiency of hot water production depends on the amounts and temperature levels of the water used. It is determined via a number of representative daily tapping cycles set down in European standard EN 16147. The resulting measure is a daily **coefficient of performance for hot water production (COP_{DHW})**.

The most comprehensive approach to determine heat pump system efficiency measures the performance of a unit installed in a building or a process. The result is called the **seasonal performance factor (SPF).**

Figure 12 **DIFFERENT SYSTEM BOUNDARIES TO DETERMINE THE SPF OF HEATING AND COOLING SYSTEMS**



Source: Sepemo-build

The SPF applies to a specific combination of heat pumps, building and climate zones. It allows the energetic assessment of the installation in a specific building. In order to compare different SPF values, the system boundaries must be identical. The EU project SEPEMO built has developed an approach to enable the assessment of annual efficiency for different parts of the heat pump systems. The different SPF values could serve as blueprint for future field measurements enabling the comparison of data across Europe.

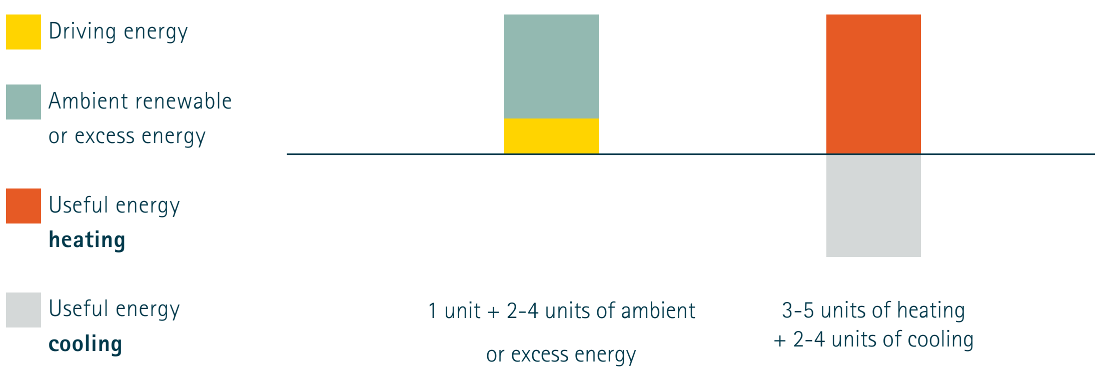
An optimal SPF requires a system's perspective during the design process. The lower the design temperature of a building's heat distribution system or the better the fit of the system to an industrial process, the better the efficiency of the whole system.

It requires skilled, trained and indeed visionary architects, designers, planners and installers to understand the interrelation between building properties and solar orientation, heating and cooling demand and the prevailing climate. New original architectural forms are emerging around the world – and across Europe – that are integrating heat pumps into the building fabric in aesthetically attractive (and often invisible) and always very efficient fashion.

Typical heat pumps require one unit of final energy (electricity) to provide 3-5 units of heat output. For cooling, typically one unit of input electricity results in 2-4 units of cooling. Obviously, this most optimal use of input energy greatly improves the units efficiency and reduces overall energy demand (see Figure 13).

One unit of electricity input provides around 5 to 9 units of heating and cooling. From an investment perspective, only one installation is necessary to provide both services. Such multiple service devices

Figure 13 **THE ENERGY BALANCE FOR A HEATING AND COOLING HEAT PUMP**



Source: Own

providing heating and cooling, hot water and dehumidification (sometimes also called polyvalent heat pumps) thus have an economic advantage both from an investment and an operating cost perspective.

EXTENDING THE SYSTEM BOUNDARY: PRIMARY ENERGY EFFICIENCY

All efficiency values explained so far are based on the efficient use of final energy input. Final energy is the energy that the user purchases to execute a function, for example lighting a building or providing heating and cooling.

For energy statistics, also the demand for primary energy is reported. In order to allow for a comparison a primary energy factor (PEF) can be applied to convert primary into final energy and vice-versa.

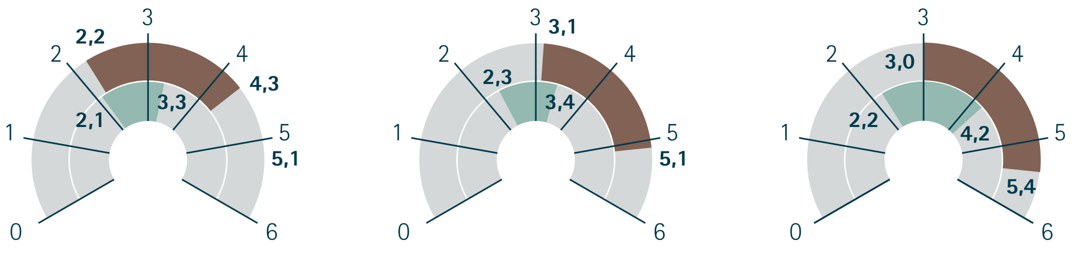
A Primary Energy Factor (PEF) connects primary and final energy. It indicates how much primary energy is used to generate a unit of electricity or a unit of usable thermal energy.

The latest revision of the EU Energy Efficiency Directive sets the default PEF in the EU at a value of 2.1. It is used in the Energy Efficiency and the Ecodesign Directive and radiates out to the Energylabel. It implies that each unit of final energy, ie. electricity requires an input of 2.1 units of primary energy. It therefore assumes that on average power generation (independent of source) in the EU has an efficiency of 47,6% (100 ÷ 2.1). The value of 2.1 is a default factor, leaving Member States with the opportunity to use their own values, pending they can justify them. In order to accommodate for progress in greening the electricity mix and in reducing its emission, the factor will be reviewed regularly.

DEVELOPMENT OF EFFICIENCY

The efficiency of heat pumps has increased over time. This can be observed both in the development of unit performance but as well when looking at the efficiency of systems. An evaluation of heat pump performance over different projects executed by the Fraunhofer ISE in Freiburg, Germany reveals an increase of top efficiency in new buildings from 5.1 to 5,4 for geothermal heat pumps whereas air-water heat pumps have increased their top efficiency from 3,4 to 4,2. Figure 14 shows data from three different projects. The chart on the left shows results from measurements in existing buildings, whereas the chart in the middle and on the right show results from heat pumps in new buildings. The comparison between existing and new buildings shows that similar efficiencies are possible, if the system is designed properly. The analysis of efficiency in new buildings also shows that the overall quality of installations is increasing while the variation of efficiency is declining.

Figure 14 **EFFICIENCY INCREASE OF AIR-WATER AND GROUND-WATER HEAT PUMPS OVER TIME**



SPF 2008-2009
Existing building

SPF 07.2007-06.2010
New building (HP efficiency)

SPF 07.2012-06.2013
New building (HP monitor)

Ground-water heat pumps   Air-water heat pumps

Source: Miara, M. (2014): Feldtest Wärmepumpen - Vergleich der Effizienz unter realen Bedingungen mit den Labor-COP Werten. Düsseldorf

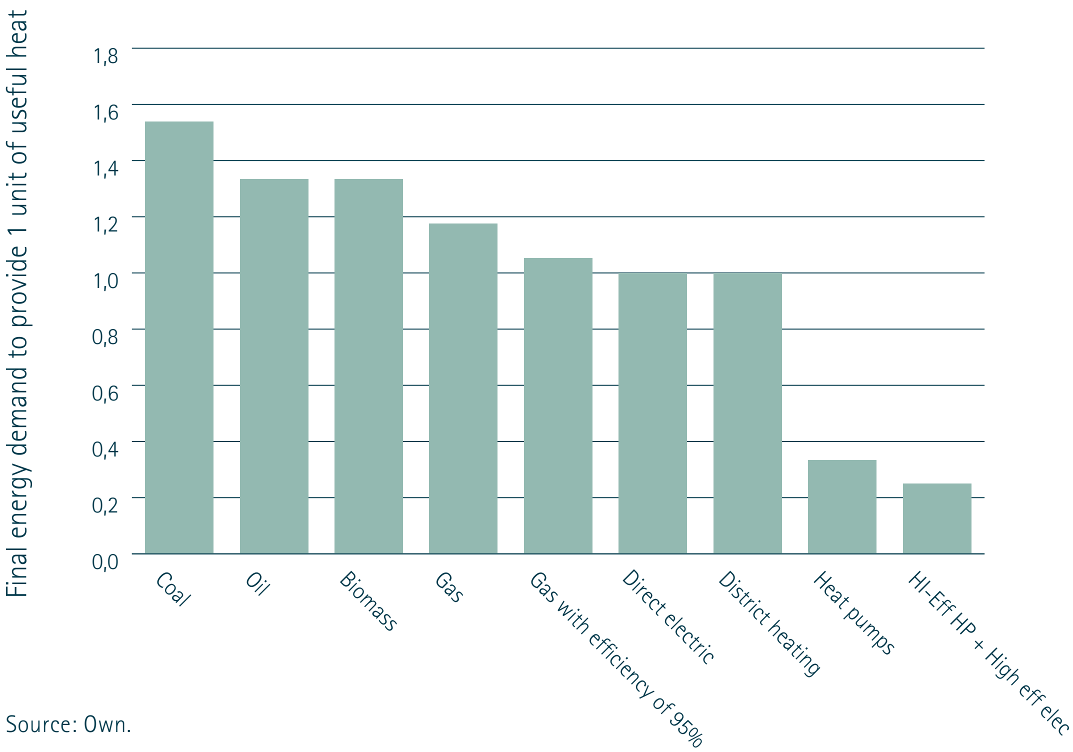
The energy needed to heat one house with a gas boiler – if converted into electricity – is sufficient to heat 2-3 houses with heat pump technology

An increase in energy efficiency means reaching lower input levels or achieving a better target with the same energy input. Energy efficiency can apply to technological improvements that increase the efficiency of the heat pump unit or can result from hardware replacements in a system – when a fossil boiler is replaced by a heat pump. In the latter case, a large share of fossil input energy is replaced by renewable energy and thus oil and gas no longer need to be purchased. In both cases, the minimum definition of energy efficiency applies: the same result in terms of energy output is achieved with much less energy input.

The maximum energy efficiency is achieved when heat pump technology is deployed. The multiplier effect kicks in when heat pumps use a given supply of energy, such as the electricity used for direct electric heating. Replacing an electric heating system with a heat pump frees 2/3 to 3/4 of electricity used - in other words, the energy needed to heat one building with direct electricity is sufficient to heat 3-4 buildings with heat pump technology. A similar effect applies to the replacement of fossil boilers with heat pumps. If the fossil energy no longer needed for heating is converted to electricity in efficient cogeneration plants, the energy content needed to heat one house with a gas boiler is sufficient to heat 2-3 houses with heat pump technology. Thus a wide deployment of heat pumps will contribute to a reduction of final energy demand and is estimated to have only a small impact on the maximum load on the electricity grid.

Figure 15 highlights the advantage of heat pumps over other heating solutions when it comes to the energy efficiency of heat provision. The graph shows the necessary energy input to provide 1 unit (1kWh) of useful heat.

Figure 15 **COMPARISON OF FINAL ENERGY DEMAND OF DIFFERENT HEATING SYSTEMS.**



Source: Own.

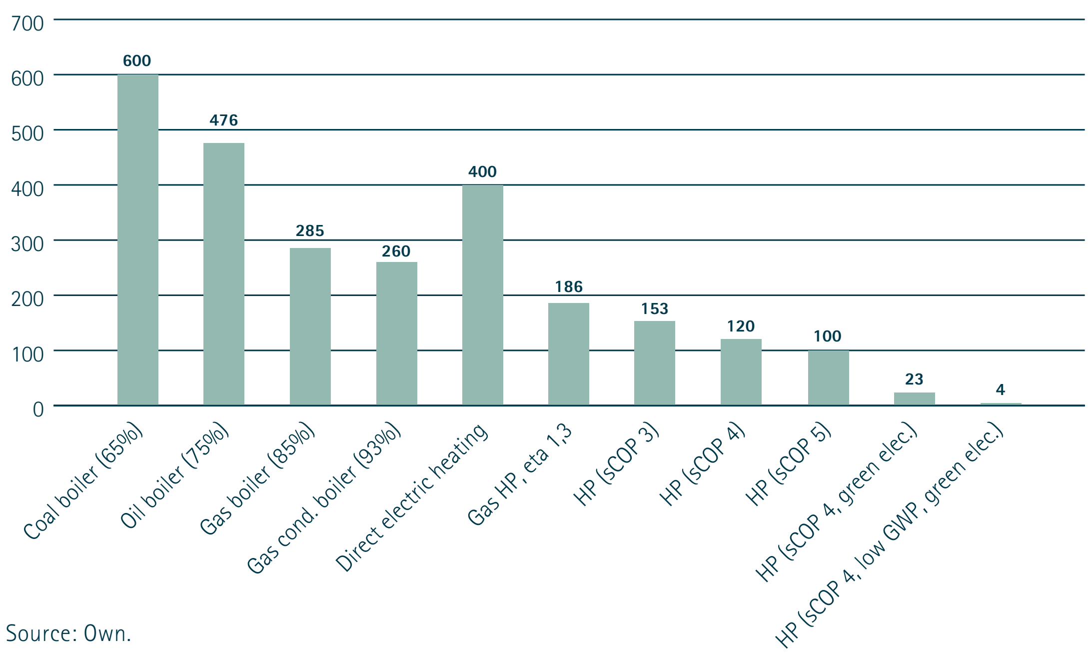
3.3. REDUCING GREENHOUSE GAS EMISSIONS

Reducing greenhouse gas emissions is the means to fighting climate change. Heat pumps achieve this goal by replacing fossil fuels with renewable energy or by making use of excess energy otherwise wasted. The consequence of replacing fossil fuels means improved efficiency, cleaner air and moving towards zero emissions in our economies and societies.

The reduction of carbon emissions from using heat pumps is calculated as a comparison of the heat pump CO_2 emissions with a given alternative. In new buildings, the alternative is the best available other technology, today a condensing fossil gas boiler. With current refrigerants and the integration of renewables in the electricity mix, heat pumps can reduce carbon emissions by 35-65% when replacing gas. If a coal or oil boiler is replaced, the savings are much bigger. When replacing a direct electric system, savings are determined directly by the efficiency of the heat pump system.

Figure 16 shows an overview of the CO2-emissions of different heating technologies per kWh of thermal energy. More efficient heat pump technology combined with green electricity has the potential to nearly fully decarbonise heating and - depending on the methodological approach - cooling.

Figure 16 **COMPARISON OF CO_2 EQUIVALENT EMISSIONS OF DIFFERENT HEATING SYSTEMS (PER KWH)**



Source: Own.

The energy transformation requires at least 60% of electricity to be produced from renewable energy sources.

40-55% demand reduction is possible in a cost-efficient manner from efficiency improvements of the building envelope. To reduce demand further, the remaining energy demand must be supplied by near-zero emission technologies and energy sources. This will not only be achieved by heat pumps, but by other sources, too. The following energy sources and related technologies are often suggested - they can often be complemented by heat pumps into energy efficient and renewables based hybrid systems:

RENEWABLE ENERGY SOURCES FOR DIRECT HEAT SUPPLY

- solar thermal energy (mind the seasonal mismatch)
- biomass (used based on sustainability criteria)
- ambient energy to be used with electric heat pumps based on a high share of renewables from local production (home PV) and the electric grid

MORE EFFICIENT USE OF (GREEN) FUELS

- combined heat & power, mainly for large power plants, but also for larger residential and light commercial applications
- gas heat pumps for individual buildings (but still very small market share)
- hybrid heat pumps complementing heat pumps with a peak demand gas boiler
- use of waste heat with heat pumps thus reducing the demand for fossil energy

An emission reduction by 85% is feasible but requires an increase of electricity consumption by 42% and a much larger share of synthetic hydrogen and methane. The following steps are required to integrate heat pump technologies into a larger share of the building stock.

- integrated solutions providing heating, cooling, and hot water
- standardized solutions for different building types, sizes and energy standards
- deploying large-scale heat pumps for district heating networks
- heat pump solutions using different heat sources (air, ground, waste heat in industry)
- gas-based high efficient solutions like hybrid heat pumps, gas driven heat pumps, fuel cells or micro-CHP
- smart solutions to connect the electricity and heating sector and to provide stability to the electric grid (for example: heat pump systems as energy storage providers and hybrid heat pumps)
- solutions responding to the phase-down of refrigerants with a high global warming potential (GWP) by 2030

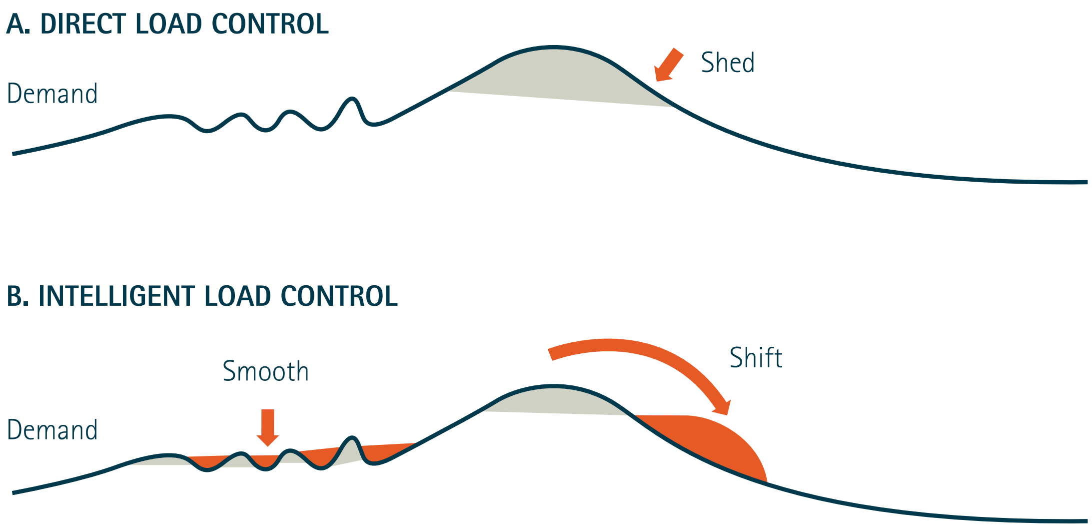
3.4. STABILIZING GRIDS BY PROVIDING DEMAND RESPONSE POTENTIAL

The electric grid is a network of transmission lines connecting power production sites with the users of electricity. The grid also includes storage, transformers and control equipment to ensure stable voltage and power. The electric grid is changing. In the past, grids where following a demand side design: consumer demand was followed by modifying the output of numerous central power plants. Electricity was mainly flowing from the supply to the demand side. With the ongoing 'greening' of electricity production, many comparatively small and decentralised power producers are entering the grid making it more competitive and generating bidirectional flows of electricity. This change makes controlling the supply side more difficult, if not impossible, as renewable energy sources, namely solar photovoltaic and wind provide energy in variable amounts and at variable times. Add to this the increasingly digital component of monitoring and measuring and you have the emergence of smart grids.

The new approach to grid stabilization requires a focus on adjusting demand to the given supply. New approaches providing demand side flexibility are getting increasingly important, some of which include:

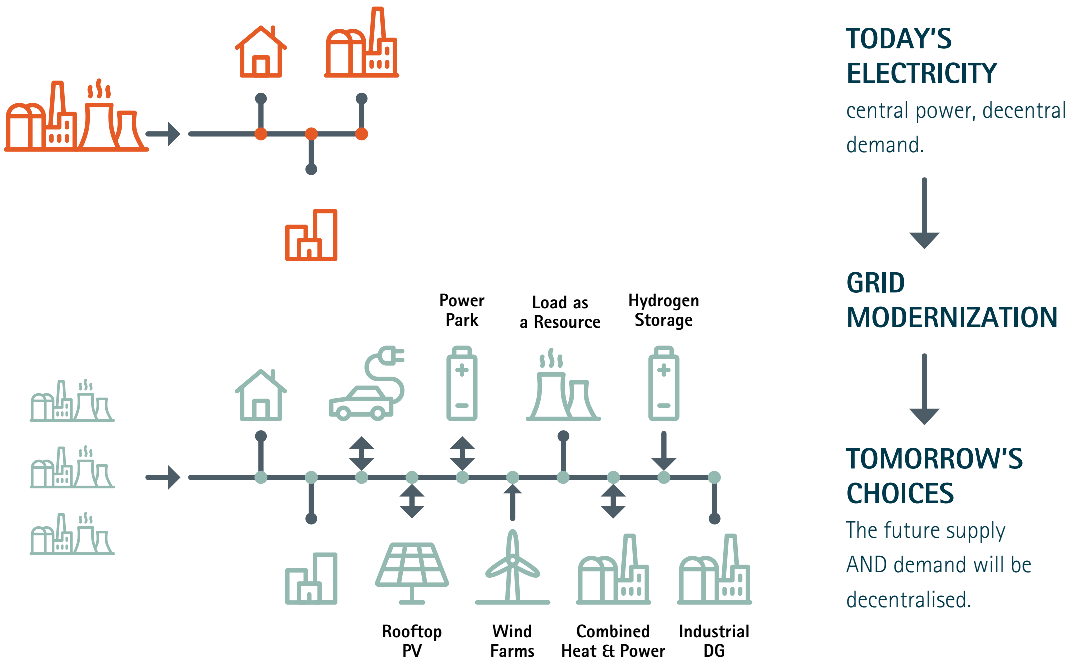
- storage (hydro, building core, ground, ice storage), and batteries
- control strategies to modify electricity demand of devices and systems in response to capacity/price signals from the grid
- new business models combining the above

Figure 17 **THE EFFECT OF HEAT PUMP-INDUCED FLEXIBILITY ON THE DEMAND CURVE**



Source: Adapted from Integral Analytics Inc.

Figure 18 **TRADITIONAL GRIDS VERSUS THE GRID OF THE FUTURE**



Source: IEE

Bi-directional communication between electricity producers and users is becoming paramount to adjust demand and future supply patterns. A smart grid delivers just that: digital technology that enables a two-way communication between producers and consumers in order to adjust demand to available supply. A **smart grid** is also equipped with sensors on all network levels providing a continuously updated picture of the status of the grid and its customers.

Heat pump-based systems can be connected to electric and thermal storage:

A. they include a water tank to store domestic hot water and (possibly) a second tank to store heat or cold for later distribution

B. if equipped with floor or wall heating, the thermal mass of the building can be heated up shifting demand

C. if equipped with a battery, its charge can be used to run the heat pump at night - for cooling and heating

Heat pump-based systems normalize the demand curve by providing load shaping and load shifting services.

In the cases of A and B, the system characteristics provide a "thermal battery" to the grid. Electricity is used in times of surplus to heat up the storage or the core of the building. In times of supply shortage, the heat pump is not used while the stored energy is distributed inside the building, maintaining the comfort of its users. Heat pump-based systems therefore normalize the demand curve by providing load shaping and load shifting services.

In addition to thermal storage, heat pump systems can also be augmented by electric batteries (case C). Batteries do increase the level of independence of such systems. While battery storage is still costly battery costs are rapidly reducing. Cost of 100 - 200 euro / kWh will be a game changer to make battery systems more attractive and an import part of a stable and reliable electric grid.

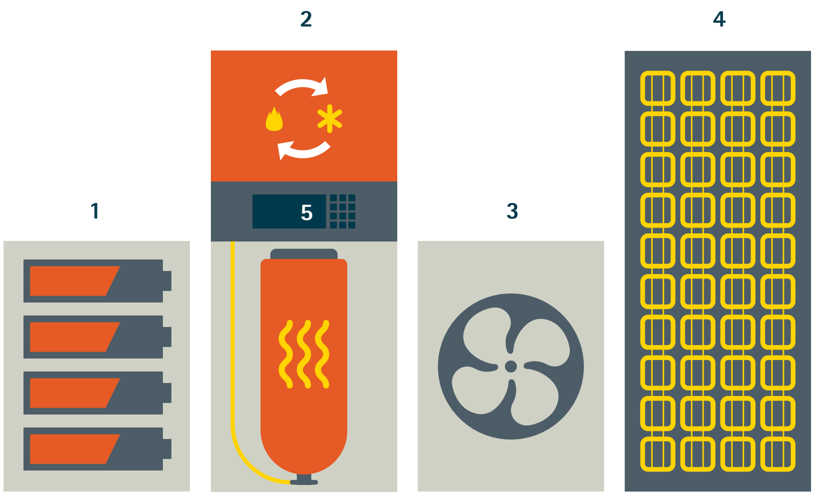
A modern heat pump system (see Figure 19 for an illustration) with thermal and battery storage can provide heating and cooling for several hours or even a few days without the need of grid-based electricity. This will help to move demand to off-peak hours. Pending the proper business models, this option will become economically interesting to the end user.

With proper system design, heat pumps can provide flexibility to the grid for heating demand and to cover the cooling needs. Such systems need to be equipped with:

- numerous sensors providing data on the temperatures in the house and the storage
- access to weather data (in particular solar irradiation)
- access to current and day-ahead price signals for electricity

Figure 19 **A FUTURE STANDARD CONFIGURATION FOR HEAT PUMPS?**

1. Battery stack with 4x 2,5kWh storage capacity (electric)
2. Air-water heat pump with a storage tank
3. Ventilation system
4. Photovotaltaic system
5. Controller optimising the system for a maximum use of locally-produced electricity and maintenance of user comfort



- a self-learning controls logic that can develop "an understanding" of the thermal behaviour of the building as well as of users' comfort requirements (answering questions like: "what are preferred temperatures in a building?", "when is hot water used?", or "how fast does the building heat up/cool down?"
- a controls logic that interprets climate data, price signals and comfort requirements into an optimised heating/cooling service

Using the German building stock, the GreenHP project analysed the load shifting potential of heat pumps. The modelling provided the following results:

- residential heat pumps reach their highest demand in winter
- domestic hot water heat pumps have a constant demand throughout the year
- heat pumps in office buildings require heating in winter and cooling in summer (the amounts in GWh/day are similar)
- residential cooling occurs in summer

These statements are standard to addressing heating and cooling demand and their comparison to the pattern of surplus energy generated from wind and solar photovoltaic (PV) generators reveals that in areas with an increased PV share in the electricity mix, more balancing potential is needed in summer time. Since this can be provided by sanitary hot water heat pumps as well as by residential and office cooling, they should be supported in such areas. In areas with surplus wind energy, the shifting potential is required throughout the year (more in winter than in summer) and can be balanced by residential heat pumps and heat pumps in office buildings. Consequently, heat pumps should be included in these buildings types.

A system's perspective is necessary to optimise the energy system and to understand that the heating and cooling sector is a burden to the system, responsible for and even demanding half of the final energy demand. Adding sensors, computing power and storage will make this demand flexible. Being able to shift demand will then be an economic advantage and exploring this opportunity will be most likely much cheaper than maintaining reserve power plants or building additional power generation assets and distribution infrastructure.

Smart heat pumps contribute to grid stability by reacting to weather data, building characteristics and user behaviour.

Combining central and decentral heat pumps with energy grids and storage will provide flexibility and stability to the electric grid in the most efficient manner. If provided with information on weather, building characteristics and user behaviour, the benefits must be expected to be even greater. The more sophisticated heat pumps become, the more often they will be used in central and decentral applications, thus accelerating its uptake across Europe.

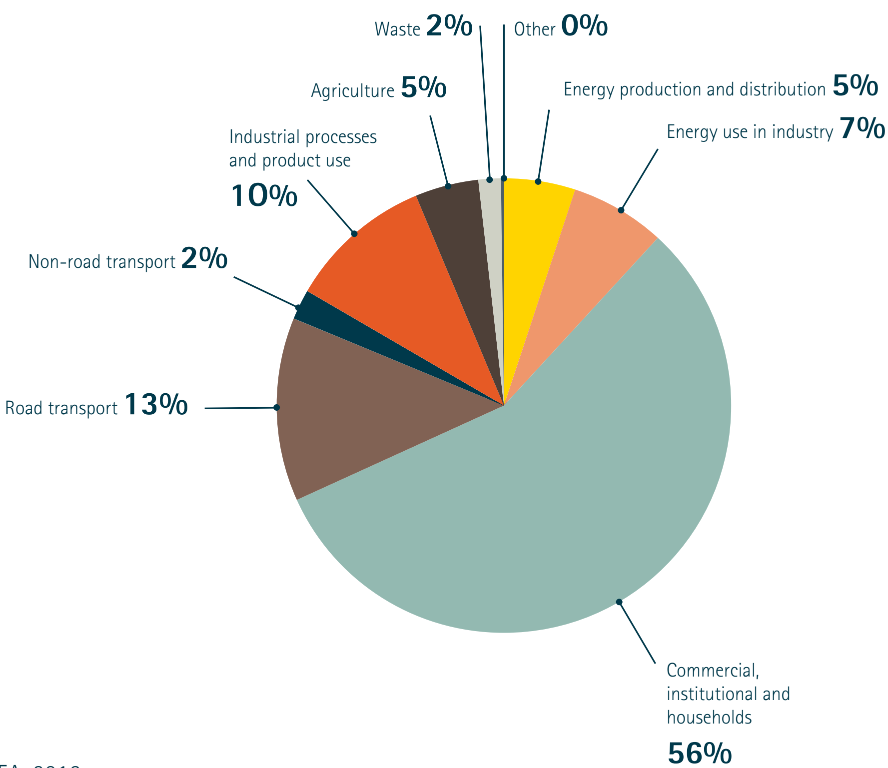
3.5. ENVIRONMENTAL IMPACT OF HEAT PUMP USE

The incremental deployment of heat pumps can reduce and even eliminate the use of fossil-fuelled energy in the building sector and thus delete the negative pollution side-effect of fossil fuel usage such as

- ► environmental pollution caused by exploration and extraction of fossil fuels, particularly in ecologically-sensitive areas.
- ► the environmental and health impacts on societies directly affected by the above-mentioned effects.
- ► emission during transport: oils spills, gas leakages, road and rail accidents
- ► air pollution during combustion, an effect with an increasingly negative impact in cities.

Figure 20 shows that emissions from the commercial, institutional and households sector group, combined with emissions from industry account for more than 60% of all PM2.5 emission. A faster deployment of heatpumps in these application areas will address the problem and should thus be supported by policy-makers on European, national and regional level.

Figure 20 **$PM_{2.5}$ EMISSIONS IN THE EU-28: SHARE BY SECTOR GROUP IN 2014**



Source: EEA, 2016c

The emissions from the installed stock of heat pumps are continuously decreasing as a result of more and more renewable source in electricity generation.

Nonetheless heat pumps are not an emission-free heating system and thus their environmental footprint needs to be observed, too.

Like for other boiler technologies, a heat pumps impact on the environment can be assessed during

- production
- use
- dismantling

As heat pumps are subject to building and waste reduction regulation, this paper will focus on the emission during the use phase that affect air and atmospheric quality.

The environmental impact from the operation of heat pumps can be split in emissions from energy use and CO_2 equivalent emissions from the use of refrigerants. The former can hardly be influenced by the technology itself, as the decarbonisation of electricity is a key aim of European energy policy. Electric compression heat pumps are using electricity, which generation is subject to the EU emissions trading scheme (EU ETS) . Thus the related emissions will automatically be reduced with the reduction of available emission rights under the ETS.

Since the emission levels of electricity generated are continuously decreasing as a result of an increasing amount of renewable energy sources, the emissions of all heat pumps - those in stock and those installed new - is continuously going down.

AIR POLLUTION & CLEAN AIR PLANS

Air pollution (emission of Nox, particulate matter – PM10 and PM2.5, Benzen etc.) has been identified as the fourth-leading risk factor for premature death worldwide. It affects the health and well-being of citizens and has a substantial impact on lost labour income. The World Health Organisation (WHO) has assessed the cost from air pollution in Europe at 1.5 trillion Euro per year, concluding that air pollution must be addressed with top political priority. The result has been the elaboration of "clean air plans" identifying solutions and implementation time tables to significantly reduce air pollution. The current discussion around emissions from diesel combustion in cars should be seen as a warning sign for the heating industry.

Emission from coal, oil and fossil gas combustion may well be treated in the same way. The "directive on ambient air quality and cleaner air for Europe" (2008/50/EC) mentions domestic heating as a target area to be addressed in political action plans. Replacing combustion-based heating systems with heat pumps would be a suitable means to address the issue of air pollution. The possibility is so far not used. The European Environmental Agency (EEA) stresses in its 2016 Air quality in Europe report that "fuel combustion in [the commercial, institutional and residential sector] is the major source of primary PM2.5 and PM10, as well as BC and BaP emissions" (EEA 2016, p. 23).

THE ENVIRONMENTAL IMPACT OF REFRIGERANTS

A refrigerant is an essential component of a heat pump. Its characteristics allow the heat pump to operate and to use renewable energy in generating useful heat and cold.

These positive characteristics come at a cost: refrigerants can be toxic, they can be flammable or even explosive or they can act as greenhouse gases with a certain global warming potential (GWP). None of these issues occurs, if the refrigerant remains inside the unit. By consequence high quality design and manufacturing of units as well as the skills of installers to dismantle and to recover refrigerants are so important.

In case the refrigerant is released into the environment, it can have a negative effect to the atmosphere.

Table 3 compares the most common refrigerants used today in terms of their global warming potential. The majority of residential units deployed today use hydrofluorcarbons while in large/industrial size heat pumps the use of natural refrigerants (Ammonia, Propane, CO_2) is more common. The use of hydrofluorcarbons in Europe is regulated under (EU 517/2014). The implemented phase-down will reduce the availability of f-gases continuously until 2030. Effects on availability and prices are starting to become visible in the market already today.

This makes the search for alternatives a key challenge to the heat pump industry. Available solutions are new mixes with a lower GWP, but these substances are usually at least mildly flammable. Other options are natural refrigerants like propane and butane (highly flammable), ammonia (toxic) or carbon dioxide (high operating pressure).

It must be stressed however that the largest share of emissions from any heating/cooling system results from the fuel used to operate the unit. The total equivalent warming impact (TEWI) calculation is an established approach to asses emissions over the useful life of a unit. Emissions are distinguished in direct emissions (chemical) and indirect emissions (energy use) of greenhouse gases from production, operation and recycling.

Figure 21 shows a comparison of the lifetime emissions of different heating solutions. The assumptions are identical to those shown in Table 3. For simplicity, heat pumps are assumed to use only one refrigerant (R410A), with the exception of the last column, where the future scenario of a heat pump with a new low GWP refrigerant (with a GWP <1) also using green electricity (CO_2 emission of 15) is used. This is a realistic consequence of the ongoing greening of the electricity mix and the phase down of the current refrigerants.

Table 3 **OVERVIEW OF TYPICAL REFRIGERANTS USED TODAY AND AVAILABLE LOW GWP ALTERNATIVES**

NAME	GROUP	FLAMMABILITY	SAFETY CLASS	GWP (AR 4)
R32	HFC	mild	A2L	675
R125	HFC	no	A1	3500
R134A	HFC	no	A1	1430
R152A	HFC	yes	A2	124
R245FA	HFC		B1	1030
R404A	HFC	no	A1	3922
R407C	HFC	no	A1	1774
R410A	HFC	no	A1	2088
R1234YF	HFO	yes	A2L	4
R1234ZE	HFO	yes	A2L	7
R448A	HFO	no	A1	1387
R449A	HFO	no	A1	1397
R290 PROPANE	Hydrocarbon	high	A3	3
R600	Hydrocarbon	high	A3	3
R717	Amonia	no	B2L	0
R744	Carbondioxide	no	A1	1

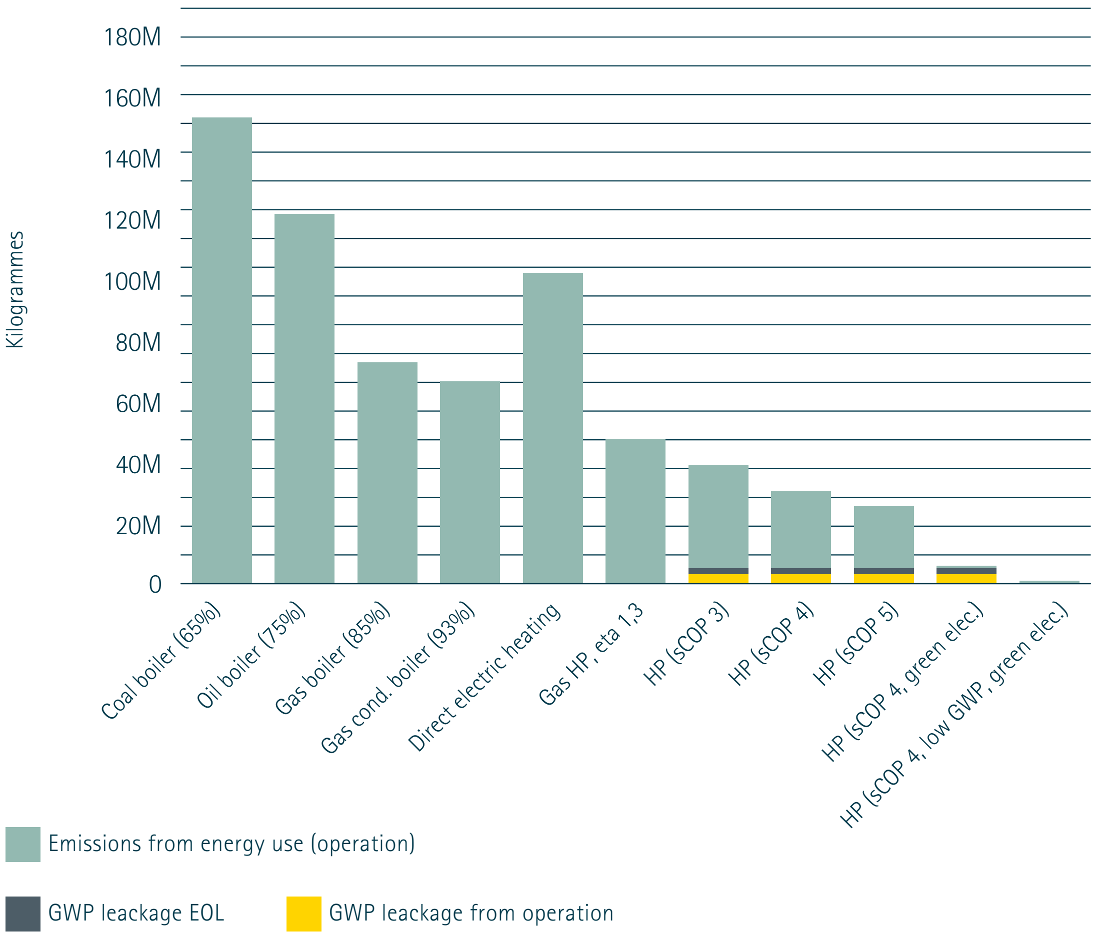
Source: Own, based on Bitzer refrigerant report 19 (A-501-19)

The figure shows that a fast reduction of emissions from electricity has a bigger impact on the life cycle based emissions of heat pumps, than the deployment of refrigerants with a low GWP. It shows also, that even heat pumps with the lowest currently allowed efficiency have lower emissions than even the best fossil combustion system.

Consequently, the key challenge for industry is the development of products and procedures that keep refrigerant losses to a minimum by designing and producing high quality, hermetically sealed units. Heat pump installers and other experts should be skilled to properly recover the refrigerant used.

From an environmental perspective, already the use of existing refrigerants - if handled properly - contributes to a reduction of greenhouse gas emissions which is accelerated by every reduction step of emissions from electricity. It should thus be kept in mind, that the first priority when addressing climate change is the reduction of CO_2 emissions to the atmosphere and not a ban of current refrigerants.

Figure 21 **EXAMPLES OF TOTAL ENVIRONMENTAL WARMING IMPACT (LIFETIME)**



Source: EHPA

From an industry perspective the development of low and no GWP alternatives to be deployed in efficient heat pump systems must be the ultimate goal to deploy a near zero emission heating technology- both from the component and the operations side.

3.6. SUPPLY SECURITY

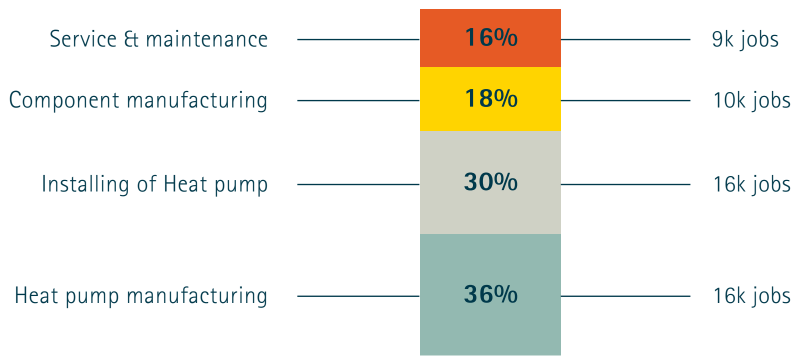
Heat pumps use local renewable energy. Their widespread deployment thus helps to increase energy independence and maintain purchasing power in the European Union.

Today more than 50% of all fossil fuel is imported, which creates a dependence on the exporting countries, such as Russia and Middle East. This energy dependence is particularly strong when it comes to crude oil (88.2 %) and fossil gas (67.4 %) imports. Supply security may be threatened, if the majority of imports stems from only a few sources. In 2014, 69,1% of all fossil gas and 43,5% of all oil imports came from only two countries: Russia and Norway and 70% of all coal is imported from three markets Russia, Columbia and the USA. An increasing import dependency will not only affect supply security but results also in a significant outflow of financial resources. The total value of energy imports in 2015 amounts to €262 billion (down from €450 billion in 2012) while the imported amount has declined only slightly.

3.7. LOCAL EMPLOYMENT

The heat pump industry is a robust provider of employment in Europe. While the heat pump value chain today is global, many leading companies are located in Europe, creating not only products that are installed locally, but also an export opportunity for the region. The EHPA estimates that more than 54,000 full-time jobs are necessary to produce, install and maintain the annual sales of heat pumps in Europe (data for 2015). Considering that not all employees work full time in pump related projects, the total number of people benefiting from the technology is even larger. In the long-run, a fast growth of heat pumps in the heating market will not increase employment significantly, but instead lead to a re-training of experts and craftsmen currently working in other product areas.

Figure 22 **ILLUSTRATION OF EMPLOYMENT**



Source: EHPA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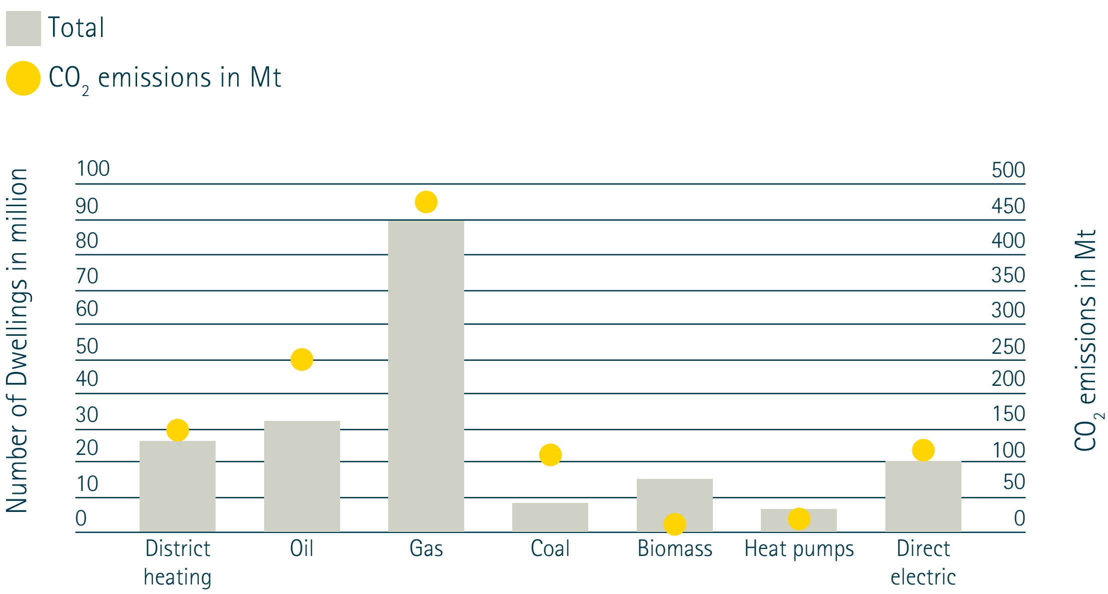
Chapter 4: APPLICATION AREAS FOR HEAT PUMP TECHNOLOGY

The heating and cooling sector is responsible for 51% of final energy demand in Europe and for 27% of its CO_2 emission: decarbonising society is impossible without decarbonising heating and cooling. The weighting of Europe's energy demand by energy source with the emission factors shown in Table 4 leads to total CO_2 emissions from heating of approximately 1,000 Mt and a distribution of emissions per energy source and technology used as shown in Figure 23.

Figure 23 **GREENHOUSE GAS EMISSIONS FROM HEATING THE BUILDING SECTOR BY ENERGY SOURCE USED**



Source: Entranze, own calculation.

In the simplest approach to reducing heating-related emissions in the buildings sector, one could draw a line starting at the emission level of today and have it end at zero in 2050. The idea is similar to the cap and trade mechanism applied in ETS or in the EU phase down for fluorinated gases. It would result in a necessary reduction of emissions by 20% every 6,5 years.

Table 4 **EMISSION LEVELS OF DIFFERENT HEATING TECHNOLOGIES AND FUELS**

	CO_2 EMISSION PER KWH OF ENERGY ($g\ CO_{2equivalent}/kWh$)	**EFFICIENCY OF TECHNOLOGY**	**CO_2 EMISSION PER KWH OF USEFUL HEAT** ($g\ CO_{2equivalent}/kWh_{useful\ heat}$)
Gas condensing boiler	Gas: 242	eta = 95%	254
Gas non-condensing (eta = 85%)	Gas: 242	eta = 85%	284
Oil	Oil: 357	eta = 75%	476
Coal	Coal: 390	eta = 65%	612
Direct electric heating	Electricity: 400	eta = 100%	400
Heat pump (SPF 3)	Electricity: 400	eta = 300%	133
Heat Pump (SPF4)	Electricity: 400	eta = 400%	100
Heat Pump (SPF4) + electricity emission = 100	Electricity: 100	eta = 400%	25

A more comprehensive approach is needed to achieve a decarbonised sector by 2050. It would include an assessment of the energy quality of the building stock, the emission levels of installed technologies, a technical assessment of the renovation pathways needed as well as a definition of maximum acceptable emission levels per decade. In the endeavour to fully decarbonise heating and cooling by mid of this century, carbon emissions of available technologies should become a primary selection criterion for heating and cooling system.

The information would be used to develop a schedule for the nearly complete decarbonisation of the heating and cooling sector. The decarbonisation plan should consider industrial policies, such as the investments and divestments from manufacturing sites, the impact on employment, alleviation measures to avoid energy poverty and an assessment of the skill level of experts and the need for re-training.

Many studies address interim decarbonisation targets by 2030 or 2040 and the endgame: a decarbonised system by 2050. The German think-tank "Agora Energiewende" published its assessment of the heat transition 2030 for Germany, and concludes that the decarbonisation of heating must be based on:

- energy efficiency
- heating networks
- and heat pumps

According to the study, achieving an ambitious 95% decarbonisation of the heating sector by 2050, requires ambitious steps to be taken even earlier. Agora Energiewende suggests the following action items to be achieved by 2030:

- phasing out oil in the heating sector and aiming for a cost-efficient heating technology mix consisting of 40% gas combustion, micro-CHP and gas heat pumps, 25% electric heat pumps, and 20% district heating (with CHP being the main energy source; slowly to be replaced by solar thermal energy, direct geothermal heat, waste heat and large heat pumps)

► energy efficiency is key: final energy demand can be reduced by 25% compared to 2015 levels

► deploying heat pumps, much faster: approximately 6 million heat pumps need to be installed in Germany by 2030. Comparing this goal to the 788,000 heat pumps installed in Germany at the end of 2015, an average growth of 17%/year is needed to achieve it in 13 years

► greening electricity production to ensure low carbon emission from heat pump-based heating. The energy transformation requires at least 60% of electricity to be produced from renewable energy sources

The Fraunhofer ISE institute comes to a similar conclusion: decarbonising the heating sector by 2050 requires ambitious goals to reduce the final energy demand of the building sector in combination with the replacement of fossil fuel technologies with low-to-zero carbon emission alternatives, which are available and can be deployed, if political will is available.

While variations will apply from country to country, two things are already clear today: decarbonisation needs early and ambitious action, but it is not an insurmountable challenge, as it is likewise clear that the necessary technologies to decarbonise Europe's heating and cooling sector are available, today.

INCREASING EVIDENCE FOR THE WIDESPREAD USE OF HEAT PUMPS

A number of new reports have come out over the past six months stressing the need for bold action when it comes to the decarbonisation of heating and cooling as well as highlighting the benefits of heatpumps in this context. The opportunity to integrate renewable or waste heat sources and to thus reduced fossil energy demand in combination with the efficient and controllable use of electricty for heating/cooling is seen as the advantage of heat pump technologies.

IRENA 2018: Global Energy Transformation: A Roadmap to 2050.

IRENA 2018: Renewable energy prospects for the European Union.

IRENA/IEA/REN21 2018: Renewable Energy Policies in a Time of Transition.

European Commission 2017: A technical analysis of FTT:Heat - A simulation model for technological change in the residential heating sector.

4.1. HEAT PUMP DEPLOYMENT IN RESIDENTIAL AND COMMERCIAL BUILDINGS

Heat pumps can replace fossil energy in buildings undergoing deep renovation already today, in case of shallow renovation a replacement is possible, but conditions apply.

Heat pumps are a solution to provide heating and hot water in residential buildings, both in single and multi-family homes. Depending on the local building tradition, heat is distributed via water-based systems (radiators, floor-heating) or via air-conditioning devices (ducted or ductless systems).

Heat pump characteristics make them an ideal technology for any building type with sufficient heat distribution surface to allow comfortable indoor temperatures at comparatively low temperatures of the heat distribution system – for hydronic distribution systems, a good indicator is a feed temperature below 55°C. These requirements are met in all new buildings including 'near-zero' energy, 'passive' houses and energy 'plus' building designs. Similarly, heat pumps can replace boilers in the deep renovation of buildings.

Replacing oil and gas boilers in existing buildings is the biggest challenge because users often do not see the added value of investing in an immediate renovation of the building envelope. Expert advice is needed to assess the suitability of heat pump technology: in some cases, heat pump solutions are available, but most likely, 'hybrid' heat pumps should be employed. Hybrid systems combine heat pumps with other technologies (solar thermal, biomass, gas, oil) and are a promising bridge to the future as they can leverage their respective advantages: during the largest part of a season, heat pump technology can efficiently provide heating and hot water while combustion is used to provide these services during very cold winter periods. If at a later stage the building envelope is refurbished, then a heat-pump only solution is feasible and preferable.

Vulkan is a brownfield located in Oslo, Norway. Close to the River Akerselva, it hosts a number of buildings grouped around a small commercial area including offices, a food hall, restaurants, bars, schools and some hotels. From an energetic perspective, Vulkan is heated and cooled from 3 large heat pump units that can provide heating or cooling, depending on the prevailing needs. The heat distribution system is also connected to Oslo's district heating grid. More details can be found here: www.visitoslo.com

While near zero energy buildings are the standard for new buildings from 2021 onwards, improvements in technology will lead to reducing energy demand in existing buildings, continuously enlarging the share of buildings suitable for heat pump deployment.

The better insulated and the more air-sealed a building envelope becomes, the more likely it is that the users comfort requirements will include ventilation and cooling services. In humid climate, dehumidification of the air in the building will also be necessary to ensure indoor comfort. Forced ventilation systems include air filters and thus contribute to better indoor air quality. In case specific filters are used, this is of particular importance for inhabitants allergic to pollen or for those living in areas with high air pollution.

Hybrid-heat pumps allow for the direct replacent of boilers introducing large shares of RES

The combined effect of lower energy demand, additional services and a small systems footprint is expected to result in **a convergence between ventilation systems and heating, air-conditioning and hot water solutions.** This requires efforts to upgrade the skill level of building experts for integrated solutions. Heat pump systems can integrate all functions required for a comfortable indoor climate: heating, cooling, hot water, and dehumidification.

Commercial spaces need comfortable indoor air temperatures and clean fresh quality to create a pleasant and productive environment. From hospitals to office buildings, air needs to be heated/cooled/ dehumidified and hot water is required. Large heat pump systems are a solution for these applications. In the past, boilers provided heat and air conditioning and refrigeration equipment provided cooling devices; now there are incremental benefits to integrating heat pumps. Waste heat from cooling can be an energy source for heating and for providing hot water, which consequently closes the energy cycles; and the total energy demand of the building can be reduced as a result. This can be extended further when heating and cooling demand is balanced across buildings via energy networks.

Commercial heating, cooling and air conditioning combines numerous solutions to offer the best user experience:

- large energy demands are often covered by geothermal drillings, the connection to the buildings foundations or via open loop systems
- cooling is provided by air handling units located on or nearby the building or by utilizing water (aquifers, open waterways, waste-water)
- heating/cooling in the building is typically distributed via fan-coil units, floor/wall heating or activated concrete floors (floor/ceiling)

- waste heat from cooling can be used as energy source for domestic hot water production

- commercial buildings have an extensive energy distribution infrastructure comprising of water and air-based systems.

A proper design of heat pumps for heating, cooling, dehumidification and hot water production uses the characteristics of a heat pump-based system in the most efficient way. If connected to district energy systems, heat storage or other balancing options, such systems do not need any rooftop cooling devices anymore and leave the top space for other use cases such as PV, solar thermal or roof-top bars.

BRIDGING THE ENERGY GAP

The combination of heat pumps, energy grids and storage allows to overcome differences in temperature, space and time of supply and demand.

A heat pump lifts energy from an unuseful to a useful temperature level. The pipes in an energy grid connect locations of energy demand with those of energy supply and a thermal storage helps overcome temporal differences between the need and the supply of energy - ranging from a few hours to some months.

For more information on industrial heat pump solutions look at

- IEA HPP Annex on industrial heat pumps (first phase, second phase)
- Large scale heat pumps in Europe
- Heat Roadmap Europe: Large-scale electric heat pumps in district heating systems

4.2 INDUSTRIAL APPLICATIONS AND DISTRICT HEATING

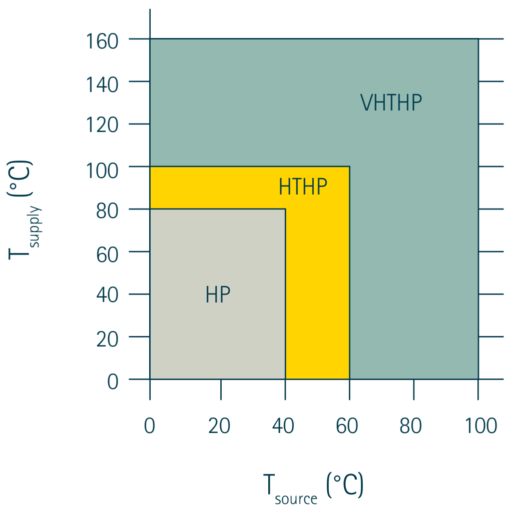
Industry uses 2,388 TWh of final energy for heating and cooling purposes, most of it for process heating. Providing this energy in the most efficient way will significantly reduce fossil energy consumption and related emissions. Many industrial processes do operate at high temperatures and thus require low emission fuels (for example green hydrogen, methane or biogas/biofuels) or a change in process design towards electrification.

The feasibility of heat pump technology in industrial applications depends on the temperature levels needed in production. Eurostat distinguishes the following sectors:

- Iron and steel/non-ferrous metals
- Chemical and petroleum
- Non-metallic minerals
- Paper, pulp and print
- Food and tobacco machinery
- Wood and wood products
- Transport equipment
- Textile and leather
- Others

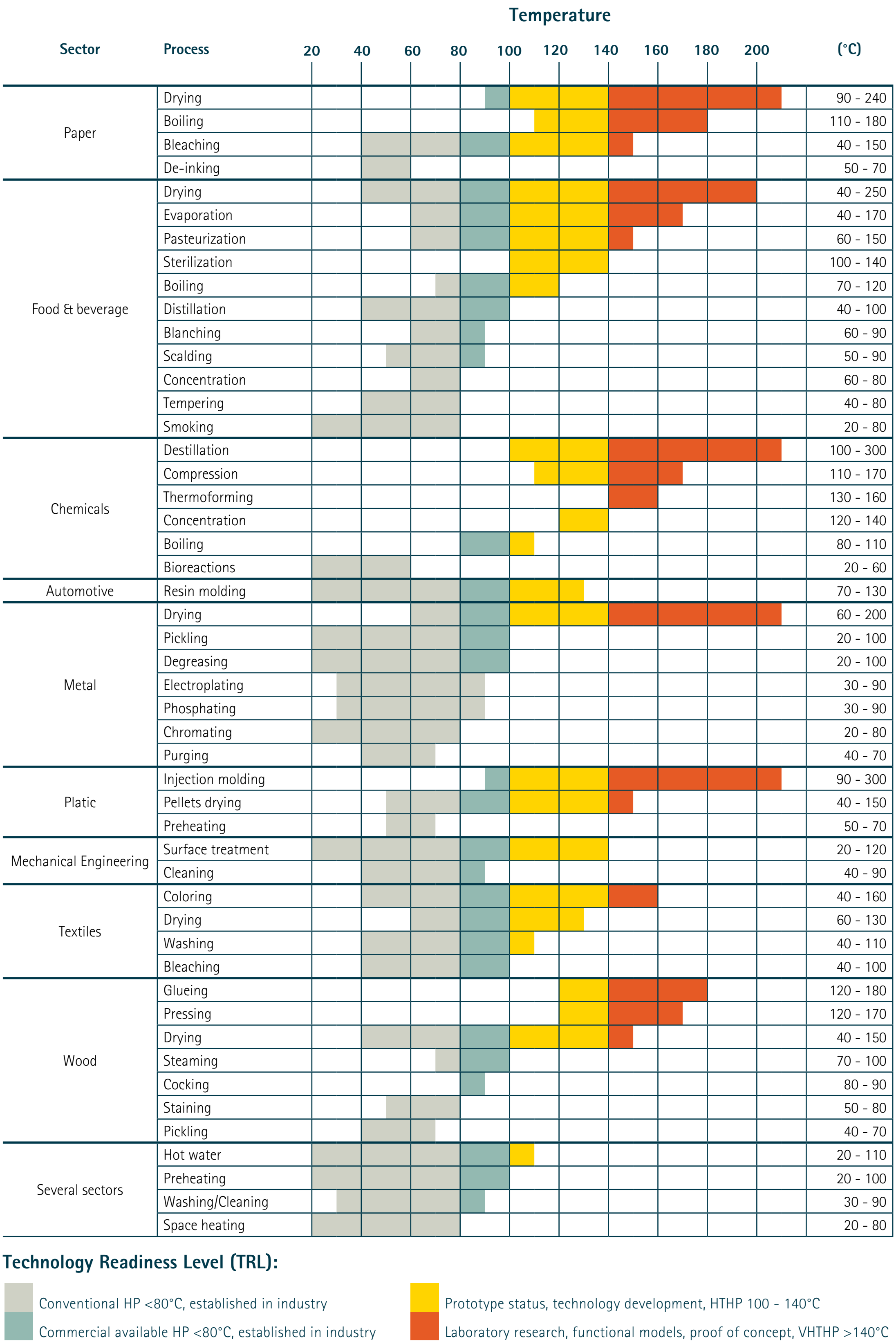
When it comes to the temperature levels covered by heat pumps, a distinction in three main categories can be made. These are based on the usable temperature of the energy source (T source) and the temperature level that can be provided (T sink) as shown in Figure 24:

Figure 24 **POSSIBLE COMBINATIONS OF SOURCE AND SINK TEMPERATURES FOR DIFFERENT TYPES OF HEAT PUMPS**



Source: Arpagaus et al.

Figure 25 **TEMPERATURE RANGES OF DIFFERENT INDUSTRIAL PROCESSES**



Source: Arpagaus et al.

► Normal heat pumps provide temperatures up to 80°C and can use energy sources from renewable and waste sources with temperatures up to 40°C. These are commercially available.

► High temperature heat pumps provide temperatures up to 100°C. and can use energy sources with temperatures up to 60°C. These are commercially available.

► Very high temperature heat pumps provide temperatures of up to 150°C. The current status of availability is limited to experimental solutions and prototypes with an optimistic outlook on their market integration.

The possibility of heat pumps providing temperatures above 150°C has been shown in laboratory research - but they are not expected to be commercially available soon.

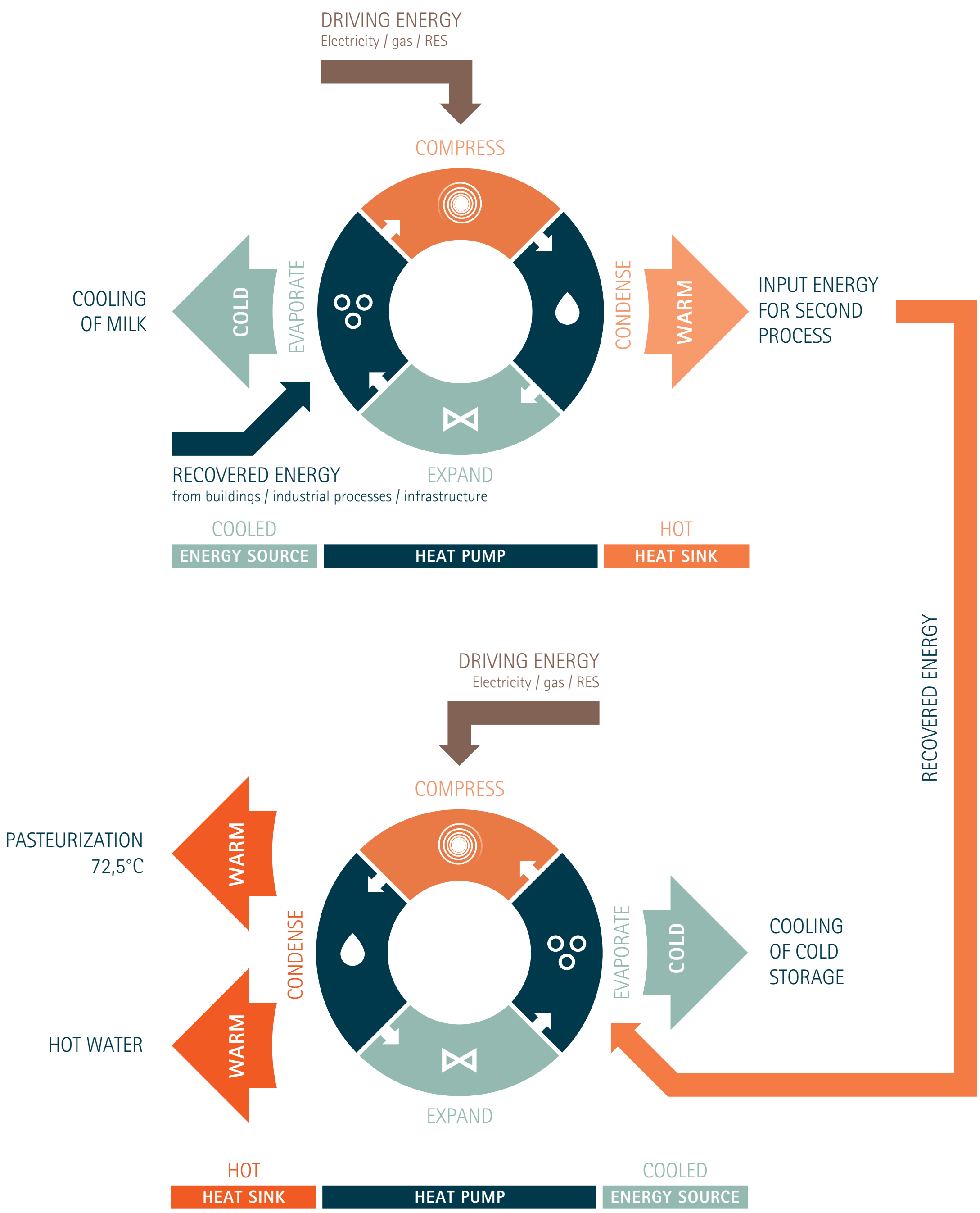
High and very high temperature industrial heat pumps with large capacities are unique solutions in decarbonising the energy demand in industry. Not only do they provide energy for heating, hot water, cooling and dehumidification but they do this by closing energy cycles and thus reducing the need for requiring additional final energy.

If heating is needed in one process or building and cooling in another, the connection of both via some pipework and one or several heat pumps makes the most of each unit of drive energy deployed.

Typical industries and processes that can be supported by heat pump technology either by providing the energy or by using the waste streams as energy source are:

- All sectors: cooling, dehumidification, heating, hot water, pre-heating, washing/cleaning, providing a controlled atmosphere for storage and transport
- Paper industry: bleaching, boiling, de-inking, drying
- Food & beverages: boiling, blanching, concentration, distillation, drying, evaporation, pasteurization, smoking, scalding, sterilization, tempering
- Chemical: bioreactors, boiling, compression, concentration, distillation, thermoforming
- Automotive: drying, molding
- Metal: chromating, degreasing, drying, electroplating, pickling, phosphating, purging
- Plastics: injection molding, pellets drying, preheating. Drying
- Mechanical engineering: surface treatment, cleaning
- Textiles: bleaching, coloring, drying, washing
- Wood: cooking, drying, glueing, pickling, pressing, staining, steaming

Figure 26 **SCHEMATICS OF AN INTEGRATED ENERGY CYCLE USING HEAT PUMP TECHNOLOGY**



Source: Own.

Figure 25 gives an overview of the operating temperature ranges of the processes listed here. All processes coloured in blue can be efficiently be covered by today's state of the art heat pump technology. All coloured in yellow are within reach. Those coloured in red must be considered the research and development challenge.

The main obstacle for heat pumps in existing processes is the fact that steam is used most often for energy distribution, resulting in high temperature system designs. Changing this equation requires new pipes and pumps and different process designs – a step decision-makers are reluctant to make. In smart system designs, heat pumps help to close energy cycles by using all output to a maximum, thus reducing heating/cooling losses to a minimum.

If you need cooling, you can get heating for free.

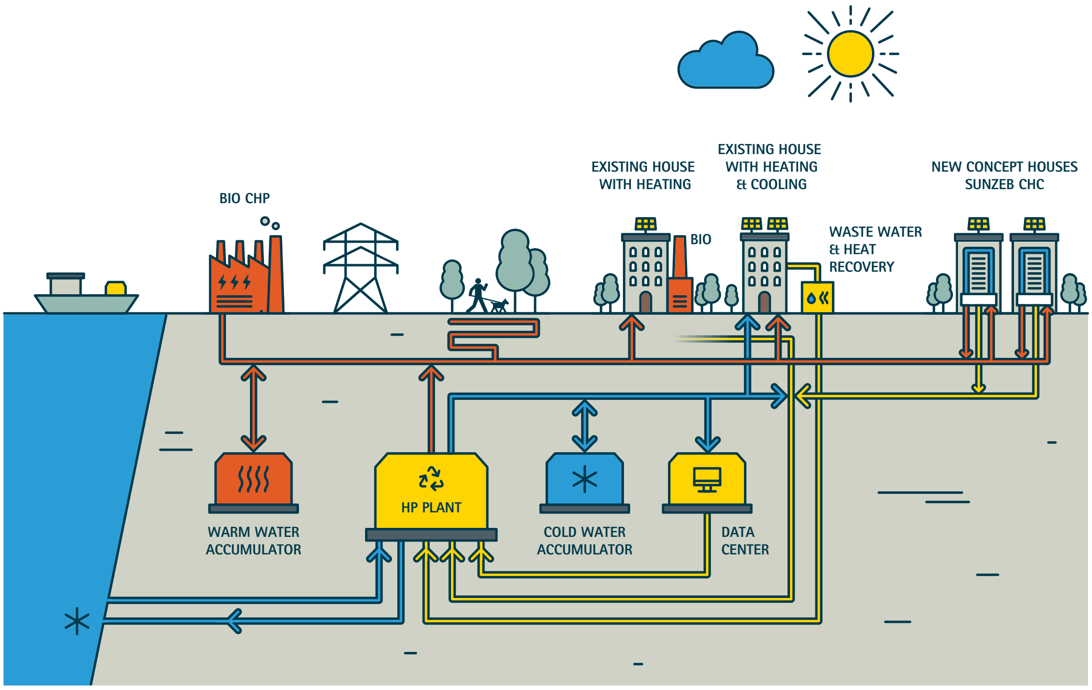
If both heating/cooling do not occur at the same time or location, thermal storage and distribution grids can overcome the differences. If required temperature levels and quantities of heating/cooling differ from supply, booster heating/cooling systems can overcome the temperature difference. Figure 26 shows an exemplary connection of two heat pumps in a dairy plant: the waste heat from the cooling process for milk becomes the energy source for pasteurization and for the hot water needed for cleaning.

This relation exists in every cooling process - the waste heat provided is surplus energy that can be used for heating and hot water production.

Apart from the use of heat pumps in industrial processes, they are also increasingly often used in district heating systems. Starting with a few 100 kW, they can reach capacities of several megawatts (MW), which is sufficient to provide the inhabitants of Helsinki, Stockholm or Oslo with heating and cooling. Currently the largest installation of this kind is the Katri Vala heating and cooling plant, located under a beautiful park in Helsinki: 5 large heat pumps use waste water and the return line of the district heating grid as energy sources; they can generate 90 MW of heating and 60 MW of cooling. As the plant is connected to the district heating and cooling grid of Helsinki, the highest efficiency is achieved when either service is needed. However Helen is taking an even more encompassing approach: buildings connected to the energy grid serve as solar collectors and the waste heat from ventilation processes is fed into the grid.

A most innovative application of heat pumps is their application in so called "cold source" energy grids. In this case, uninsulated pipes connect several buildings and serve as a huge thermal battery. Heat pumps connected to this system use it as energy source for heating (and dump the waste cold) as well as energy source for cooling (and dump the waste heat). This approach applies the principle of a circular energy economy to heating and cooling and thus reduces the need for additional energy to a minimum. As it is scalable from village to city and can employ different sources of energy and technologies, it may very well become a key solution for a future society, in which the majority of people live in cities. A good example of the approach is the Ectogrid project supplying a complex of buildings in Lund with energy.

Figure 27 **BASIC PRINCIPLE OF COMBINING DISTRICT HEATING WITH DISTRICT COOLING IN HELSINKI**



Source: HELEN, own visualisation.

4.3 HEAT PUMPS ARE EVERYWHERE

This report will illustrate the benefits of heat pump use in residential, commercial and industrial applications. But the technologies use is not limited to these areas. Nearly every residential and commercial building has at least one heat pump – the same is true for industry:

• If you use **a fridge**, you benefit from the refrigeration cycle. The refrigerant is circulated through the walls of the fridge, where it evaporates and this effect cools down the inside of the fridge and eventually the products stored in it. The refrigerant vapor is then compressed and transported to the backside of the fridge, where it is discharged to the surrounding air. Any fridge in operation will provide heating to the room it is put in. If the fridge is big enough and the house well insulated, the heating input could even be sufficient to heat the house.

• The most efficient **tumble dryers** today use a heat pump to recover the energy from the drying process. This greatly improves energy efficiency. Only heat pump tumble dryers can be labelled A to A+++ in the energy label for this product group. Tumble dryers using a heat pump have the lowest total life cycle cost.

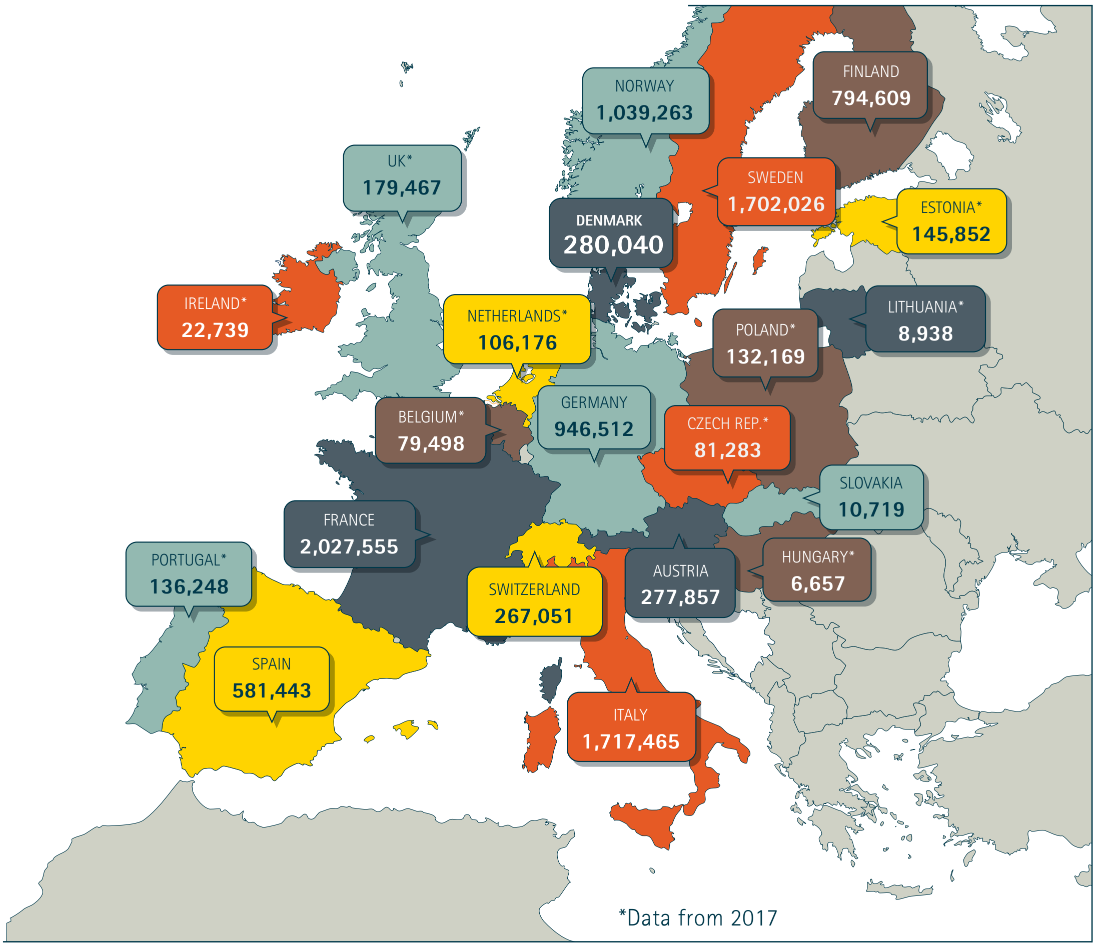
• Heat pump technology is also increasingly often deployed in **household and commercial dish-washers**, where it reduces energy demand and thus operating cost and emissions

• Heat pumps are responsible for longer range electric cars. They provide heating and cooling, not only for passenger comfort, but also for the **temperature management of the battery stack**, thus extending the possible range of the car.

Chapter 5: MARKET DEVELOPMENT

The EHPA statistics for 2017 reports more than 1.1 million heat pumps (+11%) sold in Europe leading to an installed capacity of 10.6 million units. This installed stock contributed 29.8 Mt of carbon emission reduction and 116 TWh to energy generated from renewable source. It helped reduce final energy demand by 148 TWh and ensured a total of 54,000 full time equivalent jobs in Europe. If properly connected, the current stock of heat pumps could provide demand side flexibility between 1 and 3.2 TWh over the course of a year.

Figure 28 **HEAT PUMPS INSTALLED IN EHPA MEMBER COUNTRIES IN 2018**

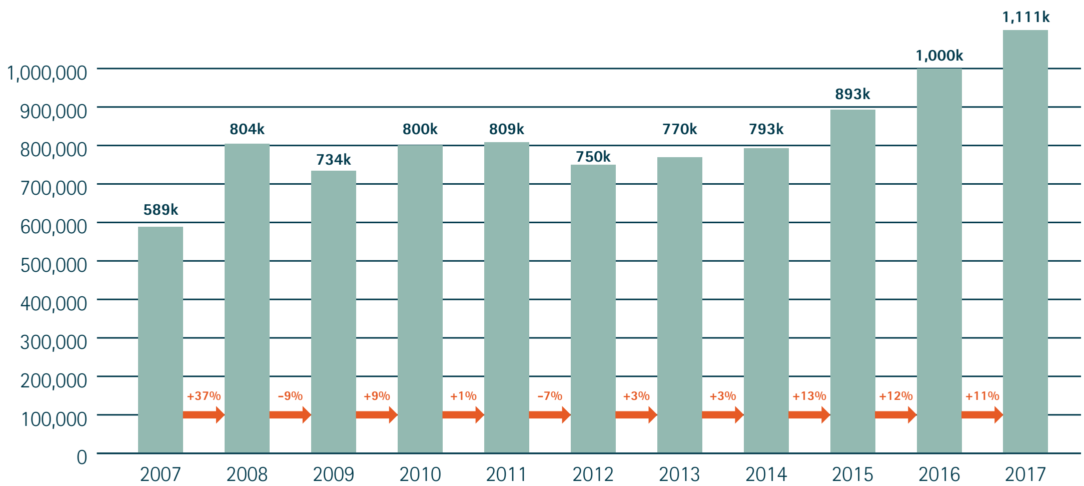


Source: EHPA.

5.1. STATUS OF THE MARKET DEVELOPMENT

2017 was the 5th year of consecutive growth of the European market. The industry development showed double digit growth or the 3rd year in a row (+10%) leading to 1.1 million units sold. Experience from several national markets shows that double digit growth is in line with the production and installation capacity of the industry. Looking at Europe's renewables and CO_2 emission reduction targets, it is essential for their achievement.

Figure 29 **EUROPEAN HEAT PUMP MARKET DEVELOPMENT (2007-2017)**



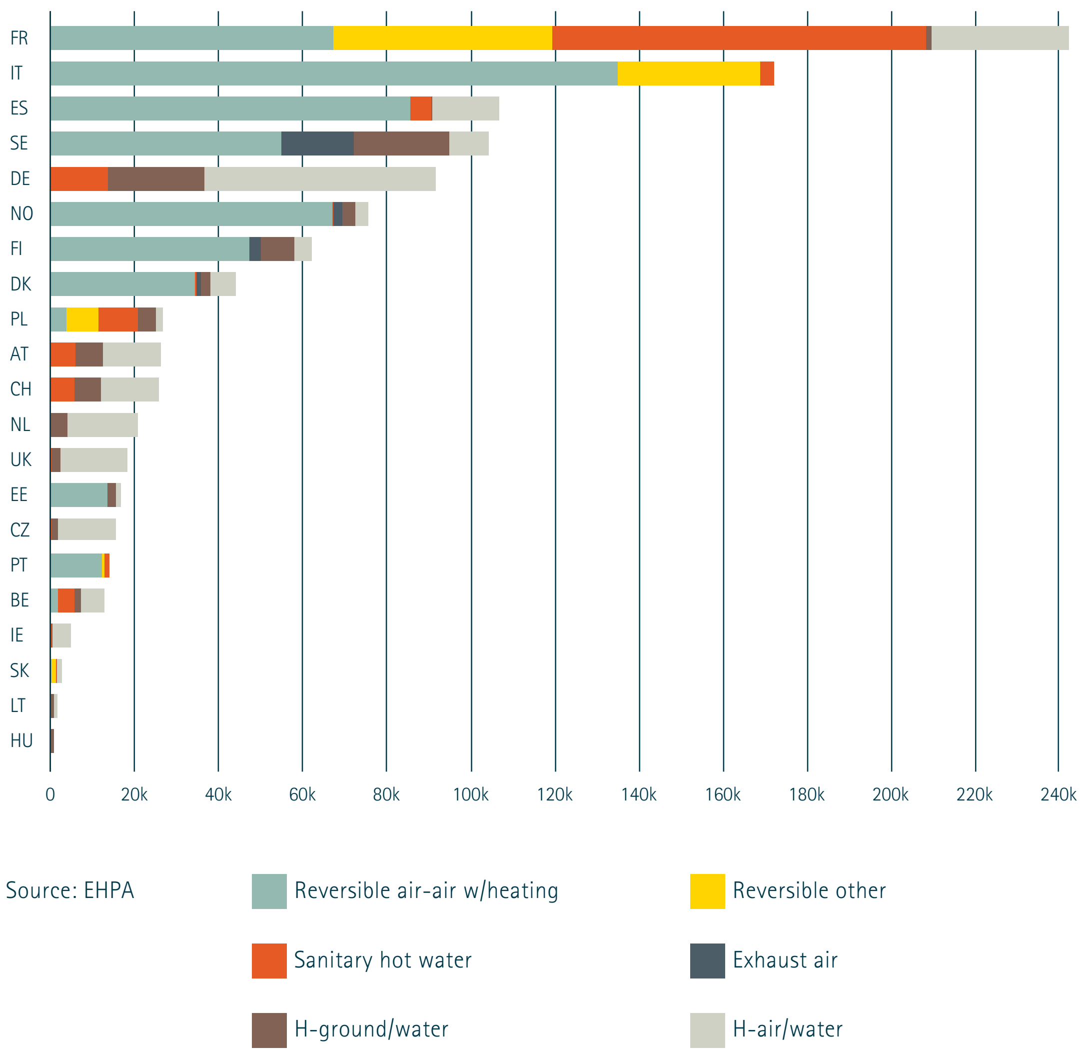
Source: EHPA

Splitting up the overall sales development shown in Figure 29 by "energy source used" reveals the dominance of air-source heat pumps in the market; the split thereafter is rather even between air-to-air and air-to-water units. Sales of ground coupled heat pumps have stabilized around 100,000 units. However, the size of installed systems is increasing as they are often used for larger commercial buildings and industrial applications.

Figure 30 also shows domestic hot water and exhaust air heat pumps which are two segments that are becoming increasingly important. While hot water heat pumps have seen double digit growth over the past 7 years, sales of exhaust air heat pumps are increasing as well. This product is expected to gain in importance, when near zero energy buildings become the building standard in Europe.

The top 3 heat pump markets in Europe are **France**, **Italy** and **Spain**, which are responsible for 50% of all units sold. The top 10 countries, which additionally include Sweden, Germany, Norway, Finland, Denmark, Switzerland and Austria are responsible for 90% of all units sold. In terms of market penetration, Norway, Estonia, and Finland lead sales on a per capita basis. The European Heat Pump Association (EHPA) estimates that potential sales for all Europe – under the assumption that all markets achieve the same penetration then the ones just mentioned, would exceed 6 million units per year.

Figure 30 **HEAT PUMP SALES DEVELOPMENT BY TECHNOLOGY**



Source: EHPA

5.2. INFLUENCING FACTORS FOR DEPLOYMENT

The deployment of heat pumps varies across Europe. The most advanced markets with a long history of deployment are Sweden, Switzerland, Italy and France. **France is the leading European heat pump market (see also Figure 31).** There are four main reasons for faster heat pump deployment:

— LACK OF FOSSIL GAS DISTRIBUTION INFRASTRUCTURE

Countries without fossil fuel infrastructure traditionally have used coal, oil and electric heating, and in recent years this input has been augmented with biomass. This made it easier for heat pumps to enter as a competitor, as they provide a more comfortable way of heating than coal and firewood - the fuel does not have to be carried into the building. From early on heat pumps were cost competitive with oil burners, as no chimney (and related cost) was needed and space could be freed in the building by abandoning the oil tank.

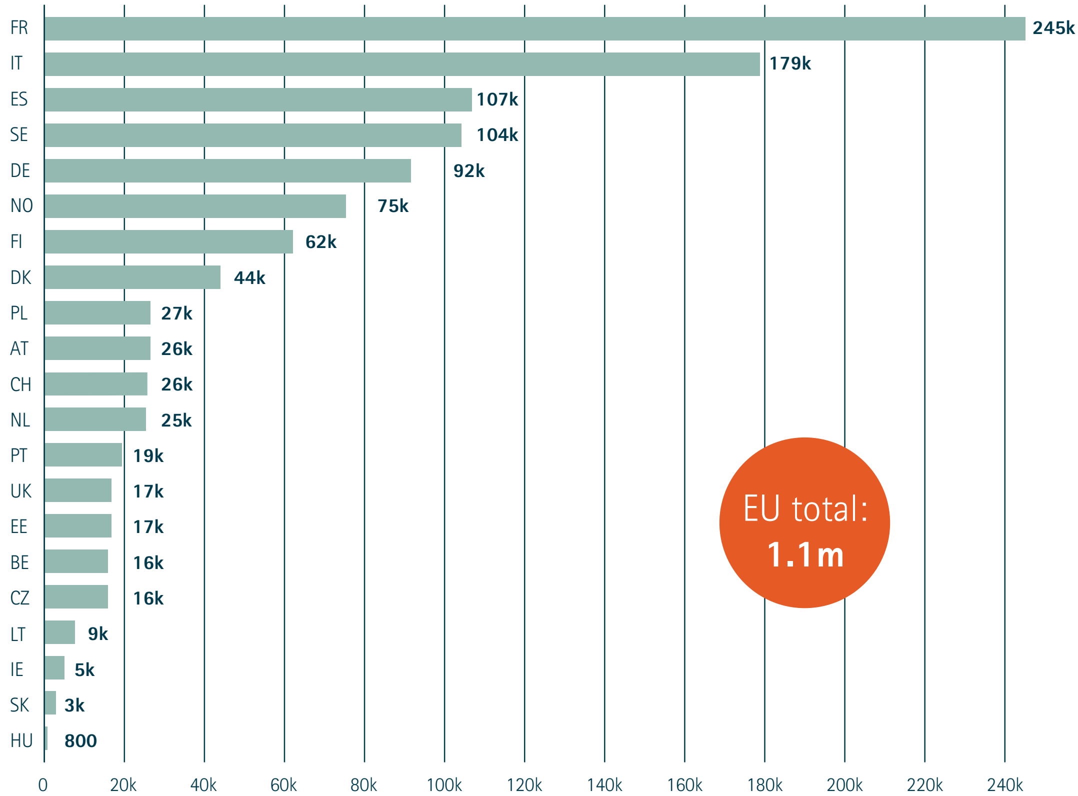
When it comes to heat pumps replacing direct electric heating, a heat pump installation results in the immediate reduction of operating cost as a result of much higher seasonal energy efficiency. A heat pump with an SPF of 4 would reduce the heating cost to 25%. Even a heat pump with an efficiency of only 2,5 would result in 60% savings of operating cost, usually enabling the investor to overcompensate the higher investment cost over the lifetime of the installation, if the price for electricity is not too high. This is one of the major reasons for the success of heat pumps in the Scandinavian countries, which are leading the European markets by far when it comes to sales of heat pumps per 1000 households.

— ACCEPTANCE OF ELECTRICITY AS AN ENERGY SOURCE FOR HEATING

The acceptance of electricity as an energy source for heating is beneficial to a faster deployment of heat pumps. In countries where this is not the case, for example in Germany, heat pumps have had a persistent image problem as they are perceived as being inefficient and pushed into the market to sell larger shares of electricity.

Scandinavian countries as well as France, that build a large part of their energy supply for heating on the use of electricity, mainly direct electric heaters, found it much easier to switch to heat pumps, particularly when each building that switched from direct electric to heat pump-based heating saved final energy, emissions and cost by a factor from 3-4. The deployment of heat pumps in these countries facilitates the rapid reduction of final energy demand.

Figure 31 **TOP EUROPEAN HEAT PUMP MARKETS**



Source: EHPA

OFFICIAL SUPPORT OF A FUEL SWITCH

Some governments have taken a very active role in shifting the heating stock away from fossil energy to more renewable energies. This typically took place in a cascade with coal addressed first, followed by oil and more recently also by fossil gas.

Typically, the ban of a certain energy carrier is announced and then support measures are introduced to overcome the most difficult financial obstacles. Sweden was a forerunner in this respect announcing to make the country oil free as early as 2005. Today, the Swedish heat pump market is largely independent of heating oil and mainly uses district heating (some supplied by large heat pumps), heat pumps, direct electricity and biomass.

Countries like Denmark and Norway have followed. In 2013, Denmark announced a ban of oil boilers and gas boilers in new buildings, and at a later stage, oil boilers are also banned in existing buildings, if gas networks or district energy is available. Norway announced to ban the use of oil in heating from 2020 onwards. A ban on the use of fossil gas is under discussion, however the latter does not have a huge impact in Norway, as only small areas are covered by a gas grid.

The biggest step was recently taken by the Netherlands. While heavily dependent on the use of gas for heating, cooking and hot water production, the Dutch government announced a complete phase out of this energy carrier by 2050. The early announcement of the transition away from fossil gas allows end-consumers to adjust their own heating solution in time. In the endeavour to make the make the building sector "gasvrij"/gasfree, the connection obligation to the gas grid was removed. Currently it is discussed to even make all new buildings fossil free from mid 2019 onwards and more measures are yet to be expected to address also the renovation sector.

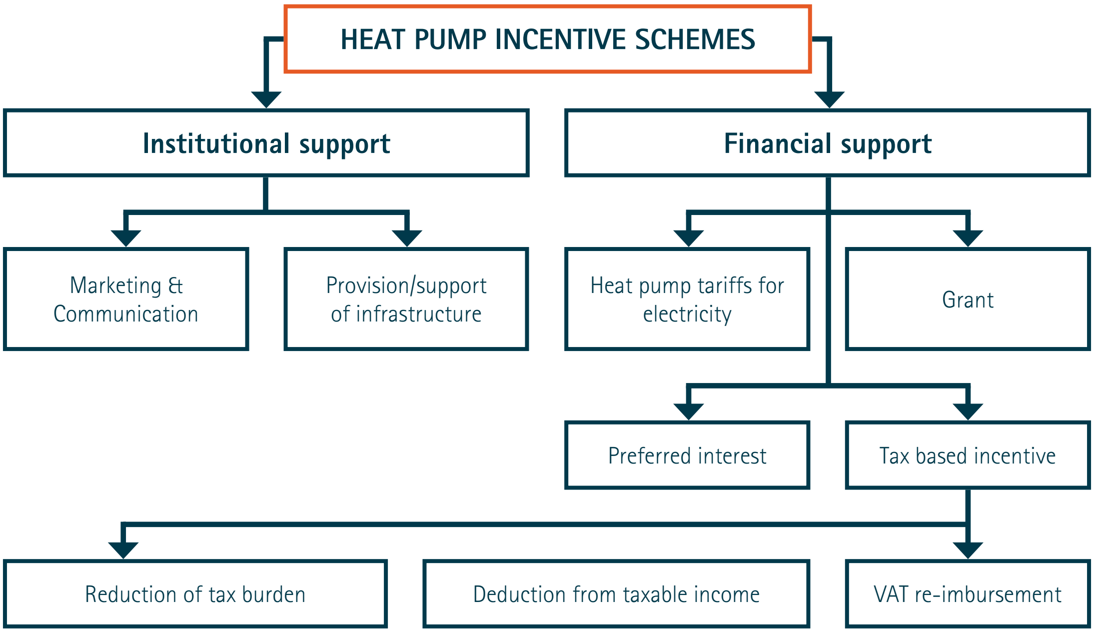
Switzerland has taken a different road. Based on a long-term energy strategy, the country has set up a slightly different kind of heat pump association as early as 1993: the Swiss expert coalition on heat pumps (Fachvereinigung Wärmepumpe) was created by the department of energy to bring together all stakeholders interested in developing the heat pump market under one roof. Originally financed by the Swiss Government with a strong focus on consumer information, technology development, quality of products and qualification of installers, this strong cooperation between industry, government, installers (and other experts) and consumer associations has become one of the most mature markets in which most new buildings are equipped with a heat pump, and a large share of renovation projects uses the same technology.

ACCELERATING HEAT PUMP MARKET DEVELOPMENT

Accelerating heat pump market development Industry orientated support schemes of institutional or financial nature (commonly referred to as incentives) can accelerate the deployment of heat pumps in the heating market. This has been proven over time by successful schemes in Sweden (supporting all building renovation efforts); Germany (level of support differed widely over time and from new to renovated buildings, from energy efficient buildings to drillings, to heat pumps); or France (direct income tax reduction or direct payment based on the investment cost of the heat pump, decreasing over time).

Figure 32 shows a generic typology of approaches aimed at supporting heat pump deployment that can be found in different market environments. They all have the common goal to raise attention for the technology, establish trust and eventually accelerate market growth.

Figure 32 **TYPES OF INCENTIVE SCHEMES FOR HEAT PUMPS**



Source: Own

SUPPORT ACTION FOR HP MARKET DEVELOPMENT

Supportive action is instrumental in:

- increasing visibility of and interest in heat pump based heating solutions in the market.
- triggering stakeholders in the value chain to become more active by investing in R&D and production as well as marketing, education and training.
- triggering an interest with end-users and inducing an increasing demand.
- accelerating technology development, the development of standards.
- increasing recognition for and ensuring production and product quality.

However financial support schemes can not only benefit markets - they can also become stress factors by triggering demand to levels that are exceeding available production/installation capacity, by encouraging the offering of sub-standard products or by encouraging insufficiently qualified stakeholders to enter the market. If not executed on a continuous basis, they can also trigger an "on-off" demand, making continuous planning difficult and even destroying markets.

That's why **good support schemes** have certain characteristics that should be adhered to by bodies considering their introduction:

- they should be transparent
    - the technology-supported, the type of support and the requirements to be met should be easy to identify
    - the duration of program should be clear, ideally set up for a long-term, with starting and ending dates clearly defined
    - in case of financial subsidies, the available funds should be openly declared
- they should be easy to administer and financial support should accessible and paid out without long delays
- they should be funded independent of budgets to ensure long-term availability
- they should be sufficiently endowed with funds to have an impact on the total cost of ownership of the individual unit and be able to support numerous applications

Market support activities should be designed to jump start market development and to institute and maintain quality. The introducing body should determine the target of each support action and determine criteria against the action can be evaluated. A regular evaluation is useful to improve the target contribution of the respective action by fine-tuning it over the course of its execution. A criteria based approach will also be helpful if not essential to decide on the need for continuation, modification or termination of the scheme at the end of the foreseen duration.

5.3. ECONOMICS ASPECTS AND COST CONSIDERATIONS

Heat pumps can only roll-out their numerous benefits when brought to market in sufficiently large quantities. Individual and corporate decision-makers need to make purchase decisions for heat pump systems and these are most often determined by cost considerations.

Deployment of heat pump systems in renovation projects is technically feasible, but needs proper planning and innovative financing solutions.

The economics of a heat pump are mainly influenced by the investments and the cost of operations. The final decision in favour or against a heat pump system is not only influence by the absolute cost of the system but even more by the relative cost differences between different heating solutions and to a certain degree also by the attractiveness/image of the technology in general and the personal preference of the investor in particular.

An overarching universal statement on the economic cost of heat pump systems is therefore not possible. It is however worthwhile to dissect the different cost components to gain a better understanding how they will be influenced by general market development and the related economies of scale as well as by the (disruptive) innovation and creation of new business models resulting from digitalisation, sector connection and the introduction of new services for heating/cooling.

In the ideal world, an end-user would compare cost of all available heating technologies over the lifetime of the product and select the one with the lowest **total cost of ownership.**

The following cost components can be distinguished:

A: Investment cost (CAPEX)

A1. cost of system design (often hidden)

A2. administration cost: permits, application procedures, etc.

A3. cost of the product or system including the tank

A4. installation cost

A5. financial advantages based on the investment cost: loans, grants, tax reductions, consulting services etc.

B: Cost of operating the system (OPEX)

B1. fuel

B2. maintenance, insurance

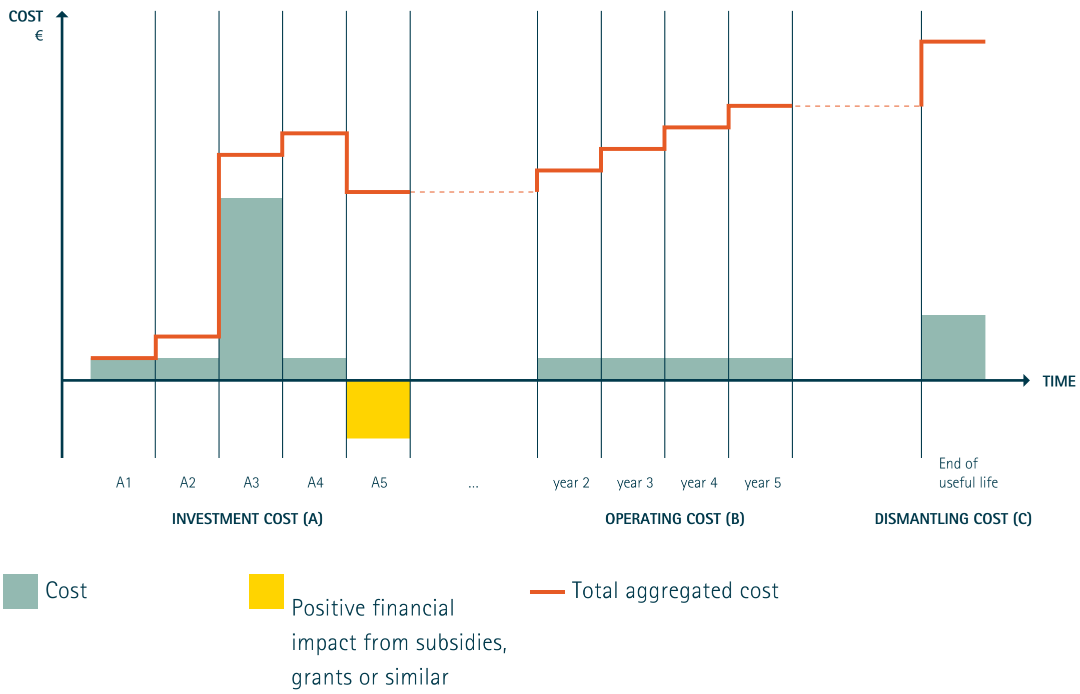
B3. competitive advantages and disadvantages affecting B1 and B2:
subsidies for the energy used,
taxation of the energy carriers
preferred electricity tariff
compensation for demand side flexibility

C. cost of refurbishment, exchange or dismantling

These cost factors depend a lot on the respective market framework and differ widely from country to country. This holds true in particular for the cost of equipment and the cost of fuel (often mainly influence by taxation levels). When referring to financial incentives and administration cost, these can differ from region to region and even from city to city. In general, items A5 and B3 will reduce the immediate and total cost of ownership of a heat pump system and increase its competitiveness.

Figure 33 shows a standard cost curve for heat pumps and highlights the influence of the different cost categories.

Figure 33 **FACTORS AFFECTING THE TOTAL COST OF OWNERSHIP OF A HEATING SYSTEM**



Source: Own

ECONOMIC CONSIDERATIONS OF A HEAT PUMP INVESTMENT

Heat pump-based solutions are fully cost competitive in new buildings

Investing in a heat pump system will often depend on the cost of the alternative. It is therefore helpful to analyse the different cost factors with regards to the best available fossil alternative and to distinguish between new buildings and building renovation.

New buildings must comply with strict requirements on the maximum allowed energy demand per metre-squared. These are continuously being revised and from 2020-2021 the European Energy Performance of Buildings Directive (EPBD) makes near zero energy buildings the standard. These requirements can be met by a combination of energy efficiency measures and the use of technologies based on renewable energy sources. Heat pump solutions are not only compliant with these requirements for new buildings, in this case they are also cost competitive when it comes to the initial investment and can provide an advantage in operating cost. TOC of heat pumps in new buildings is lower than the counterfactual.

While most buildings today will still be here in thirty years, the renovation requirements of Europe's building stock are not as stringent. This is of particular concern when considering that from today until 2050 most of these buildings will undergo only one major renovation cycle. If this opportunity is missed, their energy demand and related emissions will stay high. What may be worse: maintaining the existing stock of combustion based heaters and the related energy distribution infrastructure will slow down the general speed of the energy transition in heating and cooling.

With the new EPBD, a net-zero emission buildings stock by 2050 is a declared political goal. Thus ist decarbonisation is one of the key challenges to overcome. Decision-makers confronted with the need for renovation, either as a consequence of a boiler failure or when planning the refurbishment of the heating system or the renovation of the house need to consider the whole system to identify a "future-fit" solution:

- Is the building envelope fit for an energy system that cannot replace lost energy?
- Is the building envelope air tight?
- Does the building have a floor heating or are radiators sufficiently dimensioned?
- Will the user optimise any of the previous items as part of renovation activities?

To facilitate the long-term, environmentally-beneficial perspective on the user side, governments should focus building policy on encouraging, yet simplifying the renovation process. Such action must include training of the entire value chain, in particular planners and installers, the provision of simple financing solutions and most notably giving a value to the environmental benefits of (inter alia) heat pump solutions. Applying a price to the environmental and social cost of using fossil energy sources would make a like-for-like replacement in the renovation case more costly and encourage a decision in favour of a low emission solutions, such as heat pumps. A carbon price of €30-50 applied per ton of CO_2 emitted is deemed sufficient to shift decisions in favour of cleaner renewable based-solutions.

5.4 NEW BUSINESS MODELS

Today's dominant business model in the heating industry is based on manufacturing a boiler and selling it to the end customer via wholesalers or installers. Value is created by manufacturing, installing and maintaining the product as well as by providing the energy to operate it. The end-user pays for both, the product and the energy needed to operate it and banks act as intermediaries to provide financing. Planners and architects are responsible for the design of the buildings, also influencing the technical specification of the required system and thus the purchase decision. Innovative institutional and financial support (in particular if it honours environmental benefits) can shape the selection of the product and the total cost of ownership.

The value proposition is **a working heating system, owned by the end-user.** It is designed by experts and delivered by skilled craftsmen who install and – in case of malfunction – maintain the system. Even though end-users buy branded products, the relation between manufacturer and user is indirect.

When it comes to cooling, the same applies: the user has a demand for cooling, addresses an expert who designs the system which is then installed and later maintained by an installer company.

As heating and cooling services are often perceived to be disconnected, they will also be offered by different parties, making integrated solutions a challenge and the inherent cost reduction potential of providing two services with one application difficult to unleash.

When it comes to larger capacity heat pumps that are deployed in multi-family and commercial buildings, multi-building complexes and district heating systems, use a different business model already today. Based on a service model, the end-user pays for the delivery of heating/cooling.

This approach is becoming now feasible for aggregated numbers of individual heat pumps or even individual units. The increased availability of sensors and computing power as well as access to high speed data grids, the option to aggregate and to control larger numbers of products allows a new perspective on the product.

With a redefined value proposition the offering is no longer a physical product but a more or less comprehensive package consisting of hardware, software and support in terms of planning, financing, insurance, maintenance etc.

Heat/cooling becomes a service that the user enjoys and pays for, while the service provider/operator takes ownership and is also responsible for system design and operations. Optimising design, monitoring operations and the provision of timely maintenance leads to reduced operating cost and thus optimised profits.

In an extreme (yet quite likely) future scenario the user may even be charged a flat fee only or enjoy heating/cooling entirely for free, as providing demand side flexibility may have a value to the grid operator that exceeds the cost of operating the heat pump system. With a currently visible and accelerating deployment of renewable energy sources in electricity production, heating and cooling systems can provide much needed flexibility on the demand side thus helping to stabilize a (near) 100% renewable electricity grid.

If these services were more valuable than the cost for providing heating/cooling, business models could be conceivable, in which the required service would be offered against a flat payment or even for free. Such benefits could include:

- access to data on user behaviour (compare the whole Google product offering or the current hype around bike sharing schemes in China)
- the use of the system for balancing purposes of the electricity grid (demand response)
- the achievement of a better building class with related savings on the building envelope to avoid penalty payments
- CO_2 emission free heating that would benefit from savings on the payment of a CO_2 tax
- a particulate emission free heating systems: the quest for clean air may eventually result in penalty payments or even usage restrictions on combustion technology giving an advantage to technologies free of CO_2 emissions and particulate matter at the point of use
- cost efficient deployment of CO_2 neutral emissions in some parts of the world and benefiting from transfer mechanisms or other monetary benefits (similar to the current clean development mechanism)

A service provider would integrate all the necessary steps from system design to integration, add the necessary sensors and control systems and be the direct link to the end-user. In return, he would be entitled to reap all the benefits from the system.

In this perspective, the heating/cooling system became a black box whose contents would not matter to the user any more, as long as the required function is provided to his/her satisfaction. Such an approach could have far reaching effects on the brand value of the current market leaders and on their ability to ask high prices for top of the line products.

Table 5 provides an overview of a possible evolution of business models.

Several interim solutions could develop on the way from a fully paid for to a free heating system.

In addition, the requirement for integrated services may give an advantage to technologies that can offer a single solution. Avoiding the need to install 2 or 3 appliances in one building not only saves investment cost but also space and could prove an advantage in particular in areas, where space is limited and thus expensive (consider that by 2050 it is expected that 75% of the global population is expected to live in cities).

Other products, even unrelated to heating and cooling, may benefit from more accurate data on user behaviour and the thermal properties of buildings in different climate zones. Their providers may find an interest in offering smarter, sensor equipped building system in return for the right to use the data collected.

Any of these new value propositions could be offered by actors of the current value chain, but it is expected that new players, in particular those with access to sensors and IT technology will take an active role in their development (see the Google Nest thermostat as an example). Similarly, large utilities as providers of electric grids could commercialize their know how of large scale roll-out of products and services in this new service world. Having access to user data already today could prove as a head-start for these players.

Table 5 **BUSINESS MODELS FOR HEAT PUMPS**

	STANDARD BUSINESS MODEL	SERVICE BASED BUSINESS MODEL	DEMAND SIDE FLEXIBILITY BASED SERVICE MODEL
VALUE	Product and energy source as two different products offered to the user	Heating/cooling as service offered to the user	Indoor comfort in return for system services and access to data
KEY PARTNERS	► Manufacturers of heat pumps ► Utilities	Energy service company or energy performance company	Grid operator
SALES CHANNEL PER CUSTOMER SEGMENT	From manufacturer via end user via a number of support parties (planner, installer)	► Commercial: direct from service to end-consumer with a variety of service approaches ► Industrial: direct from developer to end-consumer	Direct from integrator to prosumer

Source: Own

CONCLUSION AND POLICY RECOMMENDATIONS

At the 2015 UN Conference of the Parties (CoP) 21 in Paris, heads of state and government agreed to limit global warming to well below 2°C by 2050. Based on the scientific evidence presented in the 5th assessment report, achieving this goal will require much stronger efforts than currently in place. For the heating and cooling sector, the main limitations result from the fact that the energy market is not working. Decision-makers willing to move towards a new heating system will be misled by the current cost structure.

The required energy transformation is going to be tremendous and cannot be achieved by governments alone. It needs a joint effort by all parties in the value chain to recognise the necessary steps for change and to start working on it immediately. Today's decisions on training, investments, research and development, and the political framework need to be taken with having the 2050 end-date continuously in mind. Announcing the indispensable change early will allow the affected actors the time needed to adjust.

Possible steps that could be feasible in light of necessary change should include the following solutions to address new buildings, and even more importantly, the renovation sector at large:

- **1.** New buildings should be designed as zero emission buildings. The near-zero emission buildings standard in Europe starting in 2021 can be strengthened and the date of introduction be moved up to avoid losing additional time. The same requirement should be set for deep renovation of existing buildings rather sooner than later.

- **2.** For partial renovation, a boiler replacement should only be allowed by technologies with a considerable efficiency gain. The current eco design methodology could be used, applying a minimum requirement of an A+ class even for replacement boilers. Heat pumps, hybrid heat pumps, gas heat pumps, fuel cells, PV, solar thermal and CHP technologies fulfil this requirement already today.

The energy transformation trajectory needs to be reviewed and adjusted regularly and ultimately accelerated. This could be achieved by connecting it to the review cycle of the energy performance of buildings directive. Some initial steps have been made: for example the obligation to prepare heating and cooling as well as renovation plans by EU Member States, but more can and must be done in the next revision.

On a global level, the IEA confirms many of the findings in its 2DS (max. 2°C global warming) and B2DS (beyond max. 2°C global warming). These scenarios are built on achieving massive energy efficiency gains and a near-to-full decarbonisation of the power sector. Even though buildings are responsible for more than half of the energy demand, their impact on GHG emissions is comparatively small.

PROMOTE THE USE OF RENEWABLE ENERGY

If renewable energy were increased in heating/cooling by 1percentage point/year, then the 30% target in 2030 would be an automatic reality.

A 20% share of all final energy demand is agreed upon to come from renewable energy in 2020. This has recently been updated to 30% by 2030, however the new target is binding only on the European and not on the Member State level. Heat pumps are fully considered as using renewable energy under the 2009 Directive and their contribution is accounted for in the bi-annual reporting of the Member States and also in the Eurostat renewable energy statistics.

The Directive is currently reviewed and among other measures, a specific article on renewable heating and cooling is suggested to be introduced, which in particular mandates an increase of the share of renewable energy to be used in heating/cooling by 1percentage point / year. If executed, it would make the 30% target in 2030 an automatic reality. In order to step up the ambition level, an increase by 1,5 or even 2 percentage points should be considered.

PROMOTE ENERGY EFFICIENCY

Gains in energy efficiency in products, processes and buildings are triggered by a number of legislations.

- In light of the 2015 Paris Agreement, the requirements are too low for the framework Directive on Eco-Design of energy-related products. Minimum energy performance standards (MEPS) need to be implemented for small air conditioning units, boilers and water heaters. In the next revision stage, an upgrade should be considered, making a minimum efficiency of today's A+ level the standard. That would support the sales of those technologies that enable the introduction of significant amounts of renewable energy. Examples are heat pumps, fuel cells, microCHP, boilers using green fuels or solar thermal energy as well as hybrid solutions combining any of these.

- In order to encourage consumer behaviour, an Energy Label has been introduced for the heating products mentioned before. It is mandatory to be shown on the product and the energy label class of the product must be highlighted in marketing activities.

- ► The Energy Efficiency Directive mandates an increase of energy efficiency across sectors and aims for a 20% decrease in final energy demand by 2020. Likewise it is currently under review with a new 2030 target suggested at 30% or even 35% energy demand reduction by 2030.

- ► The Energy Performance of Buildings Directive sets minimum requirements on the performance standards for buildings. Most important, it makes near zero energy buildings the standard of new construction in from 2021 onwards.

As new buildings make for only a small share of all construction activity, it needs a thorough overhaul to also set stringent efficiency requirements for the renovation segment of the market.

REDUCE GREENHOUSE GAS EMISSIONS

The aim to reduce GHG emission reduction by 20% in 2020 (compared to 1990 emissions) mainly regulated via the European Emission trading scheme. A special regulation on the phase-down of using fluorinated refrigerants in heat pumps and other technologies would demand a 21% reduction of their emissions by 2030 based on average emissions during the 2009-2012 period.

A specific Commission communication addresses the requirements of the heating and cooling sector. This "heating and cooling" strategy was published in 2016 and provides some guidance on the necessary steps of a decarbonised sector, highlighting the need to replace fossil fuel boilers by highly efficient and renewable solutions'. The strategy is to be executed via the previously mentioned directive and regulations on Renewable Energy, Energy Efficiency and Energy Performance of Buildings. The strategy also highlights the need for consumer empowerment, a target that is highlighted in the title of the "clean energy for all" package and addressed specifically in the all new electricity market design regulation and directive.

SHIFT FUNDING TO CLEAN TECHNOLOGY SOLUTIONS

This EU legislation is beginning to make an impact on market development and the stable growth of the heat pump sector across Europe is the result of their implementation. However, these measures are unlikely to move Europe towards meeting the Paris Agreement targets. Heat pumps remain more expensive than their fossil fuel-based equivalents in most parts of Europe.

What remains overlooked is the fact that the price mechanism in today's energy system is broken. The price for fossil energy does not reflect the cost of the (negative) environmental and social impacts of its use.

A dysfunctional energy market impacts individual decisions and affects the business modelling for a more sustainable future. Which investment cost, operating cost and discount rates are used in scenarios and impact assessments has a fundamental impact on which policy is deemed most (cost) efficient to achieve a decarbonised society and by when.

It is obvious that a low price of fossil fuels, comparatively lower investment cost for fossil technologies and comparatively high discount rates result in an advantage for fossil solutions over their renewable energy competitors. Heat pumps remain at large more expensive than their oil or gas fuelled boiler counterparts. This situation must be remedied by policy-makers to activate private capital to finance the energy transition. While this is a complex endeavour, time is running out. Short-term action items should be taken into consideration by policy-makers when reviewing and augmenting Europe's climate and energy package to move towards a decarbonised energy system.

- **Energy subsidies that distort the market mechanism need to be replaced** - particularly those supporting fossil fuels with renewable energy technologies, like heat pumps.

- **Using carbon needs to become expensive** – either via tightening the cap of the ETS and integrating all sectors in it or by establishing a price on carbon

- **The cost of the energy transition need to be distributed equally to all energy sources** (not only electricity) – energy taxes and levies need to be applied in relative, not absolute terms

- **Demand-side flexibility needs to be given a valu**e to facilitate new business models

G7, G20, and other groups of global leaders repeatedly state that fossil subsidies have to be phased out, and yet they are not. The OECD estimates the total fossil fuel subsidies in Europe in 2013 amount to up to €39 billion. The earliest date for a phase out is now set to 2025 which is incompatible with the request by the UNFCCC for a phase out latest by 2020.

It is no news, that the EU ETS is not working to create a meaningful carbon price, while safeguarding the competitiveness of the EU economy. Some EU Member States have started to introduce a carbon price in the same region, and that seems to work, however a European approach is still not near.

Last, it seems ironic, that the cost of the energy transition is often distributed over only a fraction of its participants. In countries with a feed-in tariff, typically only electricity users pay for the greening of electricity with no major efforts undertaken to green liquid fuels, let alone distribute the total cost of the energy transition to all energy carriers.

Heat pumps offer a range of advantages that make them essential for a sustainable energy system that eventually will result in zero emission in 2050. Numerous heat pump solutions exist depending on the degree of modernization/renovation, the investor foresees. In the most-simple case, an existing boiler can be replaced with a **hybrid solution** leading to significant demand reduction and the introduction of renewable energy into the system. As a boiler will remain part of the system, it can be used as back-up during cold spells.

Moving to a **heat pump only** solution is possible if the system is already fit for lower temperature heating (due to systems often being over dimensioned in the past, this is often the case) or can be upgraded to that level. While such change provides a long-term advantage in terms of comfort and environmental benefit, it does however usually require more time and effort. Under the current cost situation, it is also often more expensive.

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Heat pump technology can deliver major economic, environmental and societal benefits to society. These benefits will only continue to grow as the efficiency of systems improve and as heat pumps can be deployed in more and more application areas. With this development, production cost will fall in line with economies of scale and technological progress.

Heat pumps also contribute to the circular (energy) economy by recuperating and reusing excess heat and energy in different heating and cooling processes. The technology is pivotal to linking renewable energy use in electricity and heat with energy efficiency. It enables a faster transition of consumers and industries off of fossil fuels ultimately making Europe more competitive on the global stage.

Going towards zero emissions is a laudable goal but it will not happen. If policy-makers do not do their utmost to create a political and market framework that creates an economic advantage for energy efficiency and the use of renewable energy - starting with a removal of preferred treatment for fossil energy sources and solutions. Only then will major streams of private capital be unleashed and diverted in a zero carbon emission direction.

A successful energy transition process mandates political will and ambition on a European and national level. If achieved an accelerated decarbonisation of heating and cooling is possible laying the foundation for a decarbonisation of society based on existing technologies.

We must start this process today.

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Heat pump technology can deliver major economic, environmental and energy system benefits to Europe. Heat pumps use renewable energy and may be the single most efficient technology for heating and cooling, particularly when both services are required in the same location and at the same time.

Heat pumps are installed in larger numbers only recently, while the underlying concept has been around for over 150 years. The technology is now becoming a keystone to the energy mix for decarbonising heating and cooling in industry and society at large. The energy transition is therefore not a technology challenge but rather a policy and awareness-raising issue.

This special report sheds light on the fundamental principle of the technology, the renewable and waste-energy based sources used, the financial and energy efficiencies that are achieved, the business models being deployed, and the non-technical benefits for the environment and society.

Directed at policy-makers and industry players, this report advances the unique integrative function that heat pumps provide for decarbonising the heating and cooling sectors, thus explaining why heat pump technology will be at central component of Europe's future energy system.

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