Heat Pumps
Chances and Challenges to Decarbonisation

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The Past

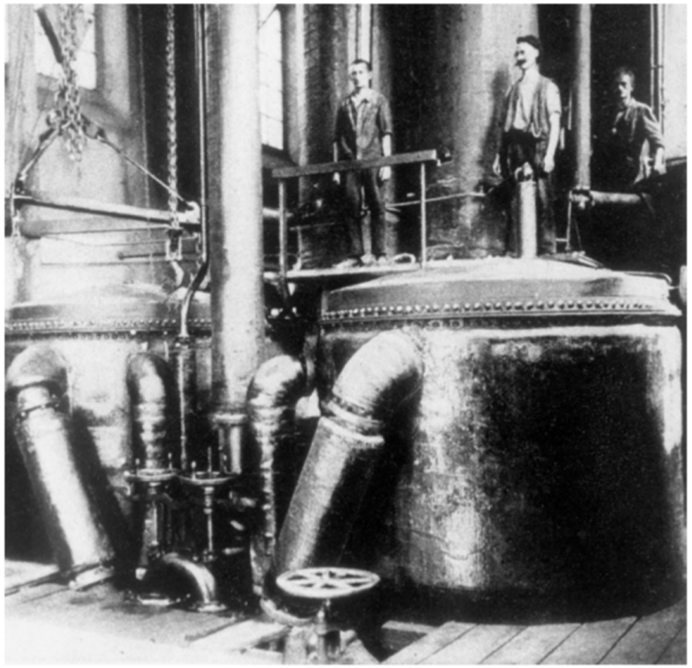
- Nicolas Léonard Sadi Carnot (FR) recognized in 1824, that mechanical energy can be completely converted into heat, but heat can only be partially converted into mechanical energy.
- Robert Julius von Mayer (DE) recognized the principle of equivalence between work and heat in 1842.
- In 1847 Hermann von Helmholtz (DE) published the law of conservation of energy in general form, the **first law of thermodynamics**.
- Rudolf Julius Emanuel Clausius (DE) formulate in 1850 the basic idea of the **second law of thermodynamics** with his mechanical theory of heat.
- Lord Kelvin (UK) predicted the heat pump as early as **1852**, in which he remarked that a **"Reverse thermal engine"** could be used not only for cooling but also for heating purposes. He realized that **such a heating device would require less primary energy** , thanks to the extraction of heat from the environment

The Front Runner (Switzerland)

- In Switzerland, coal prices rose sharply during the second World War and uncertainty about security of supply triggered discussions.
- A key goal identified was the efficient provision of heat using electricity from Swiss hydropower plants
- Even after the second World War, heat pumps remained important in Switzerland
- Legal issues such as the need for a nationwide law on heat extraction from surface waters was discussed early on. In the interest of independence from fuel imports, the Federal Council recommended that the cantons should refrain from charging fees for heat extraction.
- In 1955 about 60 heat pumps had been in operation in Switzerland. The largest with a thermal output of 5.86 MW.

Vapour Recompression – Heat Pumps for Concentration Processes

- Antoine-Paul Piccard (University of Lausanne) and J.H. Weibel (Weibel-Briquet; Geneva) built the world's first working vapour recompression system
- It was installed in 1877 at the salt works Bex. It produced around 175 kg of common salt per hour in continuous operation
- Vapour recompression plants made their way into the salt works and the sugar industry afterwards



Evaporator of the vapour recompression plant at saltworks Bex (CH)
Source: Salt Works Bex, zitiert in: Zogg, M.: Geschichte der Wärmepumpe, Bundesamt für Energie, Bern, 2008

Technologies and Application

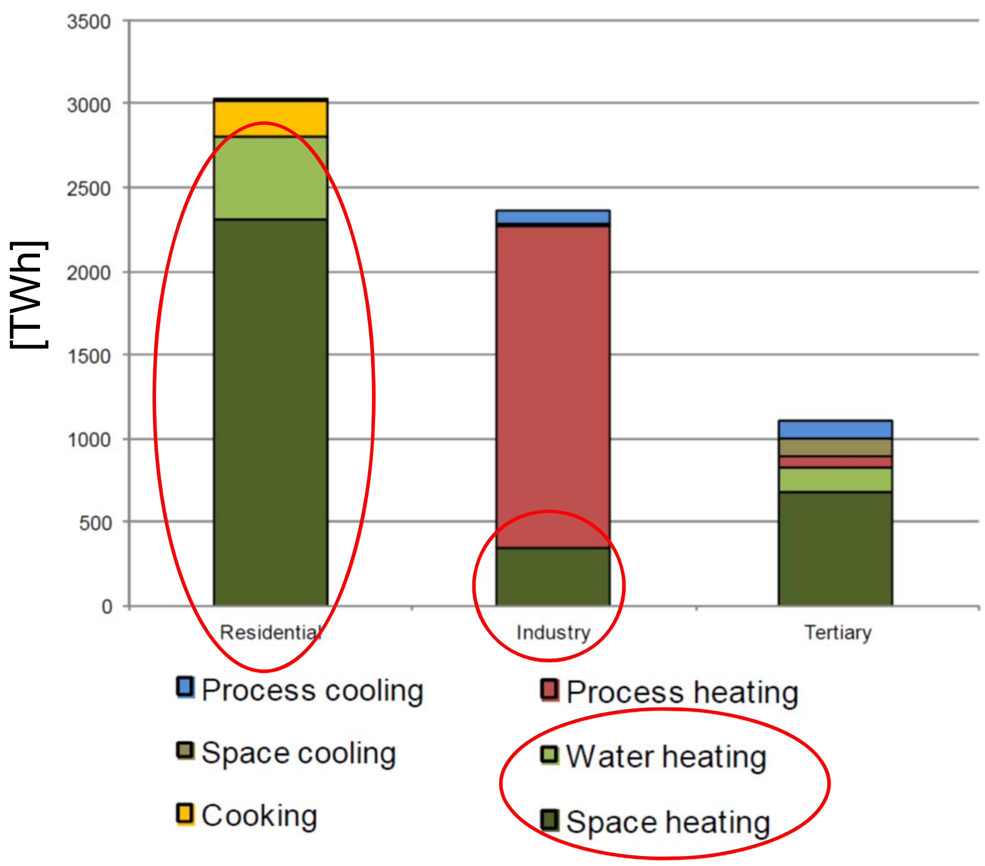
	Vapour recompression	Compression heat pump	Ab-/Adsorption heat pump
Max. temperature.	350-400 °C	140-150 °C	90-95 °C
Working fluids (examples)	process vapour	R1336mzz(Z), R1233zd(E), R1234ze(Z), R1234ze(E), R1234yf, Hydrocarbons; CO_2 ; NH_3	NH_3/H_2O $LiBr/H_2O$
Driving energy	electric drive, HP steam	electric drive, combustion engine	fuel, waste heat
Market uptake	yes	only heat pumps for low temperature provision	No
Application	concentration processes (saltworks, food industry, desalination	space heating, sanitary hot water	space heating

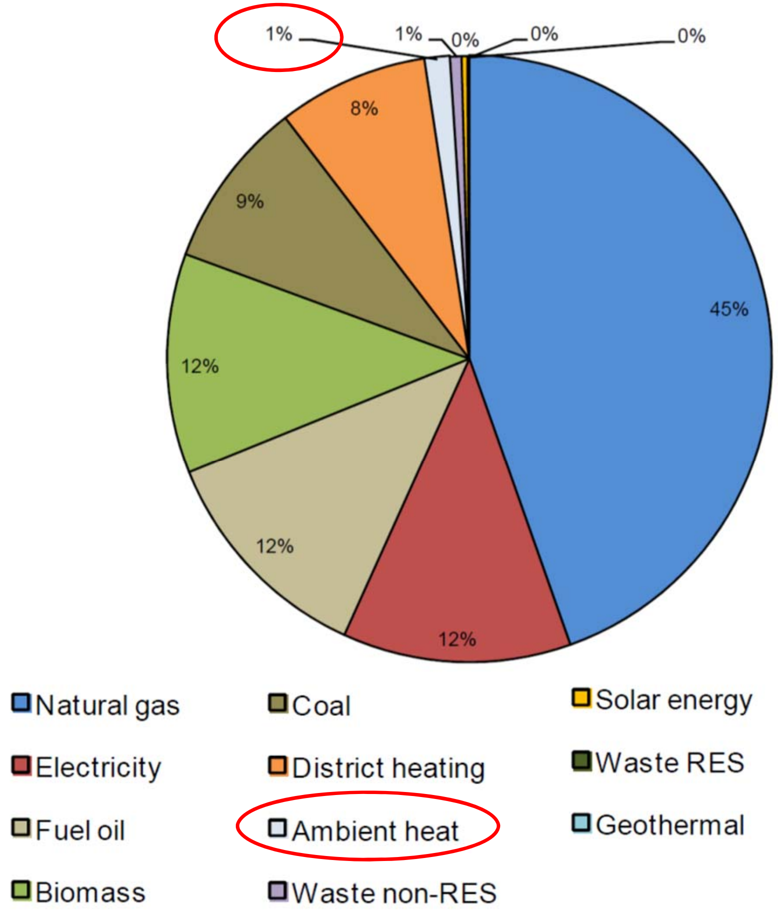
Cooling Technology and Heat Pumps – What is required

Both technologies require development of new and better or improved technologies in the following areas.

- Compressors (Piston, Turbo, Screw, Scroll)
- Heat Exchangers (especially plate heat exchangers)
- Refrigerants (thermal and chemical stability, flammability, toxicity, TEWI)
- Electric motors/drives (increase efficiency; IE4/5 instead of IE2/3)
- Control technologies (optimised and safe operation, ready for flexible operation)
- Quality control (training, information, supervision)

Final energy demand and fuel shares for heating and cooling (EU 28)

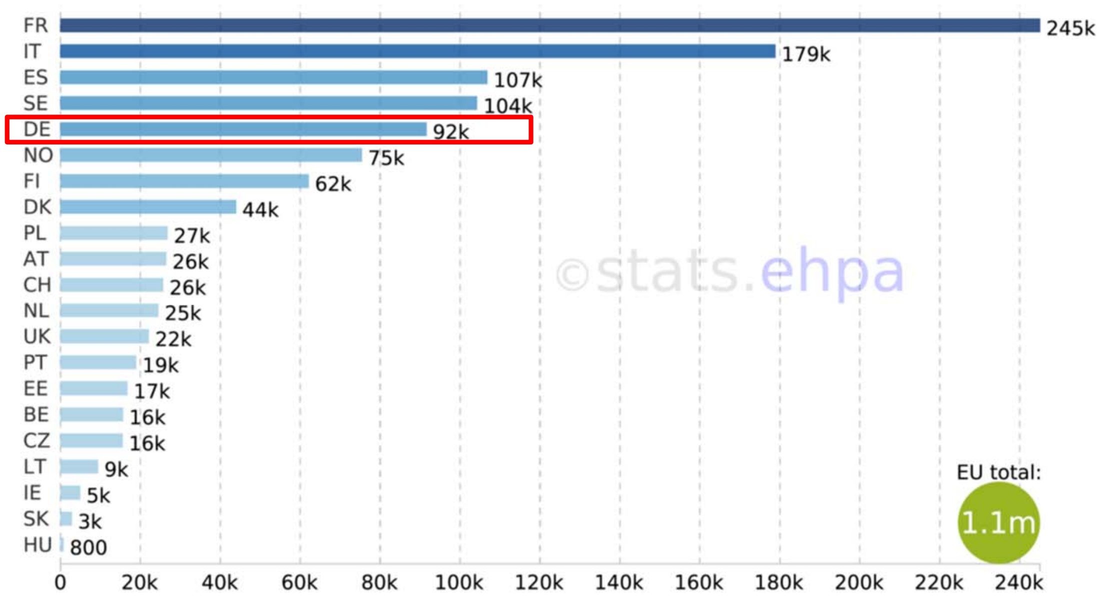




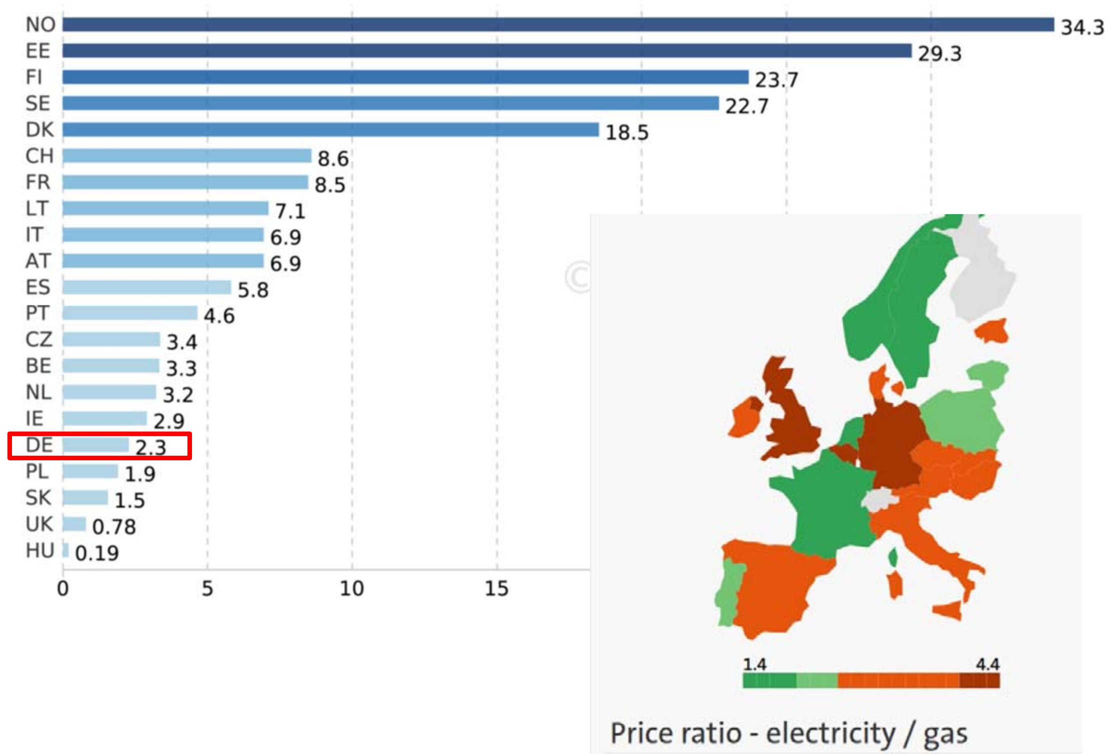
Source: Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables). Final Report WP1, European Commission contract N°ENER/C2/2014-641, 2016

Heat Pump Sales in Europe (2017)

Number of Units

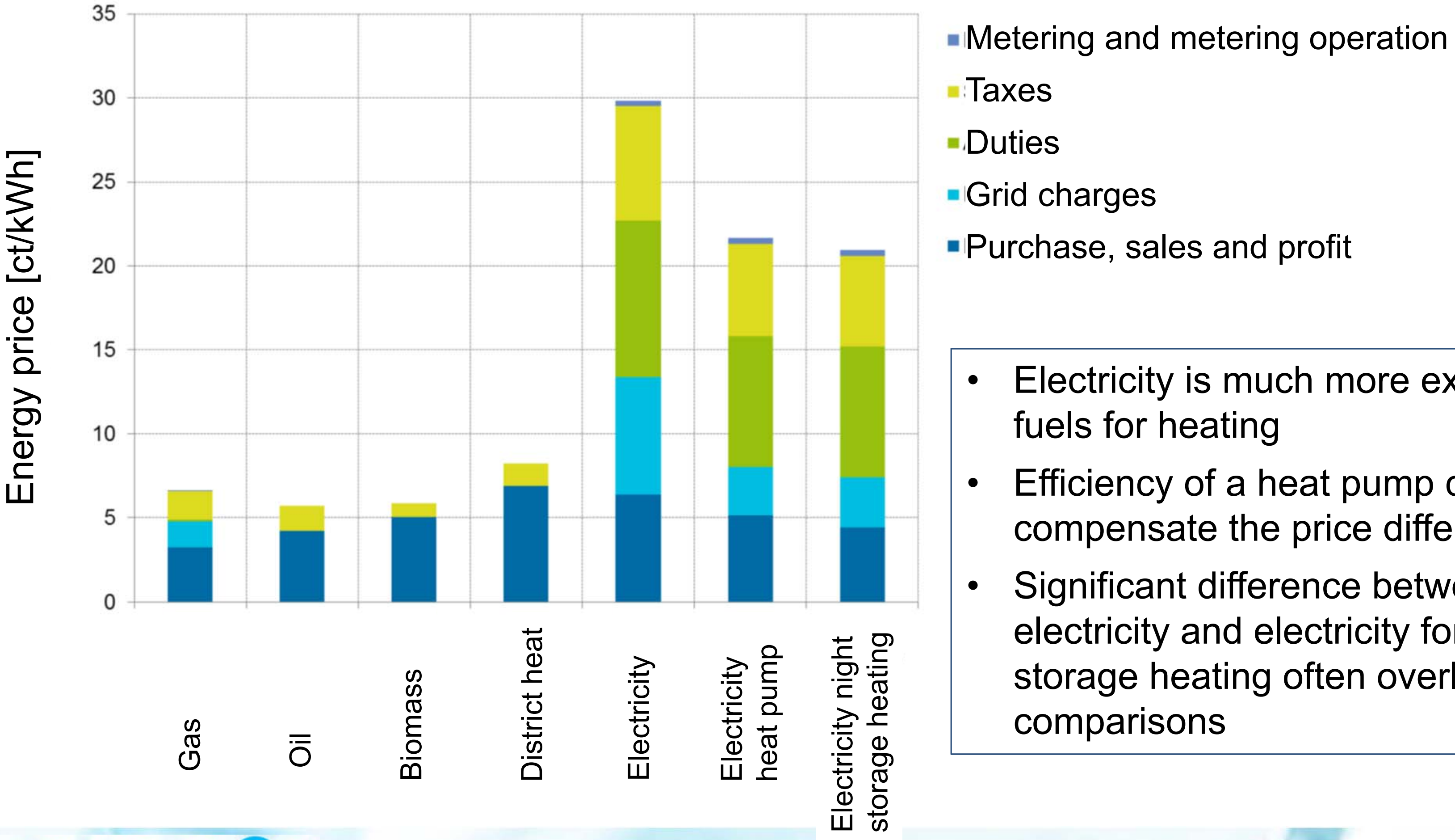


Number of Units per 1000 households



Source: www.EPHA.org, 2020

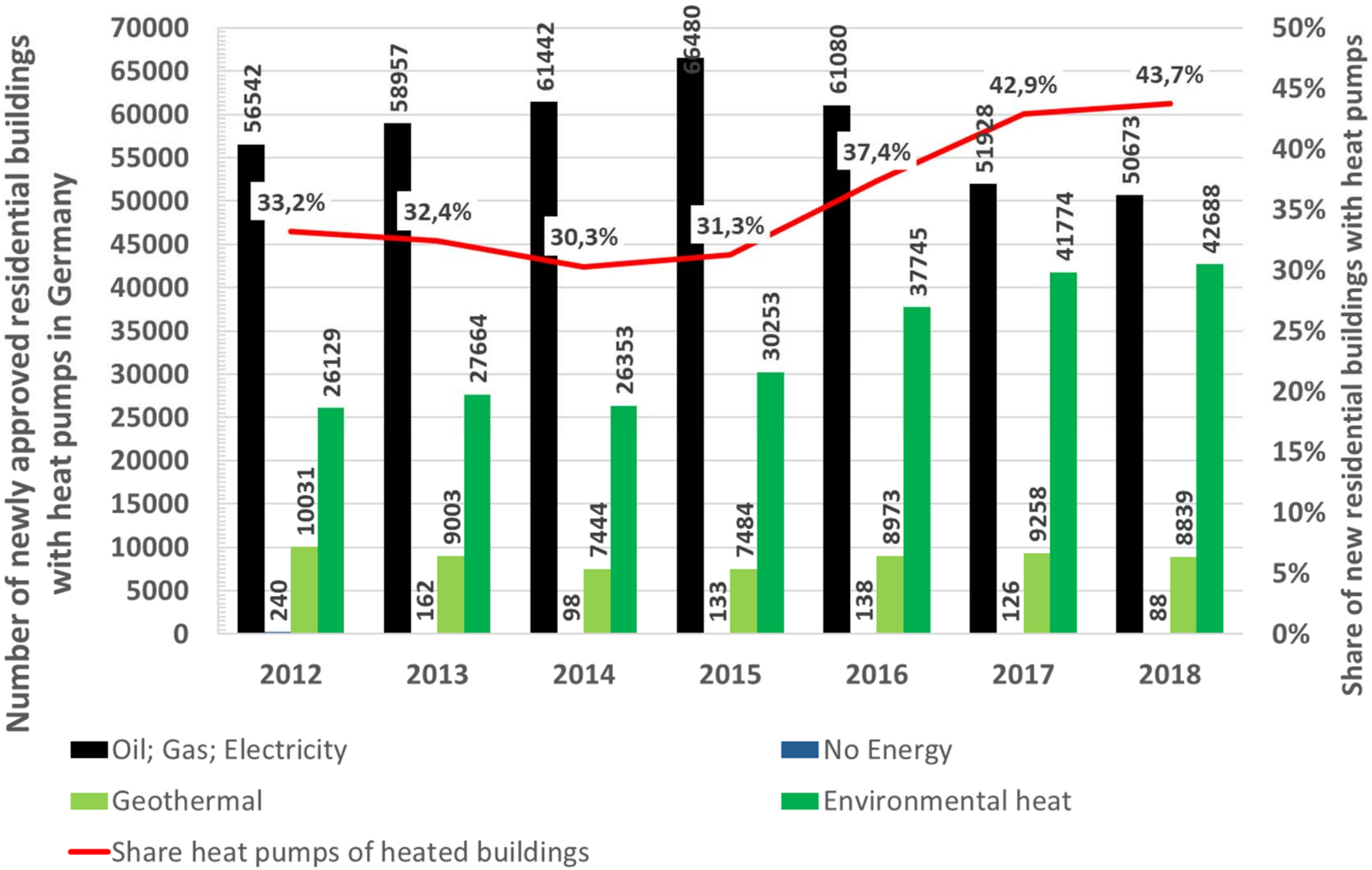
Energy Prices in Germany



- Electricity is much more expensive then other fuels for heating
- Efficiency of a heat pump can typically not compensate the price difference
- Significant difference between household electricity and electricity for heat pumps/night storage heating often overlooked in comparisons

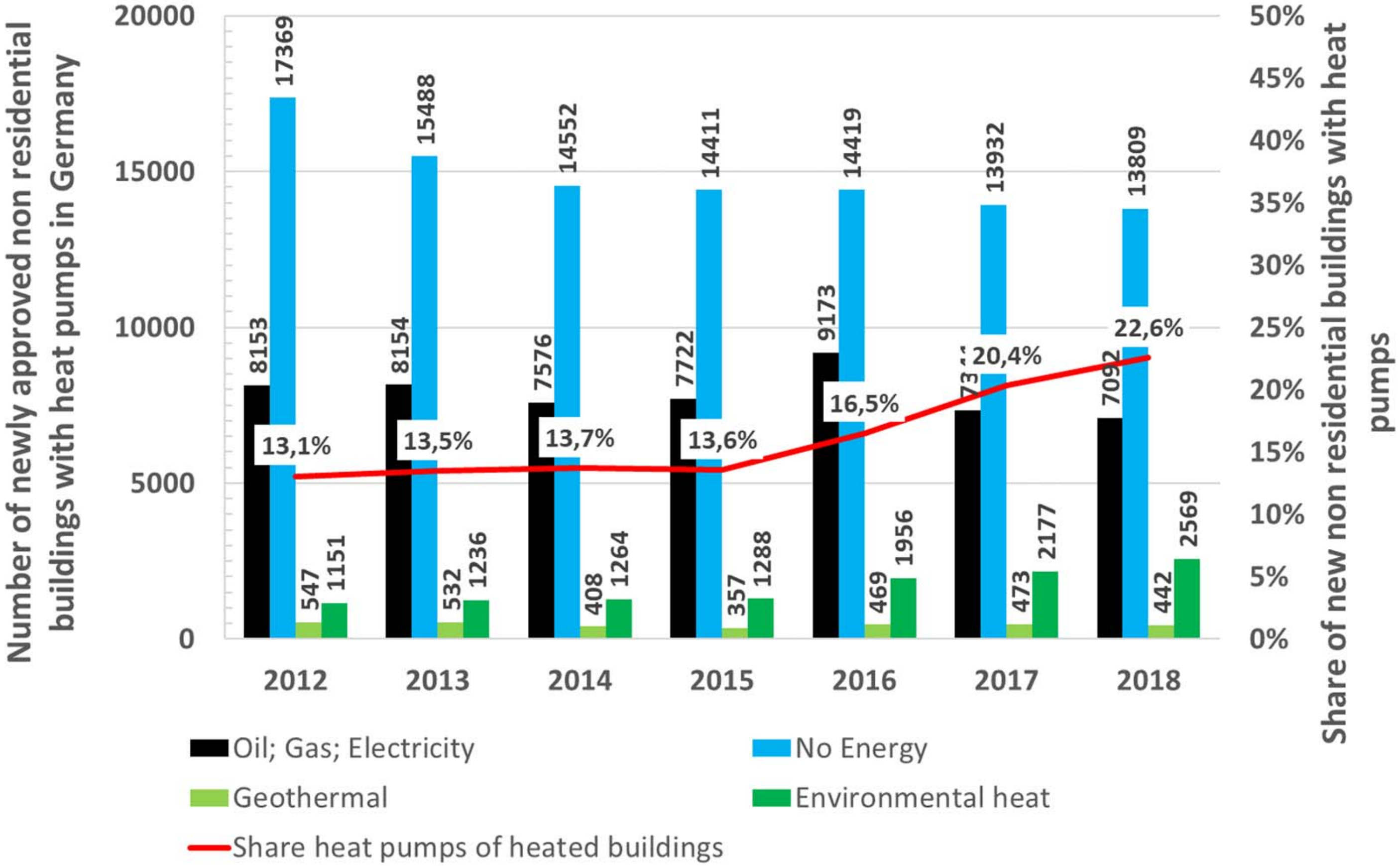
Source: Bürger et.al.: Auswirkungen der Sktorkopplung im Wärmebereich auf die Energiekosten von privaten Verbrauchern. Ökoinstitut, Freiburg, 2019, own translation.

Uptake of heat pumps in newly approved residential buildings in Germany



Source: Destatis, Baugenehmigungen / Baufertigstellungen von Wohn- und Nichtwohngebäuden (Neubau) nach Art der Beheizung und Art der verwendeten Heizenergie, Lange Reihen ab 1980, Wiesbaden, 2019

Uptake of heat pumps in newly approved non residential buildings in Germany



Source: Destatis, Baugenehmigungen / Baufertigstellungen von Wohn- und Nichtwohngebäuden (Neubau) nach Art der Beheizung und Art der verwendeten Heizenergie, Lange Reihen ab 1980, Wiesbaden, 2019

COP - The Key Metric for Heat Pumps

- Coefficient of Performance (COP) describes the performance of heat pumps.
- The COP of a reversible Carnot heat pump process is defined by the temperatures of heat reservoir T_C and the heat sink T_H

$$COP_{rev} = \frac{T_H}{(T_H - T_C)}$$

$$COP_{real} = \frac{heat\ power\ output}{electric\ power\ input}$$

$$Quality\ Grade \sim 0.5 = \frac{COP_{real}}{COP_{rev}}$$

Typical reasons fo COP_{real} < COP_{rev}

- Temperature gradients
- Pressure drop
- Friction losses in the compressor
- Compression/expansion losses
- Losses in electric motor
- Heat losses
- Irreversible expansion of the refrigerant
- Superheating of the refrigerant before entering the compressor (depending on fluid)

The Operational Field for Heat Pumps

COP_{real}	Temperature heat reservoir T_C [°C]							
Temperature heat sink T_H [°C]	-10	0	10	20	30	40	50	60
35	3,42	4,40	6,16	10,27	30,82			
45	2,89	3,54	4,55	6,36	10,61	31,82		
55	2,52	2,98	3,65	4,69	6,56	10,94	32,82	
65	2,25	2,60	3,07	3,76	4,83	6,76	11,27	33,82
75	2,05	2,32	2,68	3,17	3,87	4,97	6,96	11,61
85	1,89	2,11	2,39	2,76	3,26	3,98	5,12	7,16
95	1,75	1,94	2,17	2,45	2,83	3,35	4,09	5,26
105	1,64	1,80	1,99	2,22	2,52	2,91	3,44	4,20
115	1,55	1,69	1,85	2,04	2,28	2,59	2,99	3,53
125	1,47	1,59	1,73	1,90	2,10	2,34	2,65	3,06

cost based

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emission based

	1990	**2000**	**2010**	**2019**
CO_2 emissions German electricity mix g_{CO2}/kWh_{el}	764	644	555	401
Minimum COP_{real} for Emission reduction compared to natural gas	3.8	3.2	2.7	2.0

Key Chances and Challenges for Heat Pumps and the Heat Pump Industry

Chances

- Technology leadership for a fast growing market
  - compressor technology
  - working fluids
  - control systems
  - system integration
- Sector coupling for better integration of renewable energies
  - enable the maximised use of renewable energy
  - decarbonise the heating market
  - increasing energy independence
- Can provide heating and cooling within one single process
- Electrification (and decarbonisation) of industrial processes such as in the food and beverage, chemical, paper and pulp, electroplating industry, etc.

Challenges

- Split incentives in the heating market
- Electricity as high value energy to valuable for the heating market
- Noise level of heat pumps perceived as annoying
- Negative experiences with geothermal drillings (e.g Staufen)
- Low annual coefficient of performance (often <3) due to poor installation, system settings, controls or system integration.

Noise Level and Heat Pumps

The European Commission ErP Regulation (EU 814/2013 is requiring that sound levels of heat pumps shall not exceed the following values

Rated heat output ≤ 6 kW		Rated heat output > 6 kW and ≤ 12 kW		Rated heat output > 12 kW and ≤ 30 kW		Rated heat output > 30 kW and ≤ 70 kW	
Sound power level (L_{WA}), indoors	Sound power level (L_{WA}), outdoors	Sound power level (L_{WA}), indoors	Sound power level (L_{WA}), outdoors	Sound power level (L_{WA}), indoors	Sound power level (L_{WA}), outdoors	Sound power level (L_{WA}), indoors	Sound power level (L_{WA}), outdoors
60 dB	65 dB	65 dB	70 dB	70 dB	78 dB	80 dB	88 dB

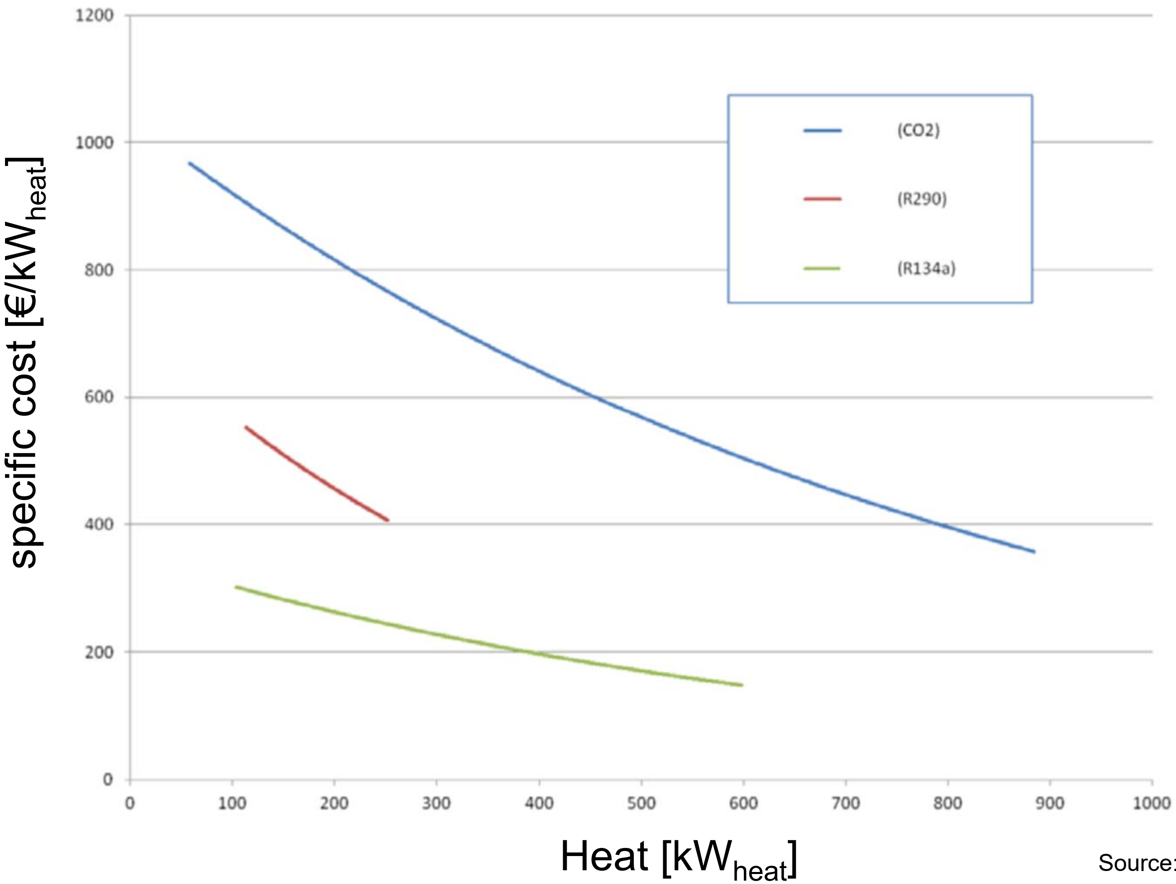
Main sources for noise emissions

- compressor
- fan
- excitation of the housing leading to vibrations and rattle.

Imission guide values for noise levels outside buildings in Germany

- **industrial estates:**
  Day 65 dB(A); Night 50 dB(A)
- **urban areas:**
  Day: 63 dB(A); Night 45 dB(A)
- **general residential areas and small housing estates:**
  Day: 55 dB(A); Night 40 dB(A)
- **purely residential areas:**
  Days: 50 dB(A); Night 35 dB(A)

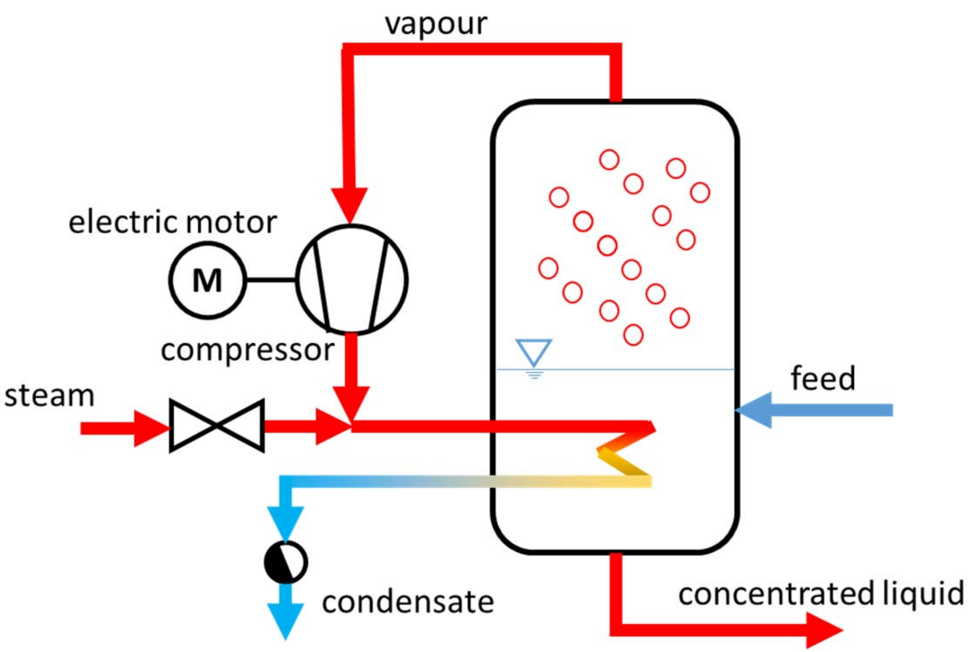
Specific Costs for Heat Pumps in Industrial Processes

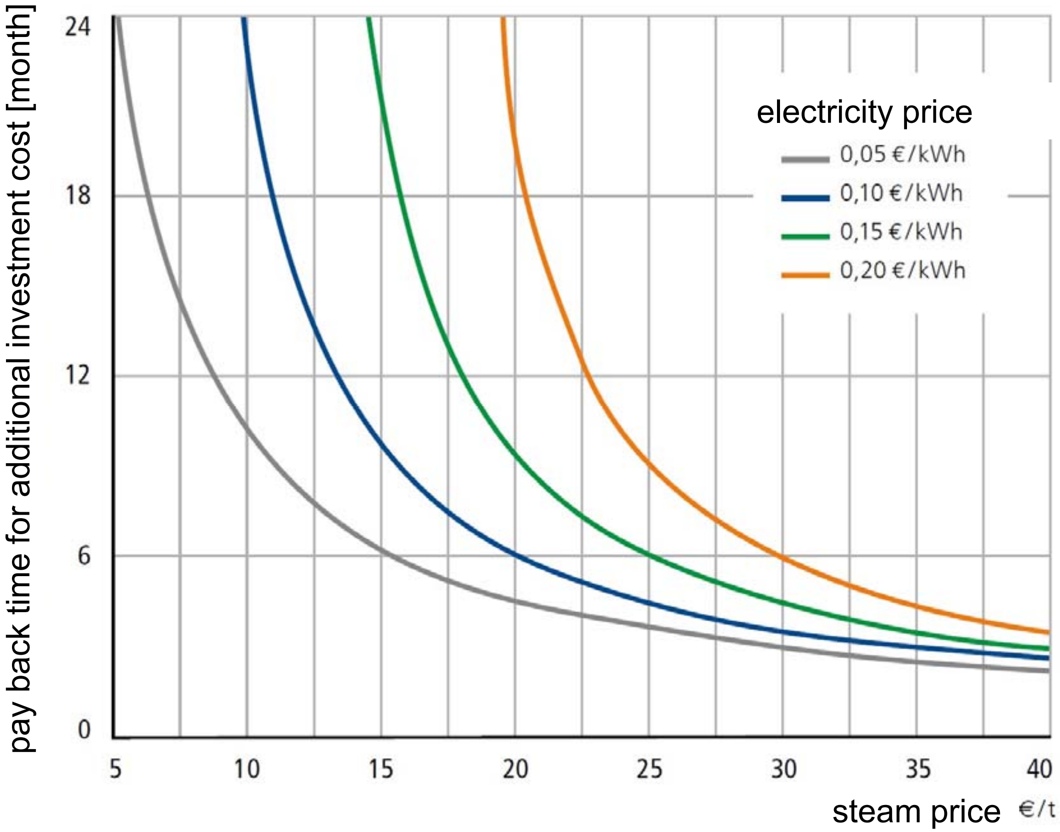


- cost highly dependent on heat source and heat pump integration
- plant costs for natural refrigerants CO_2 and Propane significantly higher than for R134a.

Source: Müller, M.; et.al.: Wärmepumpen mit natürlichen Kältemittel, Final Report, UBA, 2016

Vapour Recompression Economics





Source: GEA: Eindampftechnik mit mechanischer Brüdenverdichtung, 2014

Support for Heat Pumps in Germany

- German Government introduced a funding package for the refurbishment of home heating system
- Oil fired heating systems can no longer be installed after 2026
- **Financial support of 35% of the cost of the new heat pump.**
- Can go up to 45% if an oil heating system is replaced
- Minimum annual performance requirements for heat pumps to be eligible for funding
  - building stock
    - Brine/Water or Water/Water: 3.8 (residential) ; 4.0 (non residential)
    - Air/Water: 3.5
    - Gas driven: 1.25 (residential) ; 1.25 (non residential)
  - new buildings
    - electric driven: 4.5
    - gas driven: 1.5

System Design Options – There is no Silver Bullet

Driving energy

- electricity
- oli/gas
- steam
- waste heat

Technology

- Compressor type
- Material selection
- Driving temperature differences
- Space requirement
- Noise level

Heat Source

- Solar thermal
- Geo thermal
- Industrial waste heat including data centres
- Surface water
- Ambient Air

System design

- Heat pumps serving traditional heat distribution systems
- Cold heat networks with decentral heat pumps
- Combined heating and cooling

Refrigerant

- thermal capacity
- TEWI
- flammability
- toxicity
- operating temperatures
- filling quantity

Heat Utilisation

- Process heat
- Sanitary hot water
- Space heating
  - Radiator
  - Underfloor heating
  - Air heating

Summary and Conclusions

- Despite declining residential heat demand, most of the **renovation market in still in front of the industry**
- Privately owned multi apartment house difficult to reach due to **split incentives**
- Heat pumps are the perfect **team player with electricity from solar and wind**
- **Cost of heat pumps need to come down further** to be able to compete with fossil fuels or direct electric heating. Introduction of a carbon price of 25 € will be supportive.
- Strong political support for heat pumps but **performance improvements, noise reduction and natural refrigerants are key requirements** for success
- **Industrial applications** to support decarbonisation in industry are important but heat pumps with **higher heat sink temperatures** and better economics required.
- In densely populated areas **integration of waste heat sources** or integration of heat pumps into the district heating network important.

Energy Efficiency in Motor Driven Systems 2021 (EEMODS) 21.-23.September 2021

- Call for abstracts to be launched in October 2020
- We are currently looking for sponsors for the conference
- Mark the dates in your agenda

www.eemods21.org

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453	08	20	13
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The EEMODS adresses research and development in drive technology as well as the respective usage (fans, pumps, compressors).

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